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The need for community-led, integrated and innovative monitoring programmes when responding to the health impacts of climate change

Amy Kipp [a], Ashlee Cunsolo [b], Daniel Gillis [c], Alexandra Sawatzky [a] and Sherilee L. Harper [a,d]

[a]Department of Population Medicine, University of Guelph, Guelph, ON, Canada; [b]Labrador Institute, Memorial University, Happy Valley-Goose Bay, NL, Canada; [c]School of Computer Science, University of Guelph, Guelph, ON, Canada; [d]School of Public Health, University of Alberta, Edmonton, AB, Canada

ABSTRACT

In Northern Canada, climate change has led to many acute and interrelated health and environmental impacts experienced among Inuit populations. Community-based monitoring, in which community members participate in monitoring initiatives using various forms of technology, is a key strategy increasingly used to detect, monitor and respond to climate change impacts. To better understand the landscape of existing environmental and health monitoring programmes mobilising different technologies and operating in the North we conducted a review that used environmental scan methodologies to explore and contextualise these programmes. We consulted with academic researchers with experience in community-led monitoring, conducted systematic searches of grey and peer-reviewed literature, and conducted a secondary search for environment-health mobile-phone applications. Following specific criteria, we identified 18 monitoring programmes using information and communication technologies in the North, and three global monitoring mobile-phone applications, which cumulatively monitored 74 environment and health indicators. Several themes emerged, including the need for: (1) community leadership, (2) indicators of environment and/or human health and (3) innovative technology. This synthesis supports the development of community-led, environment-health monitoring programmes that use innovative technology to monitor and share information related to the health implications of climate change in and around Indigenous communities throughout the Circumpolar North.

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Introduction

In Northern Canada, the environment is undergoing various changes, stemming from climate change as well as resource extraction and development, which impacts often-intense socio-cultural stressors and transitions in the region (eg lack of adequate housing, food security challenges, mental health concerns, shifting cultural practices, increasing reliance on a wage economy, etc.). These changing environmental conditions present many challenges to health, with the most acute impacts identified among Inuit populations reliant on the land for sustenance and livelihoods [1–6]. Indeed, Inuit across Inuit Nunangat in Canada, and throughout the Circumpolar North, are indicating that observed changes in weather, climate and environment directly impact numerous facets of health and wellbeing, interacting with social determinants of health in a number of ways [1–6]. For example, early research indicates that these environmental stressors are already resulting in increased negative impacts on physical and mental health issues across the North [1–10]. While research has uncovered many associations between changing environments and health outcomes [1–6,10–30], detecting environment-health outcomes early and responding to them is an enormous challenge [31,45]. The need for comprehensive, sustainable, locally appropriate and integrated environment-health monitoring systems[1] is, then, a major priority in this region [33–35,45].

In the global environment-health literature, the implementation of health monitoring and response is one of the most commonly identified health-related

CONTACT Amy Kipp akipp@uoguelph.ca Department of Population Medicine, University of Guelph, 50 Stone Rd E, Guelph, ON N1G 2W1; Ashlee Cunsolo ashlee.cunsolo@mun.ca Labrador Institute, Memorial University, Happy Valley-Goose Bay, NL A0P 1E0; Sherilee L. Harper sherilee.harper@ualberta.ca School of Public Health, University of Alberta, Edmonton, AB T6G 1C9

[1]In this article, we define integrated monitoring as programmes or strategies designed to consider the range of potential interactions between environmental changes and human health within dynamic cultural, social, economic and political contexts. For example, this includes programmes aimed at observing and responding to the physical and mental health implications of changing sea ice on Inuit populations (ie increased incidence of hypothermia, or increased rates of anxiety), among others.

climate change adaptation strategies [7,9,10,34,36–54,56–62]. Important health outcomes to monitor associated with a changing environment include physical outcomes, such as: rates of foodborne, waterborne and vectorborne diseases; incidence of injury or mortality due to hazardous travel conditions; and changes to nutritional intake as a result of increased reliance on retail food. There are also mental health outcomes, such as: wide-ranging emotional responses, increased rates of anxiety, depression, loss of identify and sense of place and interpersonal conflict [1–10]. As such, there is a repeated call for the creation of integrated environment-health monitoring that uses novel approaches, integrates new types of data and includes multiple knowledge systems (eg Western Knowledge, Indigenous Knowledge, etc.) [7,9,10,34,36–54,56–62]. This is particularly important for Indigenous communities, who are often inadequately engaged in monitoring programmes [63–65]. Although public health monitoring is strong in many Circumpolar nations,[2] there is a continued need to adequately use Indigenous Knowledge in these programmes in a meaningful way; failure to do so has led to various gaps and challenges in coverage, data quality and relevance [4,10–12,21,26,27,29–31,65].

Despite identifying integrated environment-health monitoring as a key environmental health priority, as well as international efforts towards mobilising integrated environment-health monitoring strategies [70,71], there has been very little research conducted on this topic in the Circumpolar North. Timely and reliable health information, government policies and response and local knowledge are not often integrated; yet, environmental change cannot be adequately responded to at local and regional levels without integrating numerous sources of information, focusing on multiple stressors and geographic coverage and using different knowledge systems, to produce real-time, usable data – data that can inform Northern policy, programming and decision-making.

