A BEST PRACTICES GUIDE

INDIGENOUS KNOWLEDGE in Community-Based Climate Monitoring

Lessons for Indigenous Community-Based Climate Change Monitoring in Canada

University of Alberta

Produced with support from the Government of Canada, Crown-Indigenous Relations and Northern Affairs Canada and Environment and Climate Change Canada.

Cite as:
Parlee, B. (2018). A Best Practices Guide: Indigenous Knowledge and Citizen Science - Lessons for Indigenous Community-Based Climate Change Monitoring in Canada. Crown-Indigenous Relations and Northern Affairs Canada. Ottawa, Canada. Accessible via: www.

Table of Contents

Figures

Executive Summary

There are numerous community-based monitoring programs involving Indigenous communities and Indigenous knowledge that can contribute to our understanding of climate change impacts and contribute to the adaptive capacity of communities to climate change There is no "one size fits all" approach, however some critical lessons from existing programs have been developed in this report.

- Community-based climate monitoring can be a valuable tool for social learning for Indigenous communities; it can increase the adaptive capacity for communities to cope with new and uncertain kinds of ecological change;

- Indigenous knowledge has many definitions, meanings and expressions; there are arguably as many kinds of Indigenous knowledge systems are there are cultures and ecosystems (e.g., Cree communities from the northern boreal regions of Saskatchewan have different kinds of knowledges than Cree communities from western Hudson's Bay lowlands);

- Indicators based around Indigenous Knowledge, or the signs and signals of change provide insight into the values and characteristics of ecosystems and resources important to Indigenous communities; they also suggest culturally meaningful focal points of monitoring

- Place-based knowledge based around empirical observation and experience of environmental change can provide valuable information for evidence-based decision-making – in areas where observations have been consistently made over many decades or generations, Indigenous knowledge holders can offer a strong diachronic record of ecological trends and patterns.

- Practices including methods for monitoring (i.e., data, collection, interpretation, and communication) are also a dimensions of Indigenous knowledge that can inform Community-Based Climate Monitoring;

1. Background

1.1 Indigenous Community-Based Climate Monitoring Program

The Indigenous Community-Based Climate Monitoring Program is a new climate change funding opportunity offered by INAC. Through the development of the Pan-Canadian Framework on Clean Growth and Climate Change, the National Indigenous Organizations (NIOs) identified the need to support Indigenous peoples in monitoring the effects of climate change in their communities. NIOs also identified the need to connect Indigenous Knowledge with science-based climate information to better inform adaptation actions. As a result, CIRNAC received $31.4 million over 5 years in Budget 2017 to implement the program. The program is a national program that builds capacity within First Nation, Métis and Inuit communities to monitor climate change effects. The impacts of climate change are already being felt across Canada and include social, cultural, ecological and economic implications. Indigenous communities are among the most vulnerable to climate change due to their relationship with the natural world, traditional lifestyles, and in some instances, geographic location. The goal of the program is to support Indigenous peoples in monitoring climate indicators, which will provide the data required to inform community adaptation actions. In addition, data generated through this program can help address climate data gaps within Canada and improve climate models and weather predictions.

https://www.aadnc-aandc.gc.ca/eng/1512489182833/1512489213839

Figure 1 – **"What is Community-Based Climate Monitoring?"**
Centre for Indigenous Environment and Resources (CIER) Graphic from 2017 Symposium Accessed March 2018 via: www.cier.net

1.2 Objectives of this Report

The report was written with the aim of contributing to the capacity of Indigenous communities to engage in *Indigenous Community-Based Climate Change Monitoring* in Canada. This report and the accompanying plain language summary document were prepared for Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) and Environment and Climate Change Canada (ECCC). The report specifically addresses the following key questions and objectives.

Key Questions:
What are the best practices related to Indigenous led environmental monitoring that would be useful to communities seeking to be more engaged in Indigenous Community-Based Climate Change Monitoring in Canada?

Objectives
1. Critically define **key concepts** (e.g., community-based monitoring);
2. Briefly define and describe the socio-political and cultural **landscape** of community-based climate monitoring in Canada and the role Indigenous peoples and Indigenous knowledge are building in that landscape;
3. Identify **case studies** of community-based monitoring programs from Canada (and elsewhere where relevant) which feature Indigenous Knowledge (or are led by Indigenous organizations/governments) and which might offer lessons learned for Indigenous Community-Based Climate Change Monitoring;
4. Analyze case studies to determine and produce a **framework** that describe the key factors that influence the success of those programs;
5. Analyze case study examples to determine and describe the range of **focal points and indicators, and methodological approaches** (e.g., qualitative storytelling and quantitative measurement) currently evident in community-based monitoring programs;
6. Synthesize **key learnings from the case study analysis** into three *How-To Approaches* (e.g., How-to on Indigenous Community-Based Monitoring of Climate Change in Forest Ecosystems). This would include suggested approaches and tasks that may be considered by communities seeking to develop a similar community-based monitoring program;
7. Unpack the **principles of OCAP** (ownership, access, control and possession) as they relate to Indigenous Community-Based Climate Change Monitoring in Canada. Determine lessons learned from the literature written by Indigenous scholars and others that speaks to issues of intellectual property and knowledge ethics including: tensions and problems of classification (i.e., what is Indigenous Knowledge, who decides), de-contextualization/scientization of Indigenous knowledge (i.e., what are challenges of recording and sharing an oral history);
8. Discuss **emergent themes, gaps and key challenges** for Indigenous communities seeking to engage in Indigenous Community-Based Climate Monitoring Programs.

1.3 Indigenous Communities and Climate Change

Indigenous peoples in Canada are exposed to the impacts of climate change in different ways. Given their long histories of resource use and close cultural and spiritual relationships to their local and regional environments, climate change is anticipated to have profound implications for Indigenous economies, social organization, culture and health. The impacts of climate change are not homogenous; so too approaches to community-based climate monitoring programs cannot be generalized. Cree and Dene peoples in western prairie regions, for example, may experience more drought-related impacts of climate change as in southern Alberta and Saskatchewan. Inuit communities, for example, are experiencing warming temperatures, permafrost slumping, sea ice melt as well as changes in wildlife health, distribution and populations – these are creating hazards for land and resource use with significant risks for food security and health (Furgal & Seguin, 2006). In boreal regions, the impacts can include increased forest fire risk and changes in forest biodiversity. In marine regions, changes in water temperatures and ocean currents are having implications for the health and population of inshore fish species and the Indigenous fishers. In large freshwater ecosystems such as the Mackenzie River Basin, lower water levels, warming temperatures and increasing observation of invasive fish species are being observed by First Nations and Inuvialuit peoples (Parlee and Maloney 2017).

Experiences of climate change not only vary by geographic location and associated exposure. Communities can be more or less affected by climate change depending on their circumstances of vulnerability. There are a variety of indicators of vulnerability or "openness to harm" which look similar to human development indicators (Eriksen & Kelly, 2007).

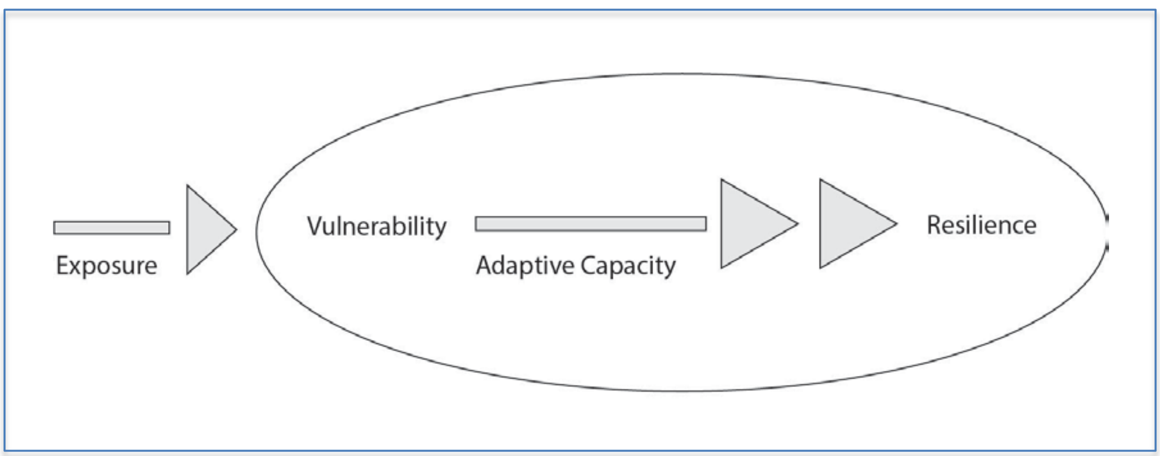


Figure 2 – A Framework of Resilience to Climate Change:

Communities characterized by poverty, poor infrastructure, low levels of formal education as well as limited voice in natural resource management, are likely to be more negatively affected by climate change than others. Over the last decade, Indigenous communities have been disproportionately defined as "vulnerable", a framing that perpetuates stereotypes of weakness and deficit rather than power and strength (Haalboom & Natcher, 2012). A more useful framework is that of adaptive capacity which is defined as the ability of institutions, systems, and individuals to adjust to potential damage, to take advantage of opportunities, or to cope with the consequences of climate change and other stresses (Chapin, 2005). In addition to basic socio-economic indicators (e.g., income, employment, education) there are a variety of other indicators of adaptive capacity that are key including social capital or strong social networks, Indigenous knowledge and cultural continuity contribute to a community's ability to cope with climate change (W. Neil Adger, 2009; W. N. Adger, Barnett, Brown, Marshall, & O'brien, 2013; Berkes & Jolly, 2001). Adaptive capacity can be seen as a continuum from vulnerability to resilience. Resilience can be defined as "the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances"(Cumming & Collier, 2005).

These terms can be interpreted together through the equation **R = (V +E) – AC** – or resilience = (vulnerability + exposure) – adaptive capacity. The terms also provide a foundation for thinking about the big picture benefits of monitoring to resilience (Figure 2). Even though a community might be exposed to stresses from climate change, and vulnerable according to many conventional indicators of adaptive capacity, they can increase their adaptive capacity to become more resilient. The more adaptive capacity that can be developed (see arrow Fig.2) the more resilient the community. Knowledge generated through community-based monitoring, like monitoring itself, is a process of social learning can build adaptive capacity and resilience to the impacts of climate change (M. E. Fernandez-Gimenez, H. L. Ballard, & V. E. Sturtevant, 2008).

1.4 New Paradigms of Education, Truth and Reconciliation

The learning opportunities created through community-based climate monitoring are significant relative to the limits of other kinds of educational forums. The impacts of residential schools in Canada had significant impacts on Indigenous societies, cultures and economies as well as relations between Indigenous and non-Indigenous peoples across the country. As a result, formal education achievement levels and representation of Indigenous youth in post-secondary education are very low. New approaches to engaging Indigenous youth in sciences and alternative kinds of educational opportunities are needed to address this gap such that Indigenous peoples are better represented in natural resource management institutions and can play meaningful roles in addressing the issue of climate change and other kinds of environmental and socio-economic challenges in Canada.

1.5 Definitions and Key Concepts

Indigenous knowledge is considered very important to many community-based monitoring programs in Canada and globally (Danielson et al., 2009). A common challenge for Indigenous communities leading community-based monitoring programs, is that their knowledge is often referred to as less-than or "not as good as" academic knowledge or science. This is also true for other kinds of community knowledge (e.g., fisher knowledge). Terms such as non-expert, subjective, personal, informal, or lay knowledge suggest communities are not systematic, rigorous or empirical in their understanding of the natural world. However, there is growing respect for Indigenous and community knowledge and "data" in many disciplines such as wildlife biology. Indigenous knowledge like other kinds of community knowledge, is recognized as no less systematic than scientific data generated through more technical and standardized processes (I. Fazey, Fazey, & Fazey, 2005; I. Fazey, Proust, Newell, Johnson, & Fazey, 2006).

Although there may be political, racial and epistemological tensions, some of the reasons why Indigenous knowledge may be considered "not as good as" science in government or academic circles are more technical in nature. These technical issues might be described as problems of cultural translation; when Indigenous knowledge documented in research and monitoring is communicated in ways that are more consistent with "science" it is more easily understood (A. Agrawal, 1995). One major translation problem is between qualitative and quantitative; whereas Indigenous knowledge is most commonly documented using qualitative methods, natural resource management tends to privilege the use of quantitative data. Indigenous communities use and have access to a diversity of tools and methods in their monitoring programs.

1.5.1. Indigenous Knowledge

The term "Indigenous knowledge", in this volume, is used interchangeably with the term Traditional Knowledge (TK) or Traditional Ecological Knowledge (TEK) - the cumulative body of knowledge, practices and beliefs that have developed over many generations by local communities about ecosystems and their relationship to it (Berkes, 2008). Although the term "Indigenous Knowledge" is being used in this report, "Traditional Knowledge" is the term embedded in legislation and various policies in Canada including land claim settlement agreements and processes (Brenda Parlee, 2012).

Although the term suggests homogeneity, Indigenous knowledge is complex and diverse. It is often more appropriate and useful to refer to the local cultural context or refer to the mode or frame in which peoples articulate their own Indigenous knowledge (e.g., *Inuit Qaujimajatuqangit* is the knowledge of Inuit peoples of northern Canada). Moreover, referring to the specific resource or management context of the Indigenous Knowledge may be ideal best practice in monitoring (e.g., Denesọłiné knowledge of caribou).

Indigenous knowledge has many different dimensions. In addition to local knowledge (observations) it also refers to the practices, beliefs and institutions (rules) for relating to and respecting resources and ecosystems.

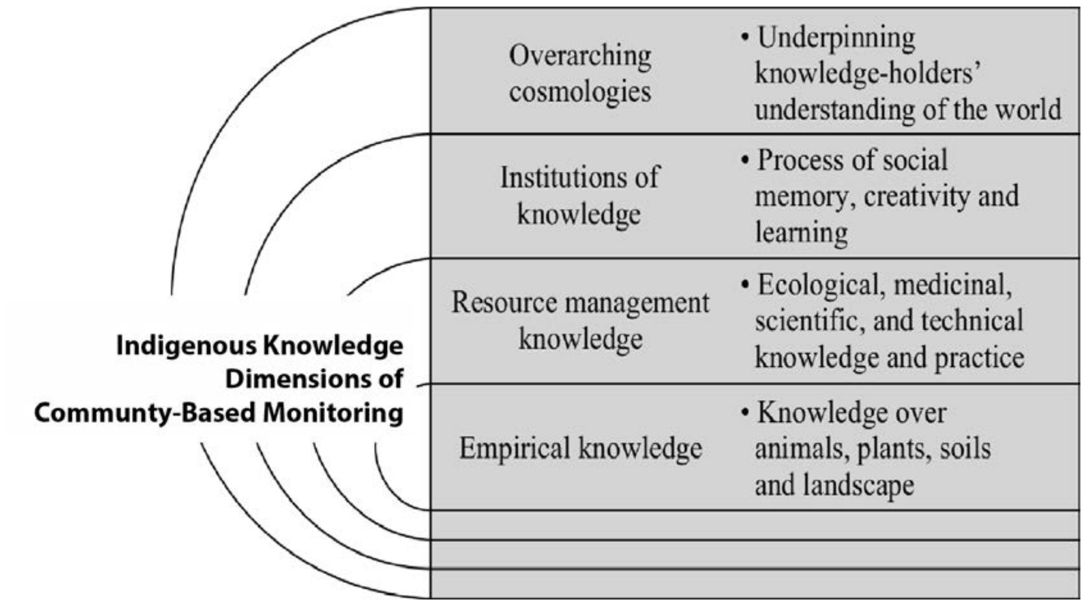


Figure 3 – The Four Dimensions of Indigenous Knowledge
(Adapted from (Berkes, 2008; Savaresi, 2017)

Not all multi-generational and land-based knowledge is attributable to Indigenous peoples of framed as Traditional Knowledge. Fishers' knowledge can refer to the knowledge of Indigenous fishers (e.g., the Haida) but can also refer to non-Indigenous fishers and their multi-generational knowledge (e.g. inshore fishers' knowledge in Newfoundland) (B. Neis, 1992).

Traditional knowledge is unique from local knowledge in that it is more longitudinal or tends to be based on many more years, if not generations, of observing, experiencing and interpreting ecosystems (Battiste, 2011; Berkes, 2009; Danielson et al., 2009; McGregor, 2000; D. Riedlinger & Berkes, 2000). It is because of this longitudinal scope, that Traditional Knowledge is increasingly recognized as useful in monitoring by many scientists, resource managers and governments (Boyce, Baxter, & Possingham, 2012; Henri, Jean-Gagnon, & G., 2018; P. Lyver, 2002; H. Moller, F. Berkes, P. O. B. Lyver, & M. Kislalioglu, 2004; Whitelaw, Vaughan, Craig, & Atkinson, 2003). In this context Traditional Knowledge may be able to help answer the following kinds of questions:

- What are useful indicators for understanding ecosystem dynamics?

- What kinds of patterns of ecological variability are characteristic of particular ecosystems and how do those differ from changes that might be associated with climate change?
- What are the ways in which different kinds of ecosystem components interact over time?
- How should we respectfully and meaningfully track these changes over time?

1.5.2 Local Knowledge

Indigenous knowledge is sometimes used interchangeably with the term local knowledge; while there are some similarities, the two knowledge systems are unique. Indigenous knowledge refers specifically to the knowledge of an Indigenous person or peoples; local knowledge has broader origins and tends not to reflect the longitudinal (long term) observation, experience nor spiritual connectedness often associated with Indigenous knowledge systems. Local knowledge is a widely used concept used in academic and practical contexts. There is no universally accepted definition of local knowledge given there is a diversity of environments and cultures in which knowledge is generated and myriad uses and outcomes of use (Berkes, 2008; Brook & McLachlan, 2005). Most descriptions of local knowledge in natural resource management refer to land-based or applied knowledge and skills including observations of ecological conditions and how-to knowledge for coping and adapting to change. Like traditional knowledge, local knowledge also tends to be orally or informally transmitted and shared locally and within family and community groups (McGregor, 2000)

Local knowledge is the knowledge that any peoples might hold about the environment around them. "This includes the way people observe and measure their surroundings, how they solve problems and validate new information. It includes the processes whereby knowledge is generated, stored, applied and transmitted to others" (FAO, 2004). Local knowledge, like traditional knowledge, is a cumulative body of knowledge and may be passed down from generation to generation and closely interwoven with people's cultural values. This encompasses the skills, experiences and insights of people, applied to maintain or improve their livelihood (FAO, 2004). A related category of local knowledge is "fishers' knowledge" (B. Neis, 1992).

Local knowledge is a resource within communities. In economic terms, it might be considered a form of capital that exists within urban centres and among rural peoples. "It is the main asset they invest in the struggle for survival, to produce food, provide for shelter or achieve control of their own lives" (FAO, 2004). A community's ability to build and mobilize knowledge capital is as essential to its development as physical and financial capital (FAO, 2004).

1.5.3 Western Scientific Knowledge

"Western science" is often defined as the mainstream body of knowledge behind conventional resource management practices. The increasing interest in alternative knowledge (e.g., Traditional Knowledge) stems in part, from a critique of mainstream science as expert-driven, centralized and top down, technocratic and reductionist with limited potential to address complex or wicked problems such as climate change (Ludwig, 2001).

1.5.4 Capacity Building

There can be many challenges for communities seeking to develop their own programs; among these is the limited availability of personnel who have the skills, resources and experience in project management, data collection, interpretation, archiving and communication. However, where capacity-building is associated with program development, these challenges can be overcome.

Capacity refers to the skills, knowledge, resources and experience needed to meaningfully carry out a community-based monitoring program in ways that enhance the process and outcomes of the program as well as contribute to the broader needs, interests and well-being of the community. It is the value-added contributions that can be made through education, mentorship, training and other kinds of resourcing from those individuals, organizations or governments that are playing and supporting role.

The term “capacity” is related to terms such as “empowerment” and can be more deeply understood through work of such globally recognized development scholars as Amartya Sen (i.e., the capabilities approach) (Bebbington 1999; Sen 1993). While there are some core aspects of capacity that can be measured, the concept is also normative. What is capacity building to one community may not be perceived the same way by others. The cultural context including Indigenous cultural histories can also influence local interpretations of what is capacity. For example, some kinds of formal education programs or the format and context in which they are offered, may be viewed as culturally inappropriate to Indigenous communities adversely impacted by residential school systems (TRCC 2015).

The capacity requirements of community-based monitoring programs can vary significantly by socio-economic, cultural and environmental context. Indigenous communities in settled land claim areas, for example, may have more capacity to carry out their work than communities in unsettled land claim areas. Those close to urban areas may be more or less advantaged than those living in more remote regions of Canada.

The development of a Community-Based Monitoring program in and of itself is a form of capacity-building. The primary purpose is to track changes in ecosystems and communities over time so as to produce useful knowledge about ecosystem dynamics. This process of knowledge generation may be viewed as adding capacity to communities who seek to play a greater role in the management of their natural resources including decisions about resource development. Such added capacity can serve to level out (partially) some of the inequities in the knowledge landscape often apparent in *Environmental Assessment* hearings and processes; (i.e., scientists, industry and governments can seem to have more documented knowledge for decision-making, when compared to Indigenous communities whose knowledge is based on oral traditions).

1.5.4 Community-Based Climate Change Monitoring

Community-based monitoring is an activity that is growing in recognition globally and is a concept well used among communities and organizations in Canada including Indigenous communities (Conrad & Hilchey, 2011). It is often used in conjunction with concepts and practices of "citizen science" and "collaborative monitoring" (Maria E. Fernandez-Gimenez, Heidi L. Ballard, & Victoria E. Sturtevant, 2008).

There has been much written about the opportunities and challenges of including Traditional Knowledge in climate monitoring. There are growing numbers of examples from across Canada and internationally. Most community-based monitoring programs involving Indigenous communities focus on tracking signs and signals of change in places, values or resources important to a community. Indigenous Knowledge can play different kinds of roles in the monitoring process such as:

- Inform the development of indicators;
- Guide methods of data collection (e.g., protocols for respecting land);
- Contribute historical or baseline data (e.g., long-time series of data);
- Guide the interpretation of outcomes and their meaning;
- Frame the purpose and relationships around the monitoring process (e.g., guide how we should be working together).

Like other kinds of monitoring, community-based monitoring is based on recognition that ecosystems and natural resources are complex and dynamic (Janssen, 2006). We cannot predict how, when and to what environments are going to change under natural conditions or how and at what scale human activities may disturb or alter these natural ecosystem dynamics. Climate change is one of those ecological stresses that is being monitoring in many parts of Canada including the north (Warren et al., 2004). Monitoring is a tool that enables learning and adaptation to such natural variability (e.g., natural cycles) and human impacts in ways that ensure that the ecosystems in which we live remain sustainable. Such adaptive management is critical in addressing many kinds of resource management problems that may emerge with climate change.

Not all kinds of adaptive management are the same. Conventional scientific approaches in which expertise is concentrated, management strategies are rigid and decision-making is top-down, are not useful in the face of the complexity and heterogeneity of climate change impacts and how they manifest at the local level (Ludwig, 2001). A bottom-up approach to the creation, dissemination and use of knowledge - possible through community-based monitoring - can better contribute to the adaptive capacity of Indigenous peoples to cope with climate change impacts in ways that ensure the sustainability of environments and communities (Johnson et al., 2015; Pollock & Whitelaw, 2005; D. Riedlinger & Berkes, 2009).

Monitoring is also among a variety of tools and processes that have come to be associated with community-based resource management (Conrad & Hilchey, 2011). Monitoring is also a tool synonymous with adaptive management. Unlike conventional approaches to management that are more predictive and rigid in orientation, adaptive management, (sometimes called, "learning by doing") enables individuals, communities and institutions to be responsive to ecosystems uncertainties (Armitage, 2005).

1.5.5 Indigenous Knowledge in Community-Based Monitoring

Community-based monitoring is generally a process where local communities and associated organized collaborate to monitor, track and respond to issues of common community concern (Danielson et al., 2009; Kouril, Furgal, & Whillans, 2015; Pollock & Whitelaw, 2005; Whitelaw et al., 2003). The concept of community-based monitoring is focused around the production of knowledge, not from labs, experiments or objective and technical processes, but through community participation. It begins with the assumption that local people are experts in the knowledge production process. In many parts of northern Canada, it also includes recognition and integration of Traditional Knowledge or Inuit Quajumaitijanik. In other parts of Canada and globally such knowledge may be called local knowledge or "citizen science". The growth in the number of programs that self-define as "community-based monitoring" and ambiguity of definition makes it difficult to identify best practices.

At the same time, there is a critical body of literature that speaks to the tremendous value and importance of Indigenous Knowledge in monitoring and community-based monitoring as both a source of data as well as a set of practices and values that can guide the social and social-ecological relationships that underpin the monitoring process as well as inform the use of data produced from monitoring.

The key difference between community-based monitoring and more conventional monitoring programs is the degree of community participation and community power (control) in the process. In simplest terms, "Who is driving the monitoring program?" or "Who is involved?". Previous reviews of community-based environmental monitoring programs in Canada and globally classify monitoring programs according to the following power and participation dynamics:

- autonomous community-based monitoring;
- collaborative monitoring with local analysis and interpretation;
- collaborative monitoring with external analysis and interpretation;
- externally driven community-based monitoring.

There are other reflections on the role of Indigenous and local knowledge in community-based monitoring. Some reviews and evaluations link or conflate

Indigenous peoples' participation with the inclusion of Traditional Knowledge. In other words, some people think that if there are Indigenous people involved, then Traditional Knowledge is implicitly included. However, in many communities there are clear rules about who is a knowledge holder; as in a scientific community, different people have different expertise about different species, resources, events or places (Davis & Wagner, 2003).

Some critics of the idea of community-based monitoring suggest the idea is a construction of western or conventional science and therefore may not be culturally appropriate. Similar to other kinds of resource management practices, there are risks of considering Indigenous Knowledge simply as "data" that is mechanically collected and disconnected from the place and person from whom it was shared (A. Agrawal, 1995). Finding ways to ensure the meaning and value of knowledge being gathered is not lost through the processes of documentation, interpretation and reporting throughout the monitoring process is maintained and nurtured.

Previous reviews suggest there are a variety of issues that complicate the sustainability of monitoring programs (Danielson et al., 2009). Among these are:

- ongoing funding
- training and capacity building within communities
- data rigour
- limits of scale
- lack of connectedness of monitoring outcomes with management and governance

The sustainability of many community-based monitoring programs is also complicated by a general lack of clarity about scope, purpose and data use. Some communities become overly focused or preoccupied with the business or details of collecting data (e.g., pH levels in water, bacteria in water) but do not necessarily see their efforts as having greater meaning or value. Other communities have become inspired by the idea of community-based monitoring as an act of sovereignty (i.e., building knowledge about our lands and resources) but generate very little data or knowledge that can be used in environmental decision-making such as land use planning or wildlife management. Without clear outcomes, it can be difficult to sustain community interest and participation over the long term.

1.5.6 Some Additional Definitions of Community

"Community" in community-based monitoring is often defined in terms of a physical location, particularly where monitoring is focused on the study of a particular environmental or resource management problem (Arun Agrawal & Gibson, 1999; David C. Natcher & Hickey, 2002). The use of community-based also tends to refer to landscape level and applied data collection as opposed to more theoretical, conceptual or desk-top research activities.

"Community" also refers to a particular set of power relations in which communities exercise significant control over all stages, inputs and outcomes of the monitoring process. While most community-based monitoring programs are formally organized by, or through, a local organization or government, other kinds of "community" are not organized around a physical space or locale but are led by a self-organized group of people with common values and interests.

The notion of "community-based" refers to the bottom-up (versus top-down) approach to program design and implementation. Many sustainable community-based monitoring programs are highly participatory and maintain local power over knowledge production, interpretation and reporting.

1.5.7 Co-Design of Monitoring Programs

Although Indigenous people have been tracking or monitoring changes in their environment for many generations, the formal development of community-based climate monitoring programs within Indigenous communities is relatively recent. The large literature on citizen science offers some useful lessons on the opportunities and challenges around community engagement in monitoring as well as co-designing monitoring programs that weave together Indigenous knowledge and science.

Citizen science provides information on ecological systems that cannot be gleaned without public participation—collecting data over long timescales and across broad geographic areas (Crain, Cooper & Dickinson, 2014). Citizen science is used to describe a form of research collaboration or data gathering that is performed by untrained or "non-expert" members of the public. A closely related concept is "civic science". Civic science refers to the democratization of science and its broad use in public dialog and interpretation. Civic science attempts to link the institutions and processes of 'science' and 'democracy' and works to challenge the conventional view of science as objective knowledge that was developed without influence from the values and beliefs of the society from which it emerges (Maria E. Fernandez-Gimenez, Heidi L. Ballard, et al., 2008).

Indigenous knowledge has many dimensions with diverse synergies are potential linkages to conventional knowledge about ecosystems that is produced through more conventional or academic methods. Where there are strong similarities in the values, indicators and methods of the monitoring program, one might consider the program as completely integrated. However, there are different degrees of integration. For example, Inuit communities and scientists may have similar values or interests in the sustainability of polar bears, however, use different kinds of indicators and methods for monitoring (Clark, Lee, Freeman, & Clark, 2008; Tyrrell, 2006).

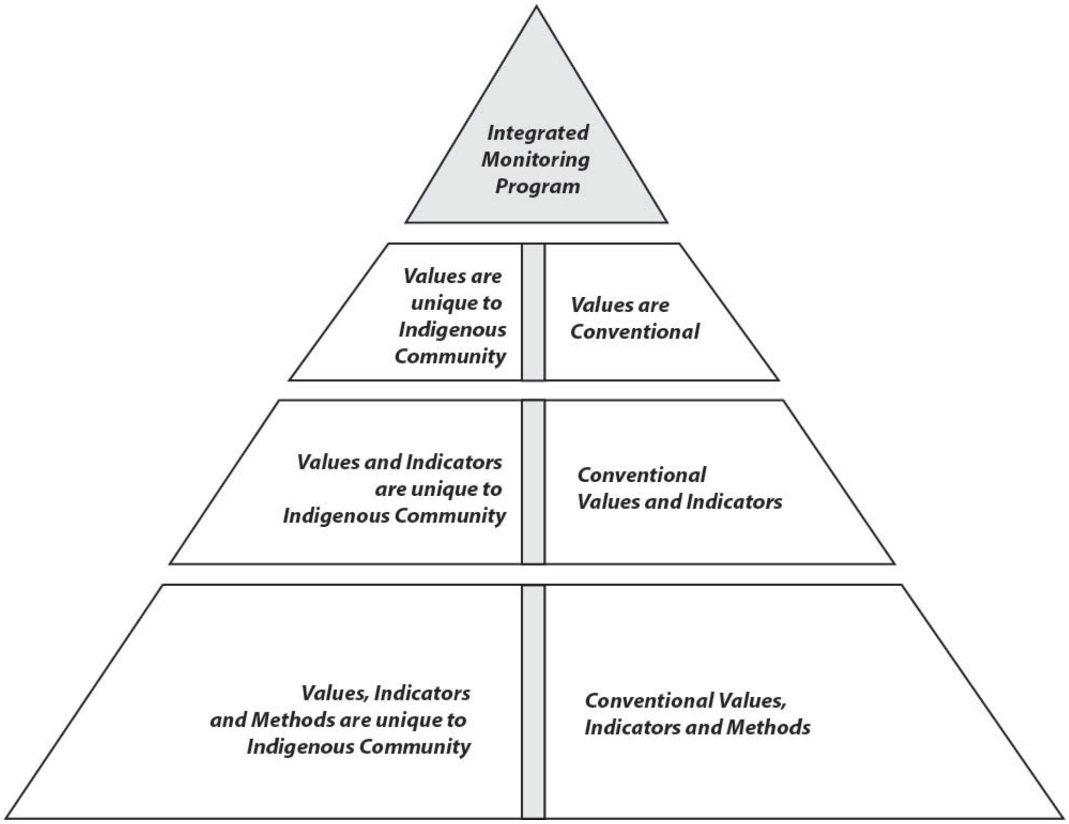


Figure 4 – A Framework for Co-Designing Monitoring

1.4 The Socio-Political Landscape

1.4.1 Indigenous Rights

Community-based monitoring, although considered a technical process is also a socio-political process; for many Indigenous communities, the capacity to build knowledge and inform decision-making about their lands and resources is a means of articulating and affirming their Indigenous rights. Indigenous rights to lands and resources are defined in the Canadian constitution, in historic treaties, contemporary land claim agreements, Supreme Court decisions, as well as in other kinds of legal agreements and processes. Rights are also implicitly and explicitly articulated in social relationship, relationships to the land, oral histories and social cultural practices such as hunting or the visiting of sacred sites (Borrows, 2002; Napoleon, 2013). The rights of Indigenous communities to a healthy land and resource base is not only well defined in Canada but is also recognized in global protocols such as the *United Nations Declaration on the Rights of Indigenous Peoples.* Within this context, there are emerging opportunities to strengthen the existing network of community-based monitoring programs in ways that respect these rights.

1.5 History of Community-Based Monitoring and Citizen Science

Community-based monitoring, in general terms, is a system of watching, listening, learning and adapting to changing environments. Although sometimes described more technically, "watching the land" is dynamic of stewardship that is well understood by Indigenous peoples. Hunters, in the Northwest Territories, for example, have been making observations of barren ground caribou movements for generations; they travel and observe changes in the same places, using the same indicators and employing similar methods to those of their fathers, mothers and previous generations. Many current monitoring programs, such as the *Innu Guardians Program*, the *Ni Hat Hi* program led by Lutsel K'e Dene First Nation, or the *Haida Watchmen*, have historical roots in Indigenous ways of knowing and learning about the land.

Community-based monitoring is also a dimension of the growing social movement toward more participatory science (Bonney, Cooper, et al., 2009). Over the last forty years, there has been greater and greater recognition and support for community-based resource management and conservation of which monitoring is an important dimension (Leach, Mearnes, & Scoones, 1999). Conservation-focused citizen science projects began in the 1970s when environmental issues caused by urbanization, reclamation, and air pollution were particularly acute and attracted much popular attention" (Kobori et al., 2016). Indeed, the proliferation of many citizen science initiatives and community-based monitoring programs dates back to the post world war II period. Numerous disasters such as the Love Canal and at Three Mile Island, led to significant triggered significant mistrust of the power dynamics associated with the scientific process, and those representing science-based institutions (Levine, 1982).

Evaluations of the impact citizen science suggest it has the potential to improve the legitimacy and value of scientific studies and transform the role of "science" in society and decision-making. But according to some critiques, citizen science has not fulfilled this theoretical potential. "A significant and obvious obstacle to citizen scientists' efforts to shape scientific policies and practices are the often extreme disparities of wealth, education, and power (among others) between them and those they seek to influence" (Ottinger, 2010). Standardized data collection measures and methods, while creating rigorous data sets as well as complimentary data form different locations and over time, can also serve as barriers to the democratization of the generation of science – there are case studies where rigid use of standards have created limitations on who can participate, and in what discussions, and essentially ruled out the involvement of citizens in knowledge making or policy making (Ottinger, 2010). Finding ways of creating rigour and consistency in the data collection dimensions of community-based monitoring while at the same time ensuring democratic and equitable participation in the knowledge production process, is an emergent challenge for "community-based monitoring" in Canada and elsewhere.

2. Typologies of Community-Based Climate Monitoring

There are numerous kinds of climate change monitoring programs involving Indigenous communities that have been developed across Canada. An inventory of climate change monitoring programs suggests more than 100 programs are currently ongoing that may be considered "community-based climate change monitoring" (Appendix A). But not everyone uses "community", "community-based", "climate change" and "monitoring" in the same way. Some key questions to consider when review such programs:

- *Is the program led by a community?*
- *Whose interests are being served by the monitoring program? Is it intended or focused on meeting the knowledge needs of the community?*
- *What is the nature and extent of community participation?*
- *Are the methods of data collection culturally appropriate?*
- *Are the monitoring programs using consistent indicators/measures year to year and place to place?*
- *How many people from the community are involved in the program?*
- *Does the program focus on documenting and sharing local and traditional knowledge or in producing conventional scientific data?*
- *Who holds the data from the program?*
- *What are the learning outcomes from the program that are visible within the communities?*
- *How are the Intellectual Property Rights of the Indigenous elders and others involved being respected?*

These questions give a sense of the diversity and sometime ambiguity of programs defined a "community-based monitoring". Not all programs that define themselves as monitoring use consistent indicators and methods from year to year. Some programs involve very few community members and are focused on scientific data collection rather than the documentation of local or traditional knowledge.

There are many community-based monitoring programs being developed in the Canadian arctic. This partly reflects an imbalance of power and capacity between northern and southern Indigenous communities. There is relatively more capacity within northern governments and organizations stemming from land claim agreements and the creation of associated co-management structures and processes of land and resource management. Climate change impacts are also considered to be more acute in arctic ecosystems; as a result organizations like the Arctic Council and the International Platform on Climate Change (IPCC) are increasingly supportive of monitoring initiatives that speak to issues such as permafrost slumping, multi-year ice loss and arctic marine wildlife population and habitat changes. Explicit and direct objectives vary widely by culture, jurisdiction, capacity and ecological focus.