Community-based monitoring (CBM) has been defined as a process in which different actors in a community – including local community members, governments, industry, community groups and academics – work together to observe and record common community concerns [35,72]. As opposed to top-town monitoring programmes in which monitoring happens *in* different communities, CBM works *with* local communities often relying on community knowledge in the design, development and implementation of monitoring initiatives. This type of monitoring is increasing in prevalence in Arctic and Subarctic regions of North America and Europe, specifically within Indigenous communities [35].[3] CBM is purported as a way of empowering communities, fostering self-determination, creating social capital, developing research skills among local people and strengthening partnerships between community members, researchers, government agencies and other like-minded institutions [35].

Considering this new and growing area of work, we conducted a review of environment-health monitoring programmes using information and communication technologies (eg tech-based platforms, software, mobile applications, etc.) in the Circumpolar North. An environmental scanning approach was used to provide a "snapshot" of the existing environment-health monitoring programmes during the review time period (September-December 2017) and identify areas of strength and areas of improvement [73]. This review aimed to discover, analyse and categorise programmes that: monitored climate change through observing and recording environmental change and/or human health indicators; took place in and around Indigenous communities; and had some level of community involvement. Additionally, this review examined the way monitoring programmes were using technology in the data collection and data sharing processes of their initiatives. This article details findings from this environmental scan review, and discusses: (1) gaps in integrated community-led climate change and health monitoring programmes; and (2) how innovative technology may enable real-time monitoring and the dissemination of information in communities. This synthesis is intended to support the development of further environment-health monitoring programmes in the Circumpolar North, which can inform and enhance decision-making, health programming and health adaptation to climate change and other environmental stressors.

Methods

To identify environment-health monitoring programmes that worked with Indigenous communities and used some form of technology (eg tech-based platforms, software, mobile applications, etc.), a review of community-based monitoring in the Circumpolar North was conducted using an

[2]For examples of public health surveillance see: The Arctic Climate Impact Assessment; The Alaska Surveillance, Epidemiology and End Results; and The International Circumpolar Surveillance System of Infectious Diseases.

[3]To help document existing programmes, *The Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic* – a website featuring many CBM programmes throughout the Circumpolar North – was established, providing many examples of CBM initiatives.

environmental scanning approach to systematically identify and consolidate information from a variety of sources [73]. An environmental scanning approach is often used in the context of needs assessments and health programming, and can be implemented to explore and contextualise specific environments and identify areas in need of improvement [73,74]. Environmental scans have been used by other researchers in the Circumpolar North [75–79], and are recognised as a responsive and cost-effective tool for public health research [73]. This approach involves examining multiple sources of data (eg reviews of unpublished reports, consultation with community leaders, surveys, analysis of publicly available information, targeted internet searches of known programmes, peer-reviewed literature, etc.), and can target different populations, subjects or types of knowledge [73,74,76]. Owing to this flexibility, responsiveness and adaptability, there is no determined overarching framework for environmental scans; however, a common outcome of this approach is the ability to identify areas in need of improvement within a specific community or region based on available information [73]. As CBM in the Circumpolar North continues to expand, this approach proved useful in this review of existing programmes in the region.

Identifying monitoring programmes

To understand the existing environment of monitoring in the Circumpolar North, this review focused on programmes that were conducting, implementing or developing monitoring initiatives actively during Fall 2017 (September-December) and met the following criterion: (1) monitored environmental and/or human health indicators linked to climate change; (2) took place in and around Indigenous communities, and had some level of community involvement; (3) used some element of technology (eg mobile-phone, web-based technology, etc.); and (4) took place in the Circumpolar North.

Identification and classification of programmes involved several strategies, similar to the approach outlined by Mews et al. [76], in which data were collected through secondary sources such as consulting with relevant stakeholders, targeted internet searches and reviewing grey and peer-reviewed literature. Specifically, this environmental scan involved the following four strategies to identify programmes that met the above criterion:

(1) *Consultation with academic researchers working on community-led monitoring in the North during September-December 2017*: In public health research, consultations have been used in the search phase of reviews to help develop key search terms, and identify relevant resources, as well as to validate and augment review findings, providing a more nuanced, robust and useful understanding of collected data [80,81]. In this study, this method involved informal discussions with researchers to catalogue existing monitoring programmes in the North, as well as attending two workshops on community-based monitoring (*The Community Based Monitoring Experience and Exchange Workshop*, December 2017; and *The Community-Based Climate Change/Environmental Monitoring Workshop*, February 2018), with participants from Northern Canada and the USA. These consultations provided information regarding monitoring programmes to include in the study, as well as resources to help identify other programmes.

(2) *Online searches of grey literature*: Between September to December 2017 grey literature was searched, including: project, research, and annual reports; conference proceedings; news articles; working papers; and webpages related to CBM programmes that fit the outlined criterion. Grey literature was searched using Google as the main search engine. Search terms used included combinations of words such as: community-based monitoring, Indigenous communities and web technology (Table 1). Additionally, programmes were identified through the *Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic*.

(3) *Additional grey-literature search for mobile-phone applications*: Owing to the dearth of monitoring programmes using mobile applications throughout the Circumpolar North, a secondary grey-literature search for global monitoring mobile applications was conducted, using Google as the primary search engine. This secondary grey-literature search provided broader data from which to draw key insights and lessons regarding mobile application use in the context of environment-health monitoring.

(4) *Systematic scoping review of peer-reviewed articles*: A systematic scoping review of the peer-reviewed literature was conducted [82,83]. This involved developing a search string, with the guidance of a research librarian, to search MEDLINE® and Web of Science™ (Appendix 1) to identify potentially relevant citations. The search was conducted in July 2015 and then again in June 2017. A hand search of three key journals (*International Journal of Circumpolar Health, Arctic*, and *Environmental*

Table 1. Search term combinations used to identify