The need and type of climate change monitoring programs that may be developed in future by Indigenous communities are also likely to vary by climate change and experience of climate change. For example, those living in south-western Canada may be more focused on understanding and addressing the issue of drought and wildfire whereas those in the high arctic focused more on permafrost melt and arctic wildlife health.

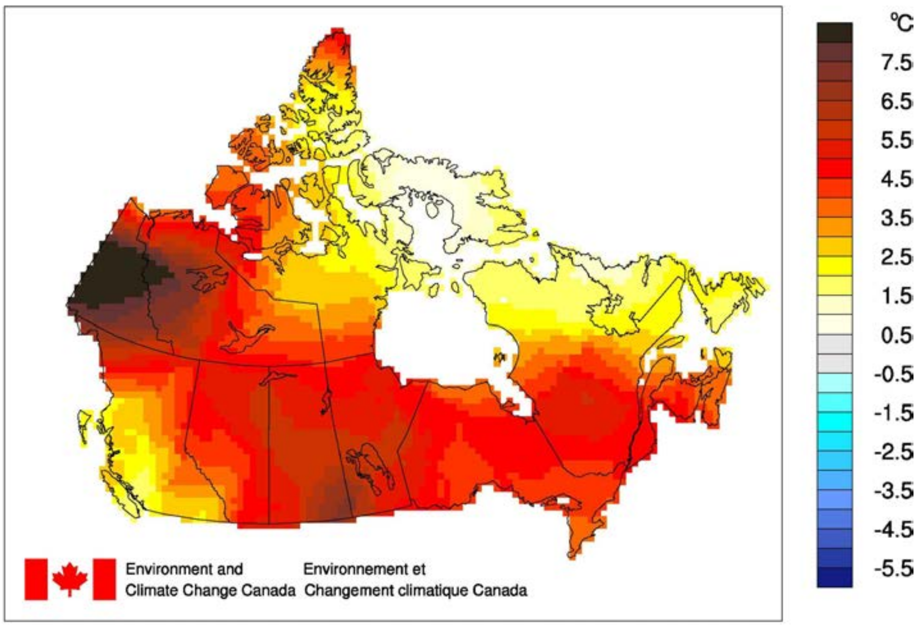


Figure 5 - Temperature Change Projections for Canada From Environment and Climate Change Canada

In addition to rendering insights about the effects of climate change, there are also many kinds of indirect benefits of community-based climate monitoring programs such as improved knowledge for adaptation to climate change impacts, conservation and management outcomes, public awareness and education, scientific discovery, recreation, social and economic contributions (e.g., employment) as well as improved engagement of Indigenous communities in land and resource management decision-making.

There are also numerous challenges however, including community capacity, limited resources to sustain monitoring programs as well, In many community-based monitoring initiatives there are “trade-offs between data quality and quantity, standardisation of sampling methods, quantification of sampling effort, and mismatches in skills and expectations between data collectors and data users” (Robertson et al., 2010).

3. Indigenous Knowledge in Climate Monitoring

3.1 Introduction to Knowledge Creation

Knowledge is generated in many different ways and the knowledge needed by Indigenous communities to adapt to climate change can come from many different places. The socio-politics and mechanics of knowledge generation should be understood as interconnected. For example, knowledge (wisdom) shared by Indigenous elders and community members are only some of the spheres of "knowledge" currently available to communities on such complex issues associated with climate change. The various types of community knowledge are not exclusive of one another but can inform each other. For example, communities may be interested in the knowledge produced by professional scientists (i.e., biologists) to determine if the fish they are harvesting are bio-accumulating mercury from melting permafrost. However, the individual harvesters may depend more heavily on the knowledge of elders and other community members about what areas of their traditional territory where permafrost is most common and problematic.

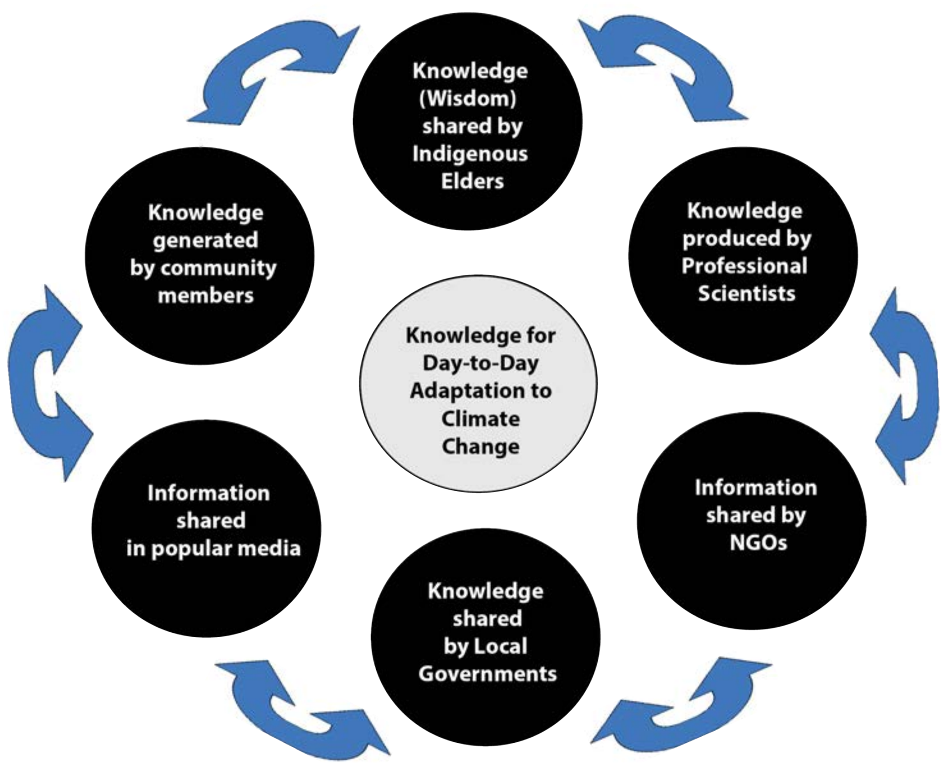


Figure 6 – A Circle of Community Knowledge Systems
Inspired by: (Kitolelei & Sato, 2016; Sato, 2014)

3.1.1 Social-Ecological Relationships

The production of knowledge is a social process; through community-based monitoring people often work together to build new insights about the world around them. "Effective citizen-science projects commonly build on the existing relationships people have with their environment. These are often highly developed, historically established relationships that bring with them a wealth of information". (Crain, Cooper, & Dickinson, 2014).

In addition to social relationships *within* communities being important, community-based monitoring programs are also based around social relationships *between* communities, and between communities, governments and other partners (e.g., academic institutions, NGOs, private industry). These relationships create opportunities for co-produced knowledge.

Many Indigenous cultures in Canada are characterized by strong human-environment relationships which are mental, physical emotional and spiritual. In some southern Indigenous communities, the medicine wheel depicts or describes these relationships including the importance of balance and respect.

These provides a strong and meaningful foundation for designing community-based climate monitoring programs. In addition to empirical observation about values, resources, and places that are loved and considered relations, some many Indigenous peoples have a spiritual connection to the land that informs their ability and understanding of ecological changed (Cruikshank, 2014; T. Ingold, 1996; T Ingold & Vergunst, 2008; Legat, 2008).

3.1.2 Observation

Observation is a critical foundation of monitoring programs. Observations about many different kinds of ecosystem components, processes and functions, characteristics and relationships can render insights about climate change impacts. But what exactly is observation? Observation, unlike opinion is based on empiricism or a sensory experience of change. In essence, it is an evidence-based understanding of what is happening in the environment. We can have opinions about many things (e.g., politics in Russia, melon farming in Guatemala) but is the observations in one's own backyard or local environment that are critically useful.

Observation is a process of: "receiving and recording of information about the environment using rigorous methods, tools and instruments". In simpler terms, it can be framed as *watching, listening, learning and adapting to change.*

A consistent and specific observation is critical to ensuring that trends and patterns in the health and sustainability of resources can be easily and consistently measured, communicated and understood by others. However, finding ways to holistically track changes and what they mean for people's land use, livelihood, and well-being is equally important. The lens of a strong community-based monitoring program is thus not objective nor strictly biophysical in nature - a people-centred approach involves addressing the following questions:

- What ecosystems, resources, and places are important?
- Why are they important?
- What would change in these ecosystems, resources and places mean to the community?

Efforts to collect "objective" data are usually problematic since our social, cultural and personal values always influence what we do and don't see. Approaches to observations that make one's social and cultural values explicit can render far more useful data about ecological change.

> "Citizen-science projects that gather only ecological data represent a missed opportunity to gather social data from participants. Likewise, when social scientists study citizen scientists using surveys, ignoring the ecological data that participants are contributing, they miss interesting opportunities to explore the feedbacks between the two. Integrating these two research endeavours with citizen-science methodologies can open up new areas of inquiry and reveal the complex interrelationships among specific aspects of human and natural systems, allowing them to be studied within one integrated data collection system" (Crain et al., 2014).

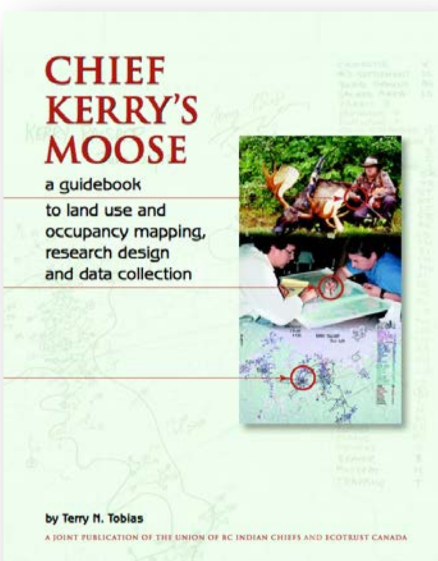
3.1.3 Place-Based Knowledge – Mapping and Monitoring

Many of the kinds of impacts of climate change of concern to communities are place-based. There is a location (latitude/longitude marker) or geographic space in which people observe or experience change of concern or other value. Mapping is therefore a very important tool in community-based monitoring.

Mapping is a tool that has been well used in Indigenous communities for decades so there are a lot of different kinds of resources and critical discussion of best practice. One of the most useful resources available is Chief Kerry's Moose (Tobias, 2000). The guidebook was written with the aim of building capacity for Indigenous communities seeking to document their land use histories but many of the lessons and methods can be adapted for community-based monitoring.

Some of the critical issues of mapping are the same as those involved in other aspects of data collection:

- How many people are willing to participate?
- Are there staff available who are trained or willing to be trained in appropriate methods of data collection?
- How is the data gathered, translated, transcribed and archived?
- How are data verified?
- Who has access to the information?
- How can it be updated?
- How will it be used?



Some of the more unique opportunities and challenges of mapping related to rigorously record spatial information.

The adage, "keep it simple" is among the most useful principles when considering how to record spatial information. Many communities involved in community-based monitoring use basic hard copy maps (paper maps) and simple formats of pens, pins or other tags to record information. Other communities use more complex kinds of technologies including GIS software, archival platforms and apps for smart phones to record and make spatial information relevant in their monitoring programs.

Figure 7 - Chief Kerry's Moose Guidebook
(Tobias 2000)

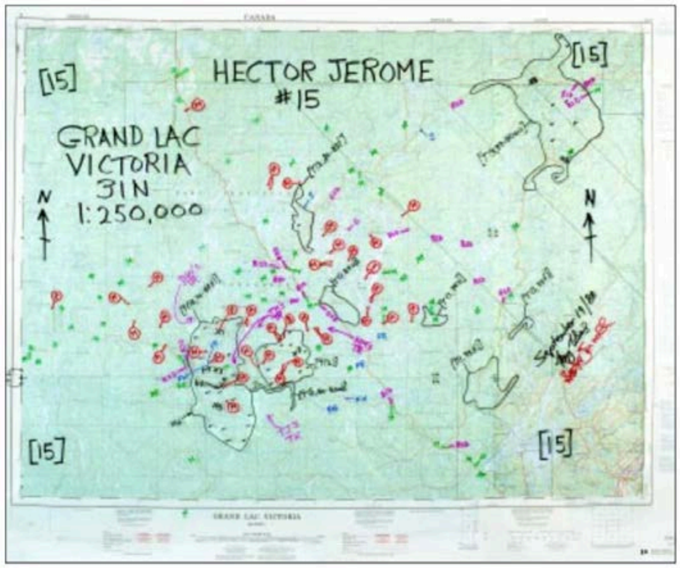


Figure 8 – **Map Biography from Chief Kerry's Moose**
(Map 1 in Tobias 2000).

Figure 9 - **Developing a collaborative Map Biography**
(Joseph Catholique and Madeline Drybones, Lutsel K'e, NT)

3.2 Indicators – Signs and Signals of Change

Ecological indicators are used by many indigenous peoples to understand and communicate about ecological change. They are the signs and signals that guided understanding and decisions within Indigenous communities for hundreds if not thousands of years. For example, hunters watched for ecological signs and signals on the land to determine, where to harvest, when to travel, how to harvest and whether it was safe to eat the food that was harvested. Among the Cree and Inuit of western Hudson Bay, indicators are the voices of the earth that are always talking to us (Tarkiasuk, 1997) For many Aboriginal peoples, physical and spiritual signs and signals that the land is healthy are very important to their own feelings of health and well-being and that of their communities. As described by a Cree man from Chissasibi, "If the land is not healthy, how can we be?" (Adelson, 1998)

The idea of indicators being the "voices of the earth that are always talking to us" is evocative but speaks to the deep cultural and spiritual insights and intuitive ways in which Indigenous peoples learn about and understand change in their environment. "People who live in, or frequent, a particular place may have an intuitive and scientifically valuable understanding of that area, which would be extremely difficult to acquire without time and similar experiences in that place. This could bias them or it could allow them to notice exceptional cases and to gain access to important data resources that are not widely known"(Crain et al., 2014).

The process of identifying indicators for monitoring has multiple phases. At its simplest indicators are tools that help people identity and measure changes in values, resources, places, events and processes that are important to the community. "They are the signs and signals that are always talking to us".
A critical starting point therefore in the development of a monitoring program is to understand clearly what values are important and determine how community members identify and articulate changes in those values.

Globally, most formal programs are focused on species of common significance (e.g., common songbirds) and other charismatic animals, such as frogs and butterflies (Kobori et al., 2016). Community-based monitoring programs are most successful and sustainable when their focus as well as methods of monitoring are familiar and easily accessible. "Citizen science programmes directly rely on the curiosity and pleasure of the volunteers to learn and observe things that they have never noticed in their most familiar places" (Devictor, Whittaker, & Beltrame, 2010). A result terms such as 'familiar species', 'wider countryside', 'ordinary nature' and 'everyday nature', are terms now frequently used in conservation biology and land-use policy (Devictor et al., 2010).

....

3.3 Counting Change: Using Quantitative Data

Ecological monitoring is most often associated with the collection of quantitative data. Although Indigenous knowledge is sometimes assumed to be only narrative, (i.e., oral histories), such framing of knowledge is misleading. Many Indigenous peoples track quantitative data in their daily and traditional practices. For example, species and species diversity counts are critical indicators of changes across Indigenous cultures (H. Moller, F. Berkes, P. O. Lyver, & M. Kislalioglu, 2004). ***Birdwatch*** monitoring programs are among the earliest examples of community-based monitoring or citizen science that engaged community members in the "counting" of birds.

There are different kinds of things that can be counted. Different kinds of categories can be created to describe how things have changed (e.g., was the water clear, green or brown? Was the ice very thick, thick or thin?). More precise kinds of variables are most useful; these are sometimes called interval variables because there is a consistent numeric value that is consistently used (e.g., inches, kilometres, years, pounds, dollars). Using multiple variables for each value can help verify or determine more details about what and why something is changing.

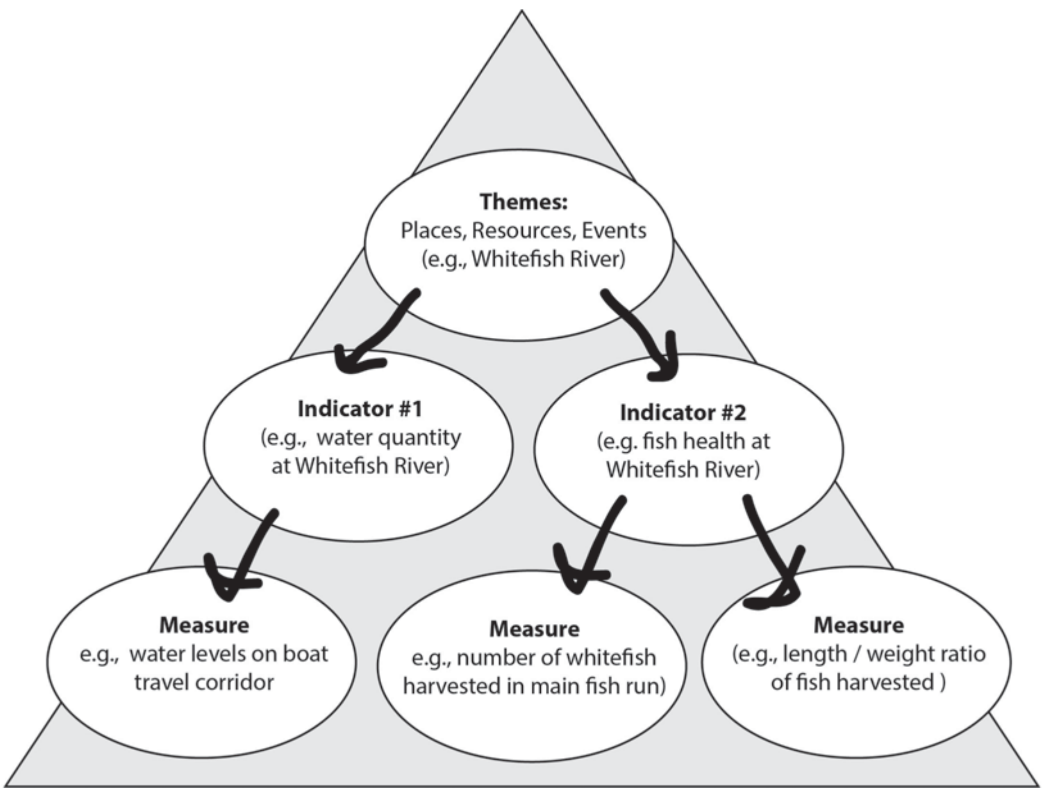


Figure 10 – Themes, Indicators and Specific Measures

A critical question in the activity of counting is, "did we get it right?" This essentially speaks to the quality of quantitative data.

Data quality in the case of counting species or determining species diversity has been studied extensively (e.g., assessing how many and what kinds of birds might be using a staging area or wetland on route north or south), In some cases, researchers and community monitoring program leads have determine that pilot evaluations to establish sampling biases can be helpful to determine data quality. To avoid or limit error, community groups can be trained along with a biologist. Biologists and community leaders can work together to develop or employ a sampling "key" that provides clear information about identifiable features of each species. Little tests or games (e.g., even video games with youth) can serve to improve accuracy of counts and determine sampling bias. "Once these sampling biases are clearly established, methods and statistics can thus be specifically developed to properly handle variability in citizen science datasets" (Devictor et al., 2010).

Most programmes only rely on a selected list of the most common species. These chosen species are generally the easiest to detect and the most abundant. They thus provide less biased data as they carry fewer false (and non- detection) events (Devictor et al., 2010).

Once variables have been chosen, deciding on a strategy or set of methods of measuring change in the variables. There are numerous ways of measuring change in ecological variables. Using standardized scientific protocols (tools and methods) can ensure that the data collected is viewed to be rigorous by scientific researchers (e.g., published, or used in hearings or legal processes). Working with a scientist to become trained in using standardized methods is useful; scientists who respect local and traditional knowledge may also be helpful in adapting protocols to the particularly social-cultural context of the community.

> Scientists who design research projects have to write study protocols that take citizen scientists into account. "You have to develop specific protocols [for citizen scientists] and then go out and measure to test the results [they get] for reliability (Cohn, 2008).

There are a few examples of scientific protocols available in the appendix of this report.

In many communities across Canada, Indigenous peoples may already be using their own methods of counting. A good example of such protocols exists in northern Canada in the case of caribou health. Dene elder and hunters worked with a biologist to assess the usefulness of hunter perceptions (quantification) of caribou body condition (i.e., the fatness of the animal). It was determined that elders and hunters were highly consistent from year to year in their assessment of the animal health.

> Hunters in this study made consistent assessments of body condition in both survey years (i.e., animals with the same or similar body

> condition rating that were considered skinny by the hunters in 2000 were also considered skinny in 2001)(P. O. Lyver & Gunn, 2004).

This study suggested that hunters' traditional knowledge was useful to understanding herd health. Hunters assessed body condition in complex ways and took into account a variety of variables in assessment whether a caribou was fat including location of fat on the animal, sex of the animal, geographic location of harvest and the time of the year. They were thus were considered useful in determining whether a skinny animal was skinny due to natural variability (i.e., winter condition) or was unhealthy. Such tracking of unhealthy animals was considered useful in assessing overall herd health since body condition is key to animal fecundity (e.g., ability of females to reproduce) (P. O. Lyver & Gunn, 2004; P. O. B. Lyver, 2005).

Another useful example of community-based monitoring involving "counting" data is in fisheries research. Fishers are very knowledgeable about many aspects of their catch. Standardization of protocols have been developed for fishers to contribute to calculations of fish stocks in a marine area, a river or lake (including age structure of the stock), as well as species diversity of species (as well as invasive species). Catch per unit effort (CPUE) data are often collected where fishers are asked how many fishers were caught in a particular area relative to some measure of effort (i.e., time, size of net etc.).

Where fishers' who have many decades of experience are involved and are known to be consistent in where, when and how they fish, they can provide very detailed information about trends and patterns in stocks. For example, such knowledge was critical on the east coast of Canada/United States in relation to cod and haddock.

> In New England, interviews with older, retired fishers have produced maps of present and former spawning areas for cod and haddock. These interviews also generated information on the sequence and nature of the collapse of local stocks, highlighting localized fishing impacts (Ames 1998). Similarly, Trinity and Bonavista Bay fishers who had gill- netted very large, whitish cod in the deeper areas of the bays believed that these local aggregations of mother fish disappeared with the expansion of the gillnet fisheries in the 1960s and 1970s. They also observed juvenile cod, making associations between fluctuations in juvenile cod abundance and a large bycatch of juvenile cod in capelin traps in Trinity Bay (B. Neis et al., 1996).

Simply duplicating scientific protocols (i.e., rules) for collecting quantitative data is rarely as useful or successful as developing protocols that reflect the day-to-day realities of local communities involved in monitoring. These alternative methods for tracking change may be considered more respectful of the environment and of socio-cultural relationships to the environment. They are also likely to render data or outcomes that are more meaningful and trusted by community members (e.g., caribou collaring of data is considered less respected by Dene hunters when compared to visual observations of caribou movements at key water crossings).

3.4 Stories of Change - Qualitative Data

Not all monitoring data has to be quantitative. Qualitative assessments of changes can be incredibly useful in rendering a deeper understanding of how, to what extent as well as *why* an important resource or ecological value has changed.

Questionnaires and face-to-face interviews are the commonly used method when trying to learn directly from land users and other knowledge holders. These interviews can range from informal storytelling and discussions or formal question/answer interviews. They can be recorded using pen/paper or using audio, video or computerized software (e.g., an online survey). The more structured and formal the interview, the more likely that the data is consistent and can be used and compared over time. However, a certain amount of flexibility is necessary to enable people to adapt their programs to new information and insights. However, too much flexibility makes comparison or identifying patterns and trends difficult or unlikely. "The researcher faces a trade-off between the goal of obtaining data that have a high probability of being consistent across observations and thus answering the original research questions if analyzed appropriately, and the goal of adapting to changing circumstances as the project proceeds" (Cox, 2015).

There is also a trade-off between detail and complexity of the interview and the willingness of participants to complete the interviews. A few simple questions (5-10) asked in an informal manner and recorded using simple technology may yield more interviews and consequently more data / observations for the monitoring program than very detailed and long interviews and questionnaires. Shorter interview guides are also easier to use by staff of the community-based monitoring program who may have limited training or supports.

There are a variety of tools that can used to document stories or engage in storytelling so as to ensure outcomes contribute to our understanding of ecosystem change. Once such technique is defined as the "Most Significant Change" or MSC. "The design involved the deliberate abandonment of the use of 'indicators', a central concept in orthodox approaches to monitoring. Instead, the focus is on the identification of significant change as perceived and interpreted by the various participants" (Davies, 1998). By encouraging people to "story" changes in their environment that are significant, one can determine the interconnections between social and ecological change or the meaning of particular events or patterns to the livelihoods and well-being of communities. There are different ways that such story-ing can be enhanced. Storying on the landscape in areas that are changing creates an opportunity for experiential learning to occur at the same time that data is being collected. Symbols and metaphors within stories can be particularly power tools to stimulate learning about critical values, resources and changes and those values and resources. This is particularly important in First Nations cultures in Canada. Materials such as storied drawings, murals and carpets can stimulate discussion and storytelling in different ways.

Figure 11 – Storytelling

There are various ways in which storytelling – including metaphorical stories, song, poetry and symbolism - can help people understand what is going on around them, communicate about these changes to others as well as innovate climate change solutions. Stories can focus on landscape level issues but can also address broader socio-political landscape of ecosystem change and offer lessons for management and decision-making. In addition to documenting specific changes in the land, water and wildlife, climate change narratives can address broader issues of equity and power around the cause and distribution of climate change impacts and the origin of their solution.

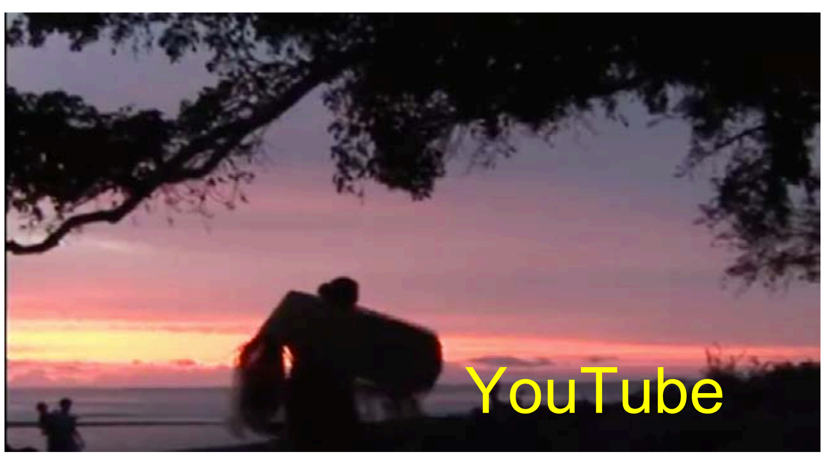


Figure 12 – YouTube Video - Community Narratives of Climate Change

https://www.youtube.com/watch?v=GVz6ZmQSiCU

There are more and more technologies around video story telling or digital storytelling which enable communities to bring forward their knowledge and capacity in narrative or artistic form (Rathwell & Armitage, 2016).

> Art is a medium through which to explore social and ecological change…. Artists explained how their works mirror changing environments or depict a memorable social-ecological event in their communities. In this way, the artworks themselves monitor environmental change, environmental anomaly, and in some cases how humans adapt to these changes. Artworks then act as picture books that tell stories of an increasingly variable environment (Rathwell & Armitage, 2016).

Figure 13 – Artistic Approach

Figure 14 – Polar Bear Drawing (Basic Ideas for Drawing)

3.5 The Role of Technology in Documenting Indigenous Knowledge

Technology is playing an increasingly important role in community-based monitoring programs including programs involving Indigenous Knowledge. This trend is visible in many kinds of similar programs including those defined as citizen science.

> The proliferation and access to a broad range of information technologies, such as GIS, iPhones, google maps and related web-based apps have made it possible to imagine and implement large-scale citizen science initiatives across multiple continents. These technologies and capacities to document and share data - challenge the traditional relationships between scientists, the public, and conventional notions of data and data collection" (Connors, Lei, & Kelly, 2012).

While interest and purchase of the "latest-thing" in terms of technology can be evocative, communities involved in community-based monitoring must take into consideration a variety of factors related to technology adoption including:

- ✓ ***Price*** **–** How much does the technology cost? Is there a budget for it?
- ✓ ***Purpose*** – Does the technology fit with the overall purpose or strategic vision of the community-based monitoring program?
- ✓ ***Training requirements*** **–** How difficult is it to receive training?
- ✓ ***Ease of Use*** – How easy is it to use?
- ✓ ***Upgrades*** – How easy is it to keep the technology up to date?
- ✓ ***Data collection*** **–** Will the technology increase data collection opportunities?
- ✓ ***Format*** **–** Does the technology produce data in a useable format relative to data needs in the community?
- ✓ ***Data Quality*** **–** Will the technology improve data quality?
- ✓ ***Participation*** **–** Will the technology increase the number of people participating in the monitoring program?
- ✓ ***Communication*** **–** Will the technology improve the capacity of the program to communicate the outcomes of the program to the community or other necessary audiences?

There are a variety of low-cost gadgets that enable communities to jump into the technical aspect of monitoring. For example, communities can easily test and learn about their drinking water quality using test kits of various kinds - these can be made available to monitors or everyday household water consumers for less than $50/kit. These will provide information about biological water quality problems such as bacteria as well as some standard contaminants (i.e., lead). More intensive water quality testing for contaminants associated with mining or oil sands activity for example, can cost in the hundreds or thousands of dollars per sample.

The increasing availability of low-cost technology for monitoring marks a paradigm shift as well as a shift in the power dynamics related to knowledge production and use. Communities no longer have to depend on governments or industry to provide them with information about what is occurring in their own backyards or regions.

"In the case of water related monitoring, "the advent of robust, cheap, and low-maintenance sensing equipment provides unprecedented opportunities for data collection in a citizen science context" (Buytaert et al., 2014).

Simply using mass produced technology is not as useful as co-designing technologies that are culturally appropriate as well as safe and successful in harsher environments such as the high arctic with the Igliniit project (Gearheard, Aporta, Aipellee, & O'Keefe, 2011).

> In 2007, Inuit hunters from Kangiqtugaapik and geomatics engineering students from the University of Calgary began collaborating on the Igliniit design. The development of the Igliniit technology involved a process of iterative design and engineering that took place over two years of interaction between six Inuit hunters from Kangiqtugaapik and 11 senior-year undergraduate geomatics engineering students from Calgary. The focus was on codesigning a technology that would allow hunters to track their travel routes, log their observations/experiences *en route* and log the weather that they encountered (Gearheard et al., 2011).

The number of programs being developed to support Indigenous peoples to track their observations in a quantitative way (i.e., the number of animals observed). Some of the most interesting uses of technology are those in which the internet and various web platforms become a mechanism to bring communities together. By suing common data collection methods and a common computer program or web-platform communities can crowd source data about a problem of common concern.

There are numerous models and examples of crowd sourced data. It has been used in a variety of countries to amass data about industrial catastrophes (e.g., the gulf oil spill) as well as natural disasters such as earthquakes and flooding. Technologies such as phone apps for example, enable users to geo-locate themselves or particular events or problems that are immediately uploaded to an aggregated data or mapping site. Two-way flow of information is critical; people volunteer to produce data or offer information to the crowd because there is a perceived individual or collection benefit. For example, residents of Paris collectively mapped areas of the city being flooded in xx in order to ensure accurate information for disaster response teams but also to keep other members of their neighbourhood safe and away from high-risk areas (Le Coz et al., 2016).

Although there are complicated programs and sites available, most of them use Google Maps as the basis or foundation of geo-referencing data. But these technologies will continue to evolve and are doing so at an astounding rate (Goodchild et al., 2012). One of the most recent updates to Google maps is the inclusion of Indigenous lands; the map information was the result of a collaboration between Google Canada, governments and Indigenous communities.

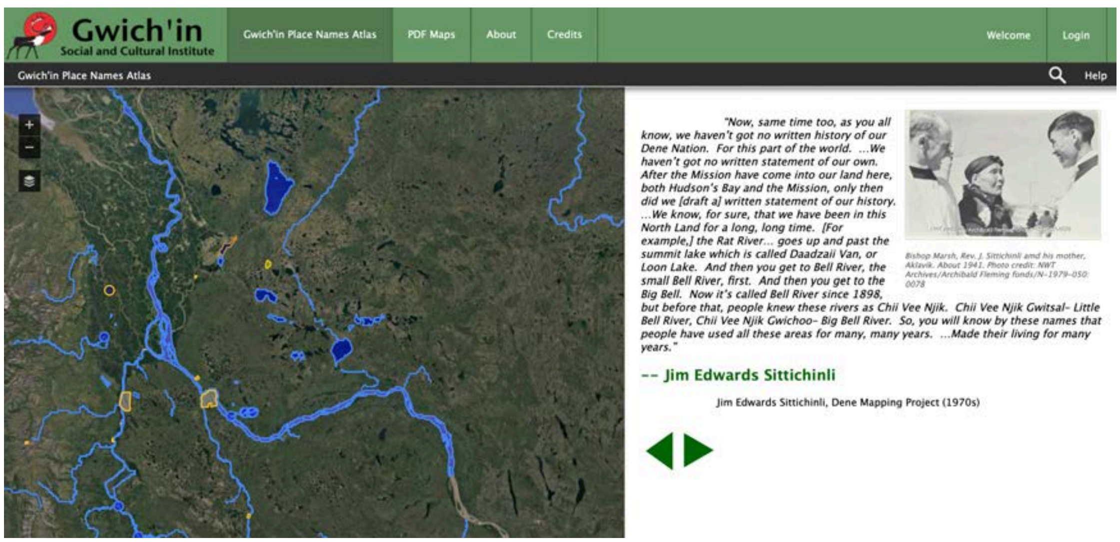


Figure 13 – Excerpt from the Gwich'in Places Names Atlas https://atlas.gwichin.ca/index.html

Since google maps are so widely available, they have been used as the basis for a variety of citizen science initiative – large amounts of data can be added quickly by thousands of people which creates a huge opportunity to learn about a variety of phenomena including climate change. For example, communities in flash flood prone areas of the United States are using the platform to share information quickly about potential hazards. Facebook with google map interface is similarly used in northern Canada to share information about ice conditions.

The use of google maps in different kinds of apps enables communities to add information easily quickly. For example, First Nations in Alberta can track the spread of chronic wasting disease in deer and moose. The apps enable community members to add data on sightings of unhealthy animals as well as improve understanding of range shift or expansion of white tailed deer, mule deer and elk westward and northward, a phenomenon associated with climate change.

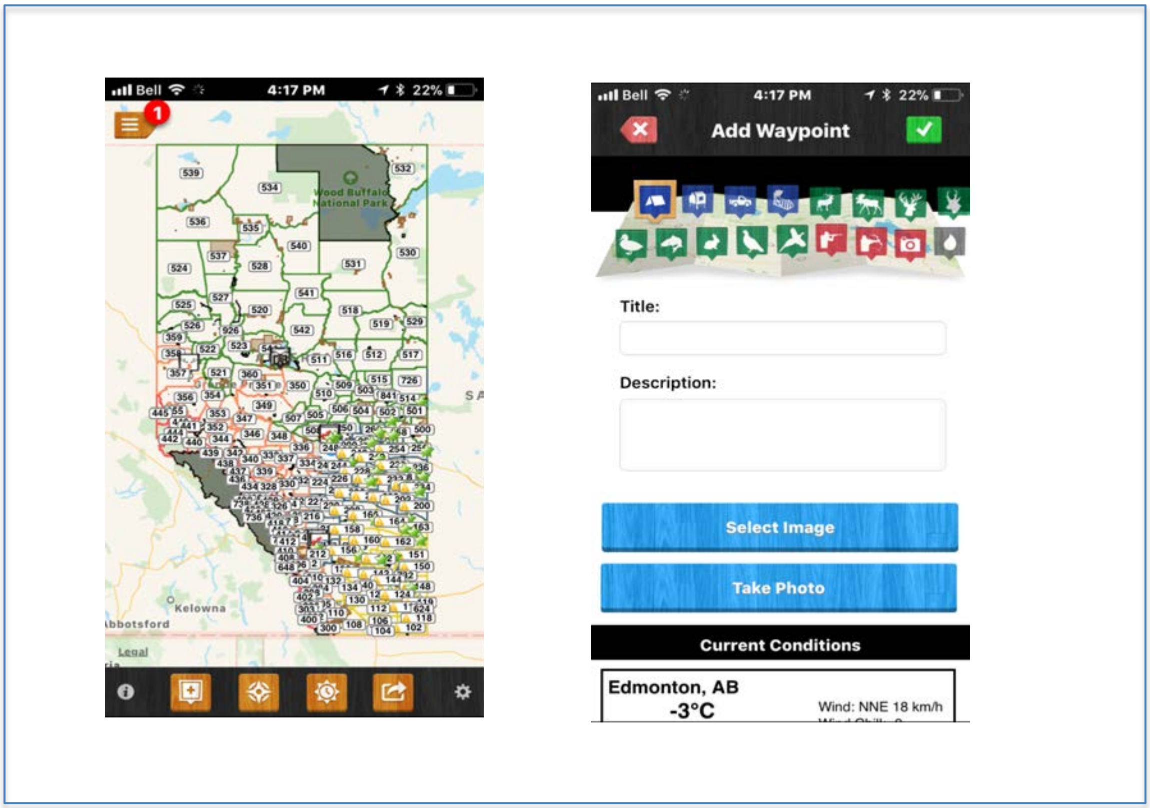


Figure 14 – iHunter App for Smartphones
(Photo Credit, 2018, Ihunter.com)

Some of the same issues about data quality emerge with the use of technologies such as smart phone apps. It can be very easy to log new data – this is both a strength and a limitation. People may be too quick to add new waypoints of an event or observation before thinking through the details or relevance of sharing that information. But many apps now include verification functions not only but the initial user but also by a secondary administrator.

> "New technologies play a major role in crowdsourcing models of citizen science. These include apps for smart phones that facilitate species identification and data entry as well as development of automated filters that request verification from participants when data are geographically or numerically outside the expected range. … (Kobori et al., 2016).

There is no doubt some technologies will only become more useful in coming years.

4. Selected Approaches to Community-Based Monitoring

4.1 Community-Based Climate Monitoring of Forest Ecosystems

Forest ecosystems are an important focal point for community-based climate monitoring. In addition to conventional scientific monitoring, there are numerous kinds of approaches to documenting Traditional Knowledge of forest ecosystems that provide meaningful indicators and data about such issues as wildlife habitat, forest fire impacts, forest health as well as cultural landscape change.

Developing Indicators of Forest Ecosystem Change

A key strength of Traditional Knowledge is its potential to provide a holistic framework for thinking about the relationships and meanings of different kinds of ecosystem change. A good starting point within this framework is "place" or the critical features of a forest landscape that have social, cultural as well as ecological meaning .

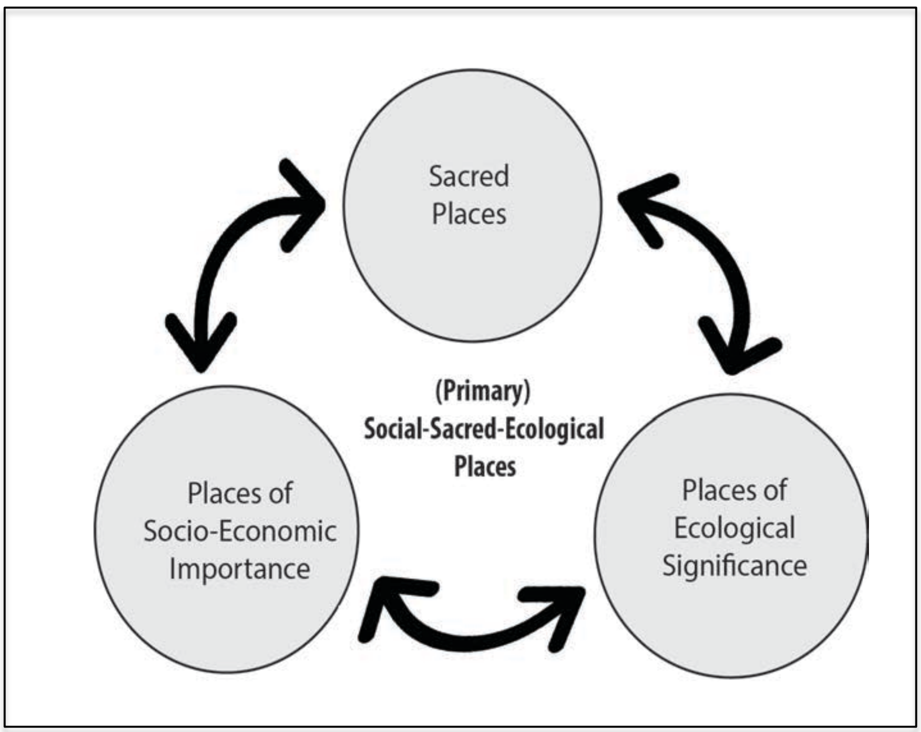


Figure 15 – Social-Sacred and Ecological Places

In many forested landscapes valued by Indigenous peoples, cultural trails provide a network between critical places. Traditional land use maps (comprised of individual map biographies) are a kind of physical, emotional and cultural guide one might follow to understand where, when and how to monitor landscape level change.

Some critical examples of such places include:
- ✓ Sacred paces (areas of spiritual healing or other therapeutic or cultural significance) (Type 1);
- ✓ Places of socio-economic importance (e.g. harvest sites for non-timber forest products such as blueberries) (Type 2);
- ✓ Places of ecological significance (e.g., areas of high biodiversity or wildlife habitats) (Type 3)

A place that is characterized by all three kinds of values might be considered a primary location (social-sacred-ecological place) for monitoring.

Figure 16 – Blueberry Picking

Tracking changes in places of sacred, social and ecological significance be developed in many ways. Place-based research creates the opportunities to knit together a variety of data gathering activities synergistically. For example, a youth-elder camp planned around a berry picking activity can create the opportunity to gather a variety of information about berries and medicinal plants (e.g., quality, abundance etc.). But it can also provide a useful base camp for gathering other kinds of information about the health of the forest and forest health.

There are different kinds of observations that berry pickers (as well as experienced land users, forest stewards and others) make on a regular basis in relation to berry harvesting. Although the activity can be brushed aside as unscientific or deemed folky, informal or simply "women's work", serious berry pickers have a significant understanding of forest ecosystems as well as capacity for monitoring (Brenda Parlee, Berkes, & Gwich'in, 2005; B. Parlee, F., & Council, 2006).

Gwich'in women from Fort McPherson for example, monitor many different indicators and at different scales to make decisions about, where, when and how to harvest berries. For example, at different points during the harvest season (i.e., summer), women keep track of plant phenology (i.e., stage of growth) to keep track of when berries will be ripe and read to pick. They also know that broader landscape level change in forest ecosystems matter to the success of berry picking including forest fire history, forest succession cycles and patterns. Broader scale climatic knowledge is also needed to inform where, when and how to harvest - such as precipitation patterns, temperature and extreme events such periods of extreme heat (i.e.,, when berries will cook or drop early) or unusually late frost conditions (i.e., when early growth of blossoms etc. might lead to a limited availability of berries later in the season), This kind of knowledge is not only generated over the course of one season but is also tracked from year to year yield in useful information about climatic trends and their impacts on forest ecosystems. The statement, "it was a good year for berries" or the "berries were late this year" is not just an opinion but reflects very complex kinds of observations over time.

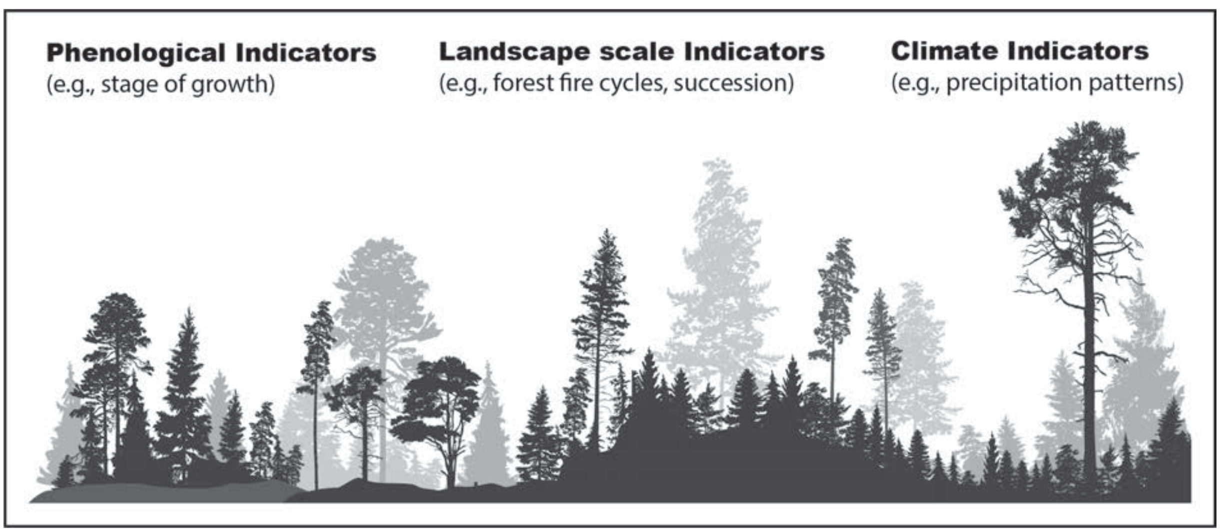


Figure 17 – Framework for Monitoring Forest Ecosystems
(From research with Tetlit Gwich'in Women from Tetlit Zheh, NT, Parlee et al. 2006)

Some additional examples of indicators used in forest ecosystem monitoring could include:

- ✓ Changes in the quality of plants valued for food and traditional medicine;
- ✓ Changes in the density and abundance of plants valued for food and traditional medicine;
- ✓ Changes in access to plants used for food and traditional medicines;
- ✓ Security of sacred sites;
- ✓ Access to sacred sites;
- ✓ Ability to exercise treaty and inherent rights to harvest;
- ✓ Extent and nature of participation in governance of forest ecosystem;

Figure 18 – Reading Oral Histories with Dendrochronology Data

Many Indigenous communities are equally interested in monitoring indicators that might be considered more standard of science-based indicators of climate change in order to better understand, manage and communicate about the impacts on forest ecosystems. These may include:

- ✓ Frequency of forest fire events;
- ✓ Prevalence of invasive species;
- ✓ Forest health / disease patterns;
- ✓ Biodiversity in forest ecosystems;

Knowledge about climate stress on forest ecosystems can also be co-produced by scientists and Traditional Knowledge holders through different kinds of monitoring activities. For example, Indigenous youth and foresters may work closely together to gather samples of tree roots or tree-cores that offer insights about historical patterns of change in temperatures, drought and forest fire and other stresses such as disease. When such dendrochronology data is linked together with Indigenous oral histories, the resulting "story" that is both ecologically and socio-culturally significant.

Figure 19 – Boreal Forest Fire

4.2 Wildlife Monitoring

There are numerous opportunities to track climatic effects on wildlife using community-based monitoring and improve knowledge about health, distribution, population as well as emerging problems of disease and bioaccumulation of contaminants (Berman & Kofinas, 2004; P. O. B. Lyver, 2005; B. Parlee, M. Manseau, & Lutsel K'e Dene First Nation, 2005).

Harvest Data

One of the most common approaches to wildlife monitoring involving Indigenous communities is the wildlife harvest study. The harvesting of traditional food including wildlife (i.e., moose, deer, caribou) is a cornerstone of northern Indigenous cultures, economies and health; where communities face limited availability of affordable market foods, such harvest is critical to food security(Egeland, Johnson-Down, Cao, Sheikh, & Weiler, 2011). The literature on Indigenous subsistence is diverse and has roots in the field of anthropology as well as sociology and economics. It is loosely defined as a mode of production that meets basic needs through the flow of valued resources. It is distinct from commercial modes of production in that it does not entail the accumulation of those resources. There are numerous terms that have been used to describe subsistence activities such as 'shadow', 'non-structured', and 'unorganized'; however, these terms have not captured the many complex ways in which people organize at the local level to meet their needs and have instead stigmatized those participating in subsistence activities as "non-progressive, backward, and resistant to change" (D. C. Natcher, 2009). Much has changed in northern Canada since the 1950s; more is known about natural cycles in caribou populations. There is also greater recognition of Indigenous rights to harvest (e.g., as defined in many Indigenous treaties and land claim agreements).

Indigenous communities and others, who depend on wildlife resources as part of their economies and cultural well-being, are proven to be highly conscientious about sustainable harvesting and accurate accounting of animals harvested; this is particularly true in small communities where there is much sharing and consequent transparency of where, when and how meat was harvested (B. L. Parlee, Sandlos, & Natcher, 2018). Detailed harvest studies have been developed in many parts of Canada that provide useful guidance on appropriate methods (Berkes, 1983; T. C. Brown & Burch Jr, 1992; Inuvialuit Joint Secretariat, 2003; Peloquin & Berkes, 2009; Rosol, Powell-Hellyer, & Chan, 2016; Statistics Canada, 2006; Usher, 1987). It is considered one keyway in which Indigenous knowledge can inform wildlife management including monitoring in the contest of different stressors or drivers including climate change.

Scholars have argued that the number of animals harvested is a measure embedded in many Indigenous resource management systems; "the harvest rate, or similar catch per unit of effort (CPUE) measurement, is the most practical population-monitoring index for customary resource users"(Moller, Berkes, Lyver, & Kislalioglu Berkes, 2004). In the absence of other kinds of population surveys such as caribou counts, CPUE is thought to be a useful proxy for understanding population dynamics – the greater the population, the less effort is required in harvest and vice versa. "The use of CPUE as an index of abundance rests on the assumption that catch is proportional to both the abundance of the harvested population and the amount of effort invested in hunting" (Keane, Jones, & Milner-Gulland, 2011). Simple summing of harvest outcomes and CPUE analysis are not however, the same thing. Harvest studies tend to focus only on the number of animals taken with lesser consideration given to the various aspects of "effort" including input and opportunity costs, distances, as well as time. CPUE also assumes the recording of both successful harvest events and unsuccessful events or trips. Unsuccessful trips are sometimes not well documented during harvest studies due to lack of recall by respondents and/or the overarching emphasis on calculating numbers of retrieved animals.

Economic anthropologists and resource economists have theorized that harvesters generally adapt to the declining availability of wildlife and other valued resources in the short-term by increasing the level of effort to find those resources (Winterhalder, 1981). Optimal foraging theories suggest there is a tipping point, however, at which it no longer becomes cost effective, given lack of harvest success, to continue along the same path(Moran, 1982). At that point, and in the context of longer-term scarcity of resources, harvesters are likely to make greater changes in their livelihood practices.

Patterns and trends in harvest can provide useful information about wildlife populations but also about food security. Are people eating the same, less or more traditional/country food? This is a critical issue that may be affected by many socio-economic, cultural as well as ecological changes including those associated with climate change. Teasing out whether a change is "caused" by climate change may be a secondary concern to communities given the larger health problems associated with declining consumption of traditional/country foods (e.g., increased risk of Type II diabetes_ (Egeland et al., 2011; Receveur, Boulay, & Kuhnlein, 1997).

Observations of Changes in Wildlife Population, Movement and Habitat

In addition to the usefulness of harvest data, Indigenous harvesters are increasingly valued for the information that can be provided about wildlife health and distribution. For example, harvesters are recognized as knowledge about a range of wildlife issues that are considered climate change related. Changes in wildlife habitat and range is an emergent issue tied to climate change; as climate warms, wildlife populations such as mule deer and white tailed deer are increasingly seen north of 60 in areas where they are considered invasive or problematic by communities (B. Parlee, Goddard, Basil, & Smith, 2014).

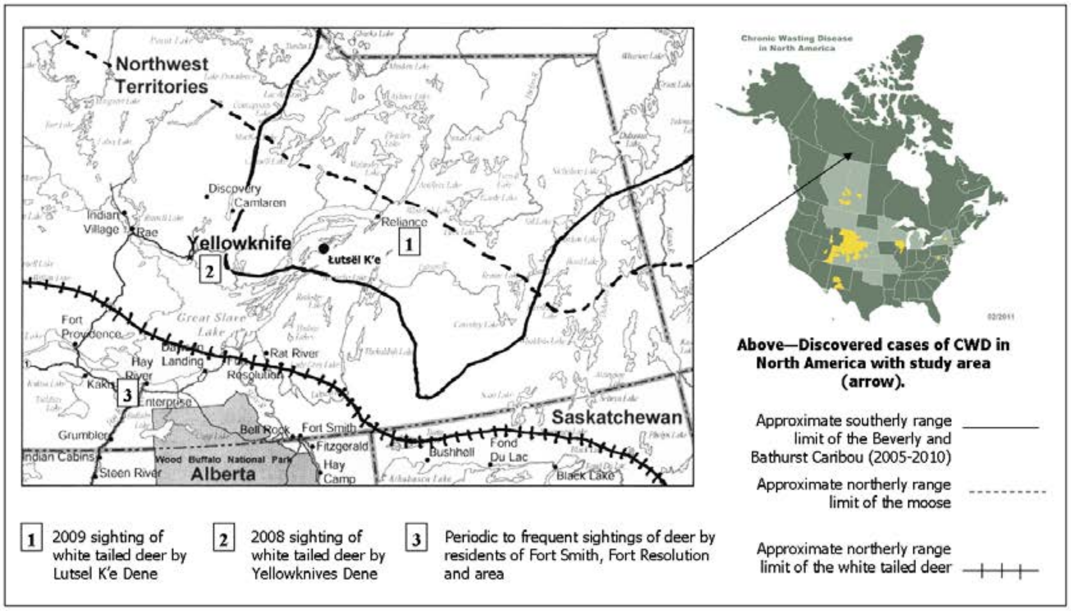


Figure 20 – Harvester observations of Deer and Moose Habitat Changes
(From Parlee et al. 2015).

This can be highly problematic as it could dramatically increase habitat degradation. It is also risk to barren ground caribou given deer in Alberta and Saskatchewan are infected with a disease called Chronic Wasting Disease which is known to have spread to other cervids including reindeer in northern Europe.

Denesoline hunters in the Northwest Territories have been involved in monitoring changes in caribou fat which is tied to habitat conditions and habitat carrying capacity; although knowledge offered by harvesters is often qualitative, caribou fat (thickness, density) is a quantitative indicator that is commonly tracked and can be predictive of fecundity and populations dynamics (P. O. Lyver, 2005).

monitors to report sightings, assess body condition (e.g., caribou fat) as well as collect tissue samples for testing for contaminants associated with resource development.

The co-production of knowledge is also emerging as important in different wildlife management contexts. In the Northwest Territories scientists with collar data about caribou movements generated by satellites work with hunters who make more local level observations of caribou distribution and health. Although sometimes the knowledges are not compatible, they are both considered valid and important by caribou management boards such as the Porcupine Caribou Management Board.

4.3 Fish Health and Water Quality

Figure 21– Canoeing in the Boreal Forest

The tracking of change in the health of aquatic ecosystems is an important focal point of research in freshwater ecosystems. There are numerous kinds of methods that are currently in use. The Tracking Change project might be considered one useful reference for Indigenous communities seeking ideas about different kinds of indicators and methods related to Indigenous Knowledge.

One approach developed in the Mackenzie River Basin is the Oral History to Action approach. In some areas of the basin such as the Deh Cho region, youth did interviews and workshops in their communities with elders and mapping critical habitats, sites and resources of social and cultural significance , hot-spot areas (i.e., areas of concern). Elders' oral history provides insight about conditions at different periods during the recent past as well as insights about historic trends and patterns. Youth can ground truth elders' hypotheses about current conditions which youth can ground truth during their canoe trip.

- ***Elder Hypothesis 1 - You will find a lot of lake trout in this lake (according to elder 1)…We found a lot of trout in this lake… over half the fish we caught in our net on Sunday were trout… (Jake…)***

- ***Elder Hypothesis 2 – You will not find any perch in this lake… (elder 2).. We did not find any perch in this lake. (Maria…)***

- ***Elder Hypothesis 3 - There used to be a lot of lake trout that were larger than 30 lbs. (Elder 1)… We did not find any lake trout over 30 lbs…***

Elders' stories can provide a valuable diachronic perspective (long term) about fish species that stem from long term experiences living in one particular place and dependence on fish as part of their diet; oral histories offer a great deal of ecological information that can be qualitative as well as quantitative. F

For example, elders' oral histories of the Lesser Slave Lake region speak to the decline in Lake Trout in the region.   The critical driver of this decline was the development of muskrat farms during the 1930s as well as commercial fishing activity, however, elders attribute the decline to over a century of over harvesting. Competition between anglers and recreational fishers for the remaining fish stocks has meant that Indigenous fishers no longer have security based on this fishery.

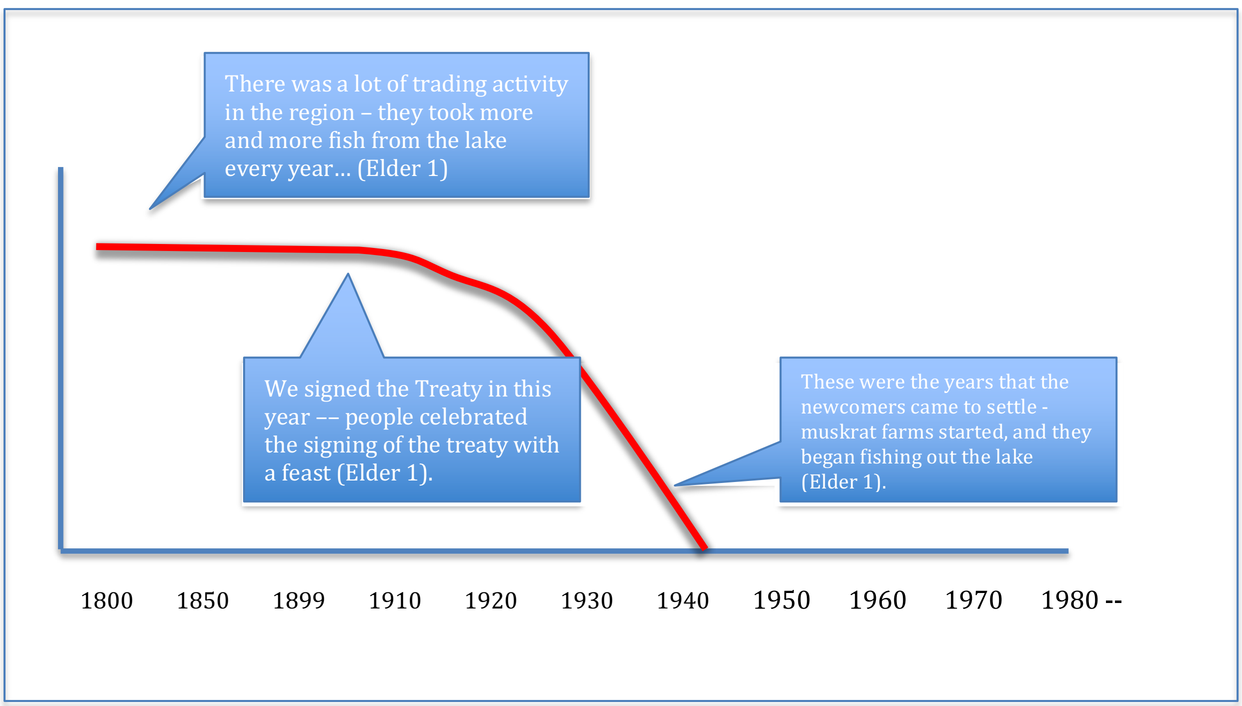


Figure 22 –   Example of Timeline of Change in Aquatic Ecosystems

4.4 Sea Ice Change and its Impact on Inuit Livelihoods

Sea ice is a common focal point in climate change discussions. Many studies related to changing sea ice conditions involving Inuit peoples in northern Canada have developed over the last twenty years. Some of the research activities have involved the documentation of oral histories of sea ice change, changes in land use activities as well as observations of various characteristics or indicators of sea ice conditions (Jolly, 2001; Krupnik & Jolly, 2002).

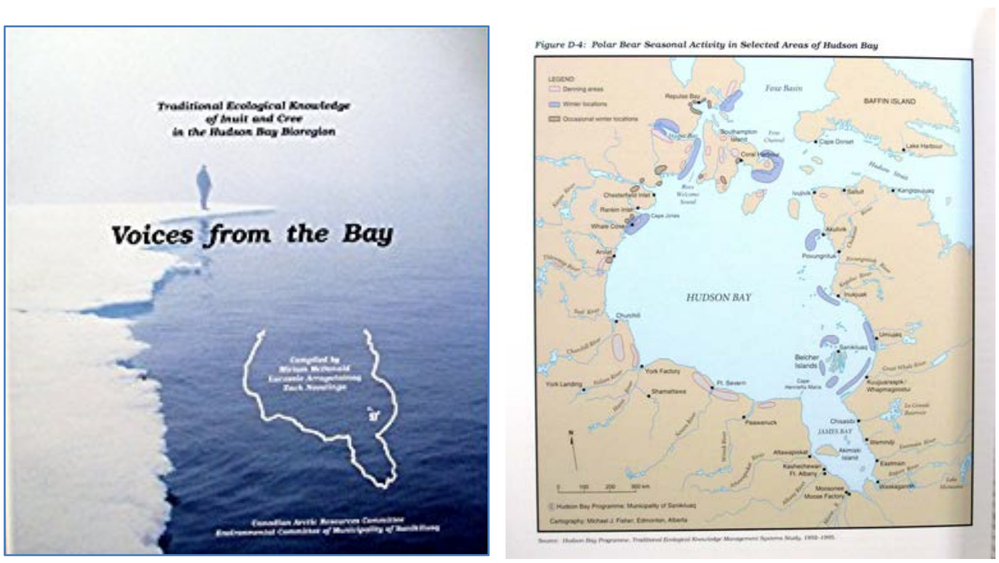


Figure 23 – Voices from the Bay
(Traditional Ecological Knowledge of Inuit and Cree from the Western Hudson's Bay).

One of the most well-known Indigenous knowledge studies related to sea ice and climate change can be found in the "Voices from the Bay" project (McDonald, Arragutainaq, & Novalinga, 1997). In that study many communities in the Western Hudson's Bay region documented observations of change in a variety of indicators of ecosystem health including migratory bird activity, marine mammal migration patterns, sea ice melt and flow. Given that the focal point of interviews and the methods were the same in every community involved in the study, the outcomes or results provide significant insights into the issue of climate change as well as its impact on Inuit livelihoods (Huntington, 2000). This kind of study provides a useful example and inspiration for Indigenous communities in other marine ecosystems about how to coordinate monitoring activities and link the associated data and knowledge together.

There are other kinds of studies related to sea ice change and Inuit livelihoods that embrace different technologies and scientific methods with Indigenous knowledge and what is often described as "traditional" methods of learning. Due to the fact it is not possible to gather detailed sea ice data from satellite imaging technology, landscape level data collection is needed. One way scientists and Inuit are collaborating is through the use of sled-based data collection systems in which instruments are attached to sleds used in regular travel by Inuit during harvesting activities etc. (Wilkinson Jeremy et al., 2011).

Other technologies being employed include buoys that are left in the ice during freeze up and are monitoring and maintained by Inuit communities. In addition to provide valuable information about patterns of freeze up, break up and temporal changes in the thickness of ice, the buoy data is used by Inuit communities for health and safety. Given sea ice conditions, can be unpredictable, the buoy data provides real-time data about ice thickness that indicate where it is safe to travel across the ice by snowmobile etc. (Bell, Briggs, Bachmayer, & Li, 2014)

Figure 24 – Traveling on the Sea Ice

There are many other kinds of methods being used to track changes in sea ice conditions and other marine ecosystems conditions that bring together science and Indigenous knowledge. See other resources provided in the back of this volume.

5. Challenges and Opportunities related to the Indigenous Knowledge in Community-Based Monitoring

Ensuring ongoing respect of Indigenous Knowledge is an important challenge of many community-based monitoring programs including those related to monitoring climate change. As interest and practice of such monitoring programs increases, so too do the challenges of ensuring such programs deliver on many of the promises and ideals that surround their development. Some critical challenges include the following:

Data Rigour

At their very root, community-based monitoring programs are about the systematic documentation of information related to a key theme or problem. However, many community-based monitoring programs struggle with the question of data rigour. Will people in and outside the community find the data useful or important? Insights about how to understand and deal with this challenge can come from a review of the literature on citizen science.

"Citizen science has a history as long as science itself (Miller-Rushing et al. 2012). The first people following the scientific method to solve problems were amateur scientists; they predated the professionalization of science. Since science has become a formal profession, the role of citizen science and the contributions of non-professionals to science have become somewhat marginalized (Miller- Rushing et al. 2012)" (Kobori et al., 2016). At the same time, critics of scientific discourse and policy suggest datasets built from citizen science efforts are increasingly used but poorly recognized; for example, in the case of migratory bird research, insights from citizen science are rendered invisible in academic publications and policy (C. Cooper, Shirk, & Zuckerberg, 2014).

> "Despite the wealth of information emerging from citizen science projects, the practice is not universally accepted as a valid method of scientific investigation. Scientific papers presenting volunteer-collected data some- times have trouble getting reviewed and are often placed in outreach sections of journals or education tracks of scientific meetings" (Bonney, Cooper, et al., 2009).

Sustaining Participation

Broad community or public participation in the monitoring process is perhaps the single most important characteristic of community-based monitoring and citizen science programs including those involving Indigenous knowledge. Dependence on volunteers or community experts allows programs such as Birdwatch etc. to produce "big data" at a scale that would not be possible, or programs such as Nihatni to track changes at a fine scale and with sensitivity that would not be possible through conventional programs (Cohn, 2008).

> "A recent analysis of 388 English-language citizen science projects that engage 1.3 million volunteers showed that projects have contributed up to US$2.5 billion in-kind annually (Theobald et al. 2015). One project alone, eBird, collects five million bird observations every month, and has contributed to at least 90 peer-reviewed articles or book chapters in ornithology, ecology, climate change, and statistical modeling (Sullivan et al. 2014)" (Kobori et al., 2016).

While there are some efforts to differentiate the degree of community participation in the design and development of the monitoring program such as, contributory, collaborative or co-created (Bonney, Ballard, et al., 2009), the knowledge-power dynamic cannot be overlooked in the design of monitoring programs. The orientation of many community-based monitoring programs is not to contribute to a greater or lesser extent to the enterprise of science but to engage in knowledge-making as a means of achieving social or environmental justice. What happens to the data? Who is using it? Are the decisions being made based on the data improving the well-being of the community and/or the sustainability of environments important to the community? This knowledge-power dynamic is often the underlying driver behind community participation and by extension the sustainability of community-based monitoring programs.

> "Strategies for attracting, sustaining, and growing the numbers of participants in citizen science projects, and for incentivizing high quality contributions, are critical to the success of citizen science projects; however, successful strategies are not always intuitive and are receiving increasing attention from researchers, including work well beyond project evaluations (Easley and Ghosh 2013; Ghosh and McAfee 2011)" (Kobori et al., 2016).

> "…adopting a flexible approach can increase participation rates, given that users vary in the amount of data they are willing to collect and in the frequency of participation. Some users have experience with formal survey methods, such as transects or quadrats, whereas others are more comfortable with simpler random survey techniques. Some volunteers take part on a one-off basis during vacations, whereas others provide regular data, monitoring change in their local area over several years"(Marshall, Kleine, & Dean, 2012).

> "Typologies to date have focused primarily on the integration of public participation in different steps of scientific research, with little attention to sociotechnical and macrostructural factors influencing the design of the study or management of participation" (Wiggins &

> Crowston, 2012). In addition to being data collectors, there are many different kinds of rationales for participation including: investigation or research, action or advocacy, conservation outcomes or, education (Wiggins & Crowston, 2012).
>
> Some have suggested that citizen-science participation is partially dependent on participants developing a sense of belonging, indicating positive feedbacks between socializing the practice of citizen science and levels of participation, effort, and outcomes and emphasizing that citizen science, like most endeavours, is a social process (Crain et al., 2014).

Resources and Supports

Lack of funding is a perennial issue for community-based monitoring programs led by Indigenous peoples and so building partnerships with government, NGOs or research institutions to establish core (multi-year) funding for Community-Based Monitoring initiatives is of growing and common interest. Long term core funding allows programs to hire and train community monitors, purchase equipment and plan for the future.

Limited budgets within government, industry, NGOs and universities for community-led programs has led to a kind of triage in decisions about which regions, issues and communities gain power in the decision-making process. For example, there is more funding available for Community-Based Monitoring in the territorial norths than in the provincial norths; Climate change driven community-based monitoring programs tend to be funded more often than programs focusing on documenting the effects of pipeline projects.

Much of the success attributed to the *Arctic Borderlands Ecological Knowledge Monitoring Program* can be tied to the funding and support that has come from Canadian federal, territorial and U.S. government agencies, co-management boards, and Inuvialuit and First Nation councils. Similarly, the funding provided to the Innu Guardians program and the individual First Nations of the Coastal Guardians Watchmen program from the Department of Fisheries and Oceans and Parks Canada, underpins the depth and contributions of that program to knowledge about environmental change in these two regions of northern and western Canada. However even these established programs struggle to secure predicable funding. Where a Community-Based Monitoring program is tied into a particular regulatory requirement (e.g., a term / condition of approval), there are more opportunities to secure long term funding. However, if budgets are too closely tied to the mandates and interests of government or industry (or other partners), community organizations may see their own interests being lost or undermined.

Communities with interests and values that fall outside the mandate of government tend also to be left out of funding arrangements. For example, Mikisew Cree First

Nations and Athabasca Chipewyan First Nations, have long been critical of the provincial and federal governments lack of support for local monitoring of the effects of oil sands development in their region. As a result, most community-based monitoring program are funded by multiple other partners (e.g., universities, NGOs, philanthropic organizations).

Most of the community-based monitoring programs reviewed have consistent challenges in maintaining funding from year to year. The ad hoc nature of funding has consequently led to significant gaps in our understanding of critical issues of social and environmental change and, in large part, explains the lack of longitudinal data about the short term versus long term effects of resource development activity in Canada.
Community-based monitoring programs must have some control over how funds are allocated over time. As discussed earlier, community-based monitoring is often viewed as an act of self-determination over traditional lands and resources. Identification of funding partners that have similar goals, values and interests is thus an important aspect of almost all community-based monitoring programs.

Participation in collaborative and community-based monitoring has resulted in community-level outcomes, such as increased social capital (Adger 2003), community capacity (Donoghue and Sturtevant 2007), and trust between scientists, managers, and the public (Fernandez- Gimenez *et al*. 2008).

6. Respecting Local and Traditional Knowledge shared in Monitoring

Community-based monitoring programs even if only involving a few people in one community, often deal with the challenge and question of how best to respect the knowledge of individual participants and honour the knowledge from the community as a whole.

Intellectual property rights are a critical dimension of this knowledge-power dynamic. The language of IPR is situated in legal-ease. Similar to other kinds of intellectual property such as an image or song, many researchers involved in legal research, suggest the individual or an organization also owns the local and traditional knowledge shared through monitoring. Much of the emphasis on intellectual property rights comes from concerns among Indigenous peoples that their knowledge is being appropriated and used to benefit others. The OCAP protocol developed by a group of First Nations in Ontario, suggest that community leaders as well as partners and allies working on research projects Indigenous peoples, we should think early about four key issues in relation to documenting local and traditional knowledge:

- ✓ Who owns the data?
- ✓ Who has control of the data?
- ✓ Who has access to the data?
- ✓ Who possesses (holds) the data?

University research ethics boards tie the issue of intellectual property together with "ethics" of research. Research Agreements and Individual Consent protocols and forms are often a well-accepted step in ensuring individuals who are sharing knowledge understand some fundamental issues:

- ✓ What is the overall purpose of the monitoring activity?
- ✓ How and why is the knowledge being collected;
- ✓ Who is involved in doing the research?
- ✓ Who is funding the research?
- ✓ What other partners are involved?
- ✓ Are participants being compensated
- ✓ How and where will the raw data be shared
- ✓ Who will have access to the raw data once collected?
- ✓ How will the outcomes from the monitoring activities be communicated within the community?
- ✓ How will the outcomes from the monitoring activities be communicated within the community?

These kinds of litigious documents which assume knowledge is "property" in a Euro Canadian sense or a material outcome, are not always the best way to deal with some of the complexities of local and traditional knowledge. For example, the knowledge of some First Nations communities is a sacred gift that is shared between a knowledge holder (such as an elder) and an individual who is in a position of trust. When such knowledge is shared, it is often not appropriate to treat it as “data” that can be archived and publicly shared. Determining the best approach to respect these special relationships of trust is critical and should be addressed early on in the monitoring design process.

However, a legal framework, is not the only lens through which we understand “respect for knowledge”. Many elders and community members get involved in community-based monitoring programs often do so because they want to be heard and they want to learn from others. Respect for knowledge in this context is about creating opportunities for people to celebrate and share their knowledge with as wide an audience as possible.

As a result, many climate change monitoring programs are equally as concerned about questions of knowledge “protection” as with knowledge sharing including:

- ✓ Cooperative Knowledge Sharing
- ✓ Knowledge Commons
- ✓ Open Access Data.

7. Indigenous Knowledge & Science in Climate Monitoring

Indigenous knowledge is the foundation for many community-based monitoring programs in Canada including those focused on climate change. However, there are in fact many more in which Indigenous Knowledge and conventional scientific methods and data collection are braided together. In some cases, this reflects the fact that Indigenous Knowledge and science are not exclusive of one another or completely different kinds of epistemologies. Many scholars refer to Indigenous Knowledge as Indigenous Science and warn against creating false dichotomies that do not serve the interests of Indigenous peoples (A. Agrawal, 1995).

Due to the fact that many formal monitoring programs in Canada are based around conventional scientific methods and indicators, the tendency for many programs to depend heavily on science rather than more culturally appropriate indicators and methods of monitoring is not surprising. As more communities become involved in developing their own kinds of indicators and monitoring systems, it is likely that the role of Indigenous knowledge will become clearer and the opportunities to braid such knowledge with existing monitoring data and processes will become more explicit.

8. Conclusion and Summary

There are numerous lessons learned from the large number of community-based monitoring programs involving Indigenous communities and Indigenous knowledge. There is no one size fits all approach, however some critical lessons from existing programs have been developed in this report.

- Community-based climate monitoring can be a valuable tool for social learning for Indigenous communities; it can increase the adaptive capacity for communities to cope with new and uncertain kinds of ecological change;

- Indigenous knowledge has many definitions, meanings and expressions; there are arguably as many kinds of Indigenous knowledge systems are there are cultures and ecosystems (e.g., Cree communities from the northern boreal regions of Saskatchewan have different kinds of knowledges than Cree communities from western Hudson's Bay lowlands);

- Indicators based around Indigenous Knowledge, or the signs and signals of change provide insight into the values and characteristics of ecosystems and resources important to Indigenous communities; they also suggest culturally meaningful focal points of monitoring

- Place-based knowledge based around empirical observation and experience of environmental change can provide valuable information for evidence-based decision-making – in areas where observations have been consistently made over many decades or generations, Indigenous knowledge holders can offer a strong diachronic record of ecological trends and patterns.

- Practices including methods for monitoring (i.e., data, collection, interpretation, and communication) are also a dimension of Indigenous knowledge that can inform Community-Based Climate Monitoring;

Appendix 1 - Resources

1. Consent for Individual Consent to Research Participation
2. Research Agreement for Researchers and Community Partners
3. Selected List of Community-Based Monitoring Program Leads in Canada (online)
4. Attributes of Successful Community-Based Monitoring – Table from HEG 2017.

References

Adelson, N. (1998). Health beliefs and the politics of Cree well-being. *Health:, 2*(1), 5-22. doi:10.1177/136345939800200101

Adger, W. N. (2009). Social Capital, Collective Action, and Adaptation to Climate Change. *Economic Geography, 79*(4), 387-404. doi:10.1111/j.1944-8287.2003.tb00220.x

Adger, W. N., Barnett, J., Brown, K., Marshall, N., & O'brien, K. (2013). Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change, 3*(2), 112.

Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Development and Change, 26*(3), 413-439.

Agrawal, A., & Gibson, C. C. (1999). Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation. *World Development, 27*(4), 629-649. doi:https://doi.org/10.1016/S0305-750X(98)00161-2

Armitage, D. (2005). Adaptive Capacity and Community-Based Natural Resource Management. *Environmental Management, 35*(6), 703-715. doi:10.1007/s00267-004-0076-z

Armitage, D., Marschke, M., & Plummer, R. (2008). Adaptive co-management and the paradox of learning. *Global Environmental Change, 18*(1), 86-98. doi:https://doi.org/10.1016/j.gloenvcha.2007.07.002

Battiste, M. (2011). *Reclaiming Indigenous Voice and Vision*. Vancouver, BC, Canada UBC Press.

Bell, T., Briggs, R., Bachmayer, R., & Li, S. (2014). Augmenting Inuit knowledge for safe sea-ice travel—The SmartICE information system. *Oceans-St. John's IEEE*, 1-9.

Berkes, F. (1983). Quantifying the harvest of native subsistence fisheries. In R. Wein, R. R. Riewe, & L. R. Methven (Eds.), *Resources and Dynamics of the Boreal Zone* (pp. 346-363). Ottawa: Association of Canadian Universities for Northern Studies.

Berkes, F. (1993). Traditional ecological knowledge in perspective. In J. T. Inglis (Ed.), *Traditional Ecological Knowledge: Concepts and Cases* (pp. 1-9). Ottawa: International Development Research Centre.

Berkes, F. (2007). Community-based conservation in a globalized world. *Proceedings of the National Academy of Sciences, 104*, 15188-15193.

Berkes, F. (2008). *Sacred Ecology. Traditional Ecological Knowledge and Resource Management*. London: Taylor & Francis.

Berkes, F. (2009). Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand, 39*(4), 5.

Berkes, F., Berkes, M. K., & Fast, H. (2007). Collaborative Integrated Management in Canada's North: The Role of Local and Traditional Knowledge and Community-Based Monitoring. *Coastal Management, 35*(1), 143-162. doi:10.1080/08920750600970487

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications, 10*(5), 1251-1267.
Berkes, F., & Jolly, D. (2001). Adapting to Climate Change: Social Ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology, 5*(2).
Berkes, F., Kislalioglu, M., Folke, C., & Gadgil, M. (1998). Exploring the basic ecological unit: Ecosystem-like concepts in traditional societies. *Ecosystems, 1*, 409-415.
Berman, M., & Kofinas, G. (2004). Hunting for Models: grounded and rational choice approaches to analyzing climate effects on subsistence hunting in an Arctic community. *Ecological Economics, 49*, 31-46.
Björkman, M., & Svensson, J. (2009). Power to the People: Evidence from a Randomized Field Experiment on Community-Based Monitoring in Uganda*. *The Quarterly Journal of Economics, 124*(2), 735-769. doi:10.1162/qjec.2009.124.2.735
Bjorkman Nyqvist, M., de Walque, D., & Svensson, J. (2014). Information is Power : Experimental Evidence on the Long-Run Impact of Community Based Monitoring.
Blaikie, P. (2006). Is Small Really Beautiful? Community-based Natural Resource Management in Malawi and Botswana. *World Development, 34*(11), 1942-1957. doi:https://doi.org/10.1016/j.worlddev.2005.11.023
Bliss, J., Aplet, G., Hartzell, C., Harwood, P., Jahnige, P., Kittredge, D., . . . Soscia, M. L. (2001). Community-Based Ecosystem Monitoring. *Journal of Sustainable Forestry, 12*(3-4), 143-167. doi:10.1300/J091v12n03_07
Bohensky, E. L., & Maru, Y. (2011). Indigenous Knowledge, Science, and Resilience: What Have We Learned from a Decade of International Literature on ìIntegrationî? *Ecology and Society, 16*(4). doi:10.5751/ES-04342-160406
Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report*. Retrieved from Washingtin DC:
Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience, 59*(11), 977-984. doi:10.1525/bio.2009.59.11.9
Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next Steps for Citizen Science. *Science, 343*, 1436-1437.
Borrows, J. (2002). *Recovering Canada: The resurgence of indigenous law.* Toronto: Recovering Canada: The resurgence of indigenous law.
Boyce, M. S., Baxter, P. W. J., & Possingham, H. P. (2012). Managing moose harvests by the seat of your pants. *Theoretical Population Biology, In Press.* doi:10.1016/j.tpb.2012.03.002
Brook, R. K., Kutz, S. J., Veitch, A. M., Popko, R. A., Elkin, B. T., & Guthrie, G. (2009). Fostering Community-Based Wildlife Health Monitoring and Research in the Canadian North. *EcoHealth, 6*(2), 266-278. doi:10.1007/s10393-009-0256-7

Brook, R. K., & McLachlan, S., M. (2005). On Using Expert-Based Science to Test Local Ecological Knowledge. *Ecology and Society, 10*(2).

Brown, P. (1992). Popular epidemiology and toxic waste contamination: lay and professional ways of knowing. *Journal of Health Social Behaviour, 33*, 267–281.

Brown, T. C., & Burch Jr, E. S. (1992). Estimating the economic value of subsist ence harvest of wildlife in Alaska. In G. L. Peterson, C. S. Swanson, D. W. McCollum, & M. H. Thomas (Eds.), *Valuing Wildlife in Alaska*. Boulder CO,: Westview Press.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., . . . Zhumanova, M. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science, 2*(26). doi:10.3389/feart.2014.00026

Carvalho, A. R., Williams, S., January, M., & Sowman, M. (2009). Reliability of community-based data monitoring in the Olifants River estuary (South Africa). *Fisheries Research, 96*(2), 119-128. doi:https://doi.org/10.1016/j.fishres.2008.08.017

Catlin-Groves, C. L. (2012). The Citizen Science Landscape: From Volunteers to Citizen Sensors and Beyond. *International Journal of Zoology, 2012*, 14. doi:10.1155/2012/349630

Chapin, F. S. (2005). Polar Systems (Chapter 25) *Ecosystem and Human Well-being: Current, State and Trends* Washington DC: Millenium Ecosystem Assessment:.

Clark, D. A., Lee, D. S., Freeman, M. M., & Clark, S. G. (2008). Polar bear conservation in Canada: defining the policy problems. *Arctic*, 347-360.

Cobb, D., Kislalioglu, M., & Berkes, F. (2005). Ecosystem-based management and marine environmental quality indicators in northern Canada. In F. Berkes, R. Huebert, H. Fast, M. Manseau, & A. Diduck (Eds.), *Breaking Ice: Renewable Resource and Ocean Management in the Canadian North*. Calgary: University of Calgary Press.

Cohn, J. P. (2008). Citizen Science: Can Volunteers Do Real Research? *BioScience, 58*(3), 192-197. doi:10.1641/b580303

Connors, J. P., Lei, S., & Kelly, M. (2012). Citizen Science in the Age of Neogeography: Utilizing Volunteered Geographic Information for Environmental Monitoring. *Annals of the Association of American Geographers, 102*(6), 1267-1289.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monitoring and Assessment, 176*(1-4), 273-291. doi:10.1007/s10661-010-1582-5

Cooper, C., Shirk, J., & Zuckerberg, B. (2014). The Invisible Prevalence of Citizen Science in Global Research: Migratory Birds and Climate Change. *PLoS One, 9*(9), e106508. doi:citeulike-article-id:13346724

doi: 10.1371/journal.pone.0106508

Cooper, C. B., Dickinson, J., Phillips, T., & Bonney, R. (2007). Citizen Science as a Tool for Conservation in Residential Ecosystems. *Ecology and Society, 12*.

Cox, M. (2015). A Basic Guide for Empirical Environmental Social Science. *Ecology and Society, 20*(1), 63.

Crain, R., Cooper, C., & Dickinson, J. L. (2014). Citizen Science: A Tool for Integrating Studies of Human and Natural Systems. *Annual Review of Environment and Resources, 39*(1), 641-665. doi:10.1146/annurev-environ-030713-154609

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., & Waller, D. M. (2011). Assessing citizen science data quality: an invasive species case study. *Conservation Letters, 4*(6), 433-442. doi:doi:10.1111/j.1755-263X.2011.00196.x

Cruikshank, J. (2014). *Do Glaciers Listen? Local Knowledge, Colonial Encounters, and Social Imagination*. Vancouver: UBC Press.

Cumming, G. S., & Collier, J. (2005). Change and Identity in Complex Systems. *Ecology and Society, 10*.

Danielsen, F., Burgess, N. D., & Balmford, A. (2005). Monitoring Matters: Examining the Potential of Locally-based Approaches. *Biodiversity & Conservation, 14*(11), 2507-2542. doi:10.1007/s10531-005-8375-0

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., . . . Yonten, D. (2009). Local Participation in Natural Resource Monitoring: a Characterization of Approaches. *Conservation Biology, 23*(1), 31-42. doi:10.1111/j.1523-1739.2008.01063.x

Danielsen, F., Burgess, N. D., Jensen, P. M., & Pirhofer-Walzl, K. (2010). Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples involvement. *Journal of Applied Ecology, 47*(6), 1166-1168. doi:10.1111/j.1365-2664.2010.01874.x

Danielsen, F., Jensen, A. E., Alviola, P. A., Balete, D. S., Mendoza, M., Tagtag, A., . . . Enghoff, M. (2005). Does Monitoring Matter? A Quantitative Assessment of Management Decisions from Locally-based Monitoring of Protected Areas. *Biodiversity & Conservation, 14*(11), 2633-2652. doi:10.1007/s10531-005-8392-z

Danielson, F., Burgess, N. F., Balmford, A., Donald, P., Funder, M., & Jones, P. G. (2009). Local Participation in Natural Resource Monitoring: A Characterization of Approaches. *Conservation Biology, 23*(1), 31-42.

Daume, S., Albert, M., & von Gadow, K. (2014). Forest monitoring and social media – Complementary data sources for ecosystem surveillance? *Forest Ecology and Management, 316*, 9-20. doi:https://doi.org/10.1016/j.foreco.2013.09.004

Davies, R. (1998). An evolutionary approach to facilitating organisational learning: an experiment by the Christian Commission for Development in Bangladesh. *Impact Assessment and Project Appraisal, 16*(3), 243-250. doi:10.1080/14615517.1998.10590213

Davis, A., & Wagner, J. R. (2003). Who knows? On the importance of identifying experts when researching local ecological knowledge. *Human Ecology, 31*, 463-489.

de Araujo Lima Constantino, P., Carlos, H. S. A., Ramalho, E. E., Rostant, L., Marinelli, C. E., Teles, D., . . . xe. (2012). Empowering Local People through Community-based Resource Monitoring

a Comparison of Brazil and Namibia. *Ecology and Society, 17*(4).

Devictor, V., Whittaker, R. J., & Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Diversity and Distributions, 16*(3), 354-362. doi:doi:10.1111/j.1472-4642.2009.00615.x

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen Science as an Ecological Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics, 41*(1), 149-172. doi:10.1146/annurev-ecolsys-102209-144636

Egeland, G. M., Johnson-Down, L., Cao, Z. R., Sheikh, N., & Weiler, H. (2011). Food Insecurity and Nutrition Transition Combine to Affect Nutrient Intakes in Canadian Arctic Communities. *The Journal of Nutrition*. doi:10.3945/jn.111.139006

Eriksen, S. H., & Kelly, P. M. (2007). Developing Credible Vulnerability Indicators for Climate Adaptation Policy Assessment. *Mitigation and Adaptation Strategies for Global Change, 12*(4), 495-524. doi:10.1007/s11027-006-3460-6

FAO. (2004). What is local knowledge? *Building on Gender, Agrobiodiversity and Local Knowledge*. Rome Italy: Food and Agriculture Organization of the United Nations.

Fazey, I., Fazey, J. A., & Fazey, D. M. A. (2005). Learning more effectively from experience. *Ecology and Society, 10*(2), 1.

Fazey, I., Proust, K., Newell, B., Johnson, B., & Fazey, J. (2006). Eliciting the implicit knowledge and perceptions of on-ground conservation managers of the Macquarie marshes. *Ecology and Society, 11*(1), 1.

Fernandez-Gimenez, M. E., Ballard, H., & Sturtevant, V. E. (2008). Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring: A Study of Five Community-Based Forestry Organizations in the western USA. *Ecology and Society, 13*.

Fernandez-Gimenez, M. E., Ballard, H. L., & Sturtevant, V. E. (2008). Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring

a Study of Five Community-Based Forestry Organizations in the western USA. *Ecology and Society, 13*(2).

Fernandez-Gimenez, M. E., Ballard, H. L., & Sturtevant, V. E. (2008). Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society, 13*(2), 4.

Fleming, B., & Henkel, D. (2001). Community-Based Ecological Monitoring: A Rapid Appraisal Approach. *Journal of the American Planning Association, 67*(4), 456-465. doi:10.1080/01944360108976252

Funder, M., Danielsen, F., Ngaga, Y., Nielsen, M., & Poulsen, M. (2013). Reshaping Conservation: The Social Dynamics of Participatory Monitoring in Tanzania's Community-managed Forests. *Conservation and Society, 11*(3), 218-232. doi:10.4103/0972-4923.121011

Furgal, C., & Seguin, J. (2006). Climate Change, Health, and Vulnerability in Canadian Northern Aboriginal Communities. *Environ Health Perspect, 114*(12).

Gearheard, S., Aporta, C., Aipellee, G., & O'Keefe, K. (2011). The Igliniit project: Inuit hunters document life on the trail to map and monitor arctic change. *The*

Canadian Geographer / Le Géographe canadien, 55(1), 42-55. doi:doi:10.1111/j.1541-0064.2010.00344.x

Goodchild, M. F., Guo, H., Annoni, A., Bian, L., de Bie, K., Campbell, F., . . . Woodgate, P. (2012). Next-generation Digital Earth. *Proceedings of the National Academy of Sciences, 109*, 11088-11094.

Haalboom, B., & Natcher, D. C. (2012). The Power and Peril of "Vulnerability": Approaching Community Labels with Caution in Climate Change Research. *Arctic, 65*(3), 319-327.

Haklay, M. (2013). Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice* (pp. 105-122). Dordrecht: Springer Netherlands.

Heaslip, R. (2008). Monitoring salmon aquaculture waste: The contribution of First Nations' rights, knowledge, and practices in British Columbia, Canada. *Marine Policy, 32*(6), 988-996. doi:https://doi.org/10.1016/j.marpol.2008.02.002

Henri, D. A., Jean-Gagnon, F., & G., G. H. (2018). Using Inuit traditional ecological knowledge for detecting and monitoring avian cholera among Common Eiders in the eastern Canadian Arctic. *Ecology and Society, 23*(1), 22.

Huntington, H. P. (2000). Native observations capture impacts of sea ice changes. *Witness the Arctic, 8*(1), 1-2.

Ingold, T. (1996). Hunting and gathering as Ways of Perceiving the Environment *Ellen, R.*

Fukui, K. (pp. 117-155). Oxford: Berg: Redefining Nature: Ecology, Culture and Domestication.

Ingold, T., & Vergunst, J. L. (Eds.). (2008). *Ways of Walking: Ethnography and Practice On Foot*. London: Ashgate Publishing Inc.

Inuvialuit Joint Secretariat. (2003). *Inuvialuit Harvest Study: Data and Methods Report 1988-1997*. Retrieved from Inuvik:

Irwin, A. (1995). Citizen science : a study of people, expertise, and sustainable development. London ;: Routledge.

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R., ... & Ryan, P. . (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society,, 11*(1).

Johnson, N., Alessa, L., Behe, C., Danielsen, F., Gearheard, S., Gofman-Wallingford, V., . . . Svoboda, M. (2015). The Contributions of Community-Based Monitoring and Traditional Knowledge to Arctic Observing Networks: Reflections on the State of the Field. *Arctic, 68*, 28-40.

Jolly, F. B. D. (2001). Adapting to Climate Change: Social Ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology, 5*(2).

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge Gain and Behavioral Change in Citizen ‐ Science Programs. *Conservation Biology, 25*(6), 1148-1154. doi:doi:10.1111/j.1523-1739.2011.01745.x

Keane, A., Jones, J. P. G., & Milner-Gulland, E. J. (2011). Encounter data in resource management and ecology: pitfalls and possibilities. *Journal of Applied Ecology, 48*(5), 1164-1173. doi:10.1111/j.1365-2664.2011.02034.x

Kislalioglu, H. M. F. B. P. O. B. L. M. (2004). Combining Science and Traditional Ecological Knowledge: Monitoring Populations for Co-management. *Ecology and Society, 9*(3).

Kitolelei, J. V., & Sato, T. (2016). Analysis of Perceptions and Knowledge in Managing Coastal Resources: A Case Study in Fiji. *Frontiers in Marine Science, 3*(189). doi:10.3389/fmars.2016.00189

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., . . . Miller-Rushing, A. J. (2016). Citizen science: a new approach to advance ecology, education, and conservation. *Ecological Research, 31*(1), 1-19. doi:10.1007/s11284-015-1314-y

Kouril, D., Furgal, C., & Whillans, T. (2015). Trends and key elements in community-based monitoring: a systematic review of the literature with an emphasis on Arctic and Subarctic regions. *Environmental Reviews, 24*(2), 151-163. doi:10.1139/er-2015-0041

Krupnik, I., & Jolly, D. (2002). *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change*. Fairbanks: Arctic Research Consortium of the United States.

Lawe, L. B., Wells, J., & Cree, M. (2005). Cumulative effects assessment and EIA follow-up: a proposed community-based monitoring program in the Oil Sands Region, northeastern Alberta. *Impact Assessment and Project Appraisal, 23*(3), 205-209. doi:10.3152/147154605781765508

Le Coz, J., Patalano, A., Collins, D., Guillen, N. F., Garcia, C. M., Smart, G. M., . . . Braud, I. Z. F. L. F. R. A. (2016). *Lessons learnt from recent citizen science initiatives to document floods in France, Argentina and New Zealand %+ Hydrologie-Hydraulique (UR HHLY) %+ Universidad Nacional de Córdoba [Argentina] %+ Applied Hydrology Hydrodynamics*, Lyon, France.

Leach, M., Mearnes, R., & Scoones, I. (1999). Environmental Entitlements: Dynamics and Institutions in Community-Based Resource Management. *World Development, 27*(2), 225-247.

Lee, T., Quinn, M. S., & Duke, D. (2006). Citizen, Science, Highways, and Wildlife: Using a Web-Based GIS to Engage Citizens in Collecting Wildlife Information. *Ecology and Society, 11*.

Legat, A. (2008). Walking Stories: Leaving Footprints. In T. Ingold & J. L. Vergunst (Eds.), *Ways of Walking: Ethnogprahy in Practice on Foot*. London: Ashgate Publishing.

Levine, A. (1982). *Love Canal: Science, Politics, and People*. Lexington, MA: Lexington Books.

Leys, A. J., & Vanclay, J. K. (2011). Social learning: A knowledge and capacity building approach for adaptive co-management of contested landscapes. *Land Use Policy, 28*(3), 574-584. doi:https://doi.org/10.1016/j.landusepol.2010.11.006

Ludwig, D. (2001). The Era of Management Is Over. *Ecosystems, 4*(8), 758-764. doi:10.1007/s10021-001-0044-x

Luzar, J. B., Silvius, K. M., Overman, H., Giery, S. T., Read, J. M., & Fragoso, J. M. V. (2011). Large-scale Environmental Monitoring by Indigenous Peoples. *BioScience, 61*(10), 771-781. doi:10.1525/bio.2011.61.10.7

Lyver, P. (2002). *Use of First Nations Dene Knowledge to Monitor Changes in Barren Ground (Rangifer tarandus groenlandicus) body condition*. Retrieved from Winnipeg:

Lyver, P. O. (2005). Monitoring Barren-Ground Caribou Body Condition with Denésoliné Traditional Knowledge. *Arctic, 58*(1), 44-54.

Lyver, P. O., & Gunn, A. (2004). Calibration of Hunters' Impressions with Female Caribou Body Condition Indices to Predict Probability of Pregnancy. *Arctic, 57*(3), 233-241.

Lyver, P. O. B. (2005). Monitoring Barren-Ground Caribou Body Condition with Denésǫłıné Traditional Knowledge. *Arctic, 58*(1), 44-54.

Manseau, M., Parlee, B., & Ayles, B. (2005). A Place for Traditional Ecological Knowledge in Resource Management. In F. Berkes, R. Huebert, H. Fast, & M. Manseau (Eds.), *Breaking Ice: Integrated Ocean Management in the Canadian North*. Calgary: University of Calgary.

Mapinduzi, A. L., Oba, G., Weladji, R. B., & Colman, J. E. (2003). Use of indigenous ecological knowledge of the Maasai pastoralists for assessing rangeland biodiversity in Tanzania. *African Journal of Ecology, 41*(4), 329-336. doi:10.1111/j.1365-2028.2003.00479.x

Marshall, N. J., Kleine, D. A., & Dean, A. J. (2012). CoralWatch: education, monitoring, and sustainability through citizen science. *Frontiers in Ecology and the Environment, 10*(6), 332-334. doi:doi:10.1890/110266

McDonald, M., Arragutainaq, L., & Novalinga, Z. (1997). *Voices from the bay: traditional ecological knowledge of Inuit and Cree in the Hudson Bay Bioregion*. Ottawa: Canadian Arctic Resources Committee and the Environmental Committee of the Municipality of Sanikiluaq, NU.

McGregor, D. (2000). The State of Traditional Ecological Knowledge Research in Canada: A Critique of Current Theory and Practice. In R. Laliberte, P. Settee, J. Waldram, R. Innes, B. Macdougall, L. McBain, & F. Barron (Eds.), *Expressions in Canadian Native Studies* (pp. 436-458). Saskatoon: University of Saskatchewan Extension Press.

Moller, H., Berkes, F., Lyver, P., & Kislalioglu Berkes, M. (2004). Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society, 9*(3), 2.

Moller, H., Berkes, F., Lyver, P. O., & Kislalioglu, M. (2004). Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society, 9*(3), 2.

Moller, H., Berkes, F., Lyver, P. O. B., & Kislalioglu, M. (2004). Combining Science and Traditional Ecological Knowledge: Monitoring Populations for Co-Management. *Ecology and Society, 9*(3). doi:10.5751/ES-00675-090302

Moran, E. F. (1982). *Human Adaptability*. New York: Westview Press.

Mulwa, F. W. (2008). *Participatory monitoring and evaluation of community projects: community based project monitoring, qualitative impact assessment, and people-friendly evaluation methods*. Nairobi: Paulines Publications Africa.

Napoleon, V. (2013). Thinking About Indigenous Legal Orders. In R. Provost & C. Sheppard (Eds.), *Dialogues on Human Rights and Legal Pluralism* (pp. 229-245). Dordrecht: Springer Netherlands.
Natcher, D. C. (2009). Subsistence and the social economy of Canada's Aboriginal North. *Northern Review, 30*, 83-98.
Natcher, D. C., & Hickey, C. G. (2002). Putting the Community Back Into Community-Based Resource Management: A Criteria and Indicators Approach to Sustainability. *Human Organization, 61*(4), 350-363. doi:10.17730/humo.61.4.dem6fx3npep78xaq
Neis, B. (1992). Fishers' ecological knowledge and stock assessment in Newfoundland. *Newfoundland Studies, 8*(2), 155-178.
Neis, B., Felt, L., Schneider, D. C., Haedrich, R., Hutchings, J., & Fischer, J. (1996). *Northern cod stock assessment: What can be learned from interviewing resource users?* (Vol. 96/45). Ottawa: DFO Atlantic Fisheries.
Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment, 10*(6), 298-304. doi:10.1890/110294
Noss, A. J., Oetting, I., & Cuéllar, R. L. (2005). Hunter Self-monitoring by the Isoseño-Guaraní in the Bolivian Chaco. *Biodiversity & Conservation, 14*(11), 2679-2693. doi:10.1007/s10531-005-8401-2
Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive Comanagement for Building Resilience in Social–Ecological Systems. *Environmental Management, 34*(1), 75-90. doi:10.1007/s00267-003-0101-7
Ottinger, G. (2010). Buckets of Resistance: Standards and the Effectiveness of Citizen Science. *Science, Technology & Human Values, 35*.
Parlee, B. (2006). *Dealing with ecological variability and change: perspective from the Denesoline and Gwich'in of Northern Canada.* (Ph. D), University of Manitoba. (33059400)
Parlee, B. (2010). Using Traditional Knowledge to Adapt to Ecological Change: Denésoliné Monitoring of Caribou Movements. *Arctic, 58*(1), 26.
Parlee, B. (2012). Finding Voice in a Changing Ecological and Political Landscape: Traditional Knowledge and Resource Management in Settled and Unsettled Land Claim Areas of the Northwest Territories, Canada. *Aboriginal Policy Studies, 2*(1), 56-87.
Parlee, B., Berkes, F., & Gwich'in, T. i. (2005). Health of the Land, Health of the People: A Case Study on Gwich'in Berry Harvesting in Northern Canada. *EcoHealth, 2*(2), 127-137. doi:10.1007/s10393-005-3870-z
Parlee, B., F., B., & Council, T. G. i. R. R. (2005). Teetl'it Gwich'in Renewable Resources Council. Health of the land, health of the people: A case study on Gwich'in Berry Harvesting. *Ecohealth, 2*(2), 127-137.
Parlee, B., F., B., & Council, T. i. G. i. R. R. (2006). Gwich'in knowledge of ecological variability: Implications for commons management. *Human Ecology 34*, 515-528.

Parlee, B., Goddard, E., Basil, M., & Smith, M. (2014). Tracking Change: Traditional Knowledge of Wildlife Health in Northern Canada. *Human Dimensions of Wildlife, 19*(1), 47-61.

Parlee, B., Manseau, M., & Nation, L. K. e. D. F. (2005). Understanding and communicating about ecological change: Denesoline Indicators of ecosystem health. In F. Berkes, R. Huebert, H. Fast, M. Manseau, & A. Diduck (Eds.), *Breaking Ice: Integrated Ocean Management in the Canadian North* (pp. 165-182). Calgary: University of Calgary Press.

Parlee, B., Manseau, M., & Nation, L. K. e. D. F. (2005). Using Traditional Knowledge to Adapt to Change: Denesoline Monitoring of Caribou Movements. *Arctic, 58*(1), 26-37.

Parlee, B., O'Neil, J. D., & Lutsel K'e Dene First Nation. (2007). "The Dene Way of Life": Perspectives on Health from Canada's North. *Journal of Canadian Studies, 41*(3), 112-133.

Parlee, B., West Kitikmeot Slave Study, S., & Lutsël K'é Dene First, N. (2002). *Final report: community-based monitoring, November 2001*.

Parlee, B. L., Sandlos, J., & Natcher, D. C. (2018). Undermining Subsistence: Barren Ground Caribou in a Tragedy of Open Access. *Science Advances, 4*(2), e1701611.

Peloquin, C., & Berkes, F. (2009). Local knowledge, subsistence harvests, and social - ecological complexity in James Bay. *Human Ecology, 37*(5), 533-545.

Pollock, R. M., & Whitelaw, G. S. (2005). Community-Based Monitoring in Support of Local Sustainability. *Local Environment, 10*(3), 211-228. doi:10.1080/13549839.2005.9684248

Pomeroy, R. S. (1995). Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean & Coastal Management, 27*(3), 143-162. doi:https://doi.org/10.1016/0964-5691(95)00042-9

Pratihast, A. K., DeVries, B. R., Avitabile, V., Bruin, S. d., Kooistra, L., Tekle, M., & Herold, M. (2014). Combining satellite data and community-based observations for forest monitoring. *Forests, 5*(10), 2464-2489.

Pratihast, A. K., Herold, M., De Sy, V., Murdiyarso, D., & Skutsch, M. (2013). Linking community-based and national REDD+ monitoring: a review of the potential. *Carbon Management, 4*(1), 91-104. doi:10.4155/cmt.12.75

Rathwell, K. J., & Armitage, D. (2016). Art and artistic processes bridge knowledge systems about social-ecological change: An empirical examination with Inuit artists from Nunavut, Canada. *Ecology & Society, 21*(2), 310-323. doi:10.5751/ES-08369-210221

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management, 91*(8), 1766-1777. doi:10.1016/j.jenvman.2010.03.023

Receveur, O., Boulay, M., & Kuhnlein, H. V. (1997). Decreasing Traditional Food Use Affects Diet Quality for Adult Dene/Métis in 16 Communities of the Canadian Northwest Territories. *The Journal of Nutrition, 127*(11), 2179-2186.

Reed, M. S., Dougill, A. J., & Baker, T. R. (2008). PARTICIPATORY INDICATOR DEVELOPMENT: WHAT CAN ECOLOGISTS AND LOCAL COMMUNITIES LEARN FROM EACH OTHER. *Ecological Applications, 18*(5), 1253-1269. doi:10.1890/07-0519.1

Riedlinger, D., & Berkes, F. (2000). Contributions of TK to understand Climate Change in the Canadian Arctic. *Natural Resource Institute (University of Manitoba) Polar Record, 37*, 315-328.

Riedlinger, D., & Berkes, F. (2009). Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record, 37*(203), 315-328. doi:10.1017/S0032247400017058

Riesch, H., & Potter, C. Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. (1361-6609 (Electronic)).

Roba, H. G., & Oba, G. (2009). Community participatory landscape classification and biodiversity assessment and monitoring of grazing lands in northern Kenya. *Journal of Environmental Management, 90*(2), 673-682. doi:https://doi.org/10.1016/j.jenvman.2007.12.017

Rosol, R., Powell-Hellyer, S., & Chan, H. M. (2016). Impacts of decline harvest of country food on nutrient intake among Inuit in Arctic Canada: impact of climate change and possible adaptation plan. *International Journal of Circumpolar Health, 75*.

Ross, H., & Berkes, F. (2014). Research Approaches for Understanding, Enhancing, and Monitoring Community Resilience. *Society & Natural Resources, 27*(8), 787-804. doi:10.1080/08941920.2014.905668

Sato, T. (2014). Integrated local environmental knowledge supporting adaptive governance of local communities. In C. Alvares (Ed.), *Multicultural Knowledge and the University* (pp. 268–273). Mapusa: Multiversity India.

Savaresi, A. (2017). *Traditional Knowledge and Climate Change: A New Legal Frontier? BENELEX Working Paper N. 13.* . Retrieved from Rochester, NY:

Sharpe, A., & Conrad, C. (2006). Community Based Ecological Monitoring in Nova Scotia: Challenges and Opportunities. *Environmental Monitoring and Assessment, 113*(1), 395-409. doi:10.1007/s10661-005-9091-7

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution, 24*(9), 467-471. doi:https://doi.org/10.1016/j.tree.2009.03.017

Songorwa, A. N. (1999). Community-Based Wildlife Management (CWM) in Tanzania: Are the Communities Interested? *World Development, 27*(12), 2061-2079. doi:https://doi.org/10.1016/S0305-750X(99)00103-5

Statistics Canada. (2006). *Harvesting and community well-being among Inuit in the Canadian arctic: Preliminary findings from the 2001- Aboriginal Peoples Survey - Survey of Living Conditions in the Arctic*. Retrieved from Ottawa:

Stem, C., Margoluis, R., Salafsky, N., & Brown, M. (2005). Monitoring and Evaluation in Conservation: a Review of Trends and Approaches. *Conservation Biology, 19*(2), 295-309. doi:10.1111/j.1523-1739.2005.00594.x

Tarkiasuk, Q. (1997). Voices from the Bay: Traditional Ecological Knowledge of Inuit and Cree in the Hudson Bay Bioregion. *Northern Perspectives, 25*(1), 1.

Tobias, T. (2000). *Chief Kerry's Moose: A Guidebook to land use and occupancy mapping, research design*. Retrieved from Vancouver:

Toomey, A. H., & Domroese, M. C. (2013). Can citizen science lead to positive conservation attitudes and behaviors? *Human Ecology Review, 20*(1), 50-62.
Trumbull, D. J., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen‐science project. *Science Education, 84*(2), 265-275. doi:doi:10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5
Tulloch, A. I. T., Possingham, H. P., Joseph, L. N., Szabo, J., & Martin, T. G. (2013). Realising the full potential of citizen science monitoring programs. *Biological Conservation, 165*, 128-138. doi:https://doi.org/10.1016/j.biocon.2013.05.025
Tyrrell, M. (2006). More bears, less bears: Inuit and scientific perceptions of polar bear populations on the west coast of Hudson Bay. *Études/Inuit/Studies, 30*(2), 191-208.
Usher, P. (1987). Native harvest surveys and statistics: A critique of their construction and use. *Arctic, 40*, 140-160.
Vries, B. d., Pratihast, A. K., Verbesselt, J., Kooistra, L., & Herold, M. (2016). Characterizing Forest Change Using Community-Based Monitoring Data and Landsat Time Series. *PLoS One, 11*(3).
Warren, F. J., Barrow, E., Schwartz, R., Andrey, J., Mills, B., & Riedel, D. (2004). *Climate Change Impacts and Adaptation: A Canadian Perspective*. Retrieved from Ottawa, Ontario: http://adaptation.nrcan.gc.ca/perspective/index_e.php
Whitelaw, G., Vaughan, H., Craig, B., & Atkinson, D. (2003). Establishing the Canadian Community Monitoring Network. *Environmental Monitoring and Assessment, 88*(1), 409-418. doi:10.1023/A:1025545813057
Whitfield, A. K., & Elliott, M. (2002). Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology, 61*, 229-250. doi:10.1111/j.1095-8649.2002.tb01773.x
Wiggins, A., & Crowston, K. (2012, 4-7 Jan. 2012). *Goals and Tasks: Two Typologies of Citizen Science Projects.* Paper presented at the 2012 45th Hawaii International Conference on System Sciences.
Wilkinson Jeremy, P., Hanson, S., Hughes Nick, E., James, A., Jones, B., MacKinnon, R., . . . Toudal, L. (2011). Tradition and Technology: Sea Ice Science on Inuit Sleds. *Eos, Transactions American Geophysical Union, 92*(1), 1-4. doi:10.1029/2011EO010002
Winterhalder, B. (1981). Optimal Foraging Strategies and Hunter-Gatherer Research in Anthropology: Theories and Models. In W. B. & E. A. Smith (Eds.), *Hunter-Gatherer Foraging Strategies* (pp. 13-35). Chicago: University of Chicago.
Wollenberg, E., Merino, L., Agrawal, A., & Ostrom, E. (2007). Fourteen Years of Monitoring Community-Managed Forests: Learning from IFRI's Experience. *International Forestry Review, 9*(2), 670-684. doi:10.1505/ifor.9.2.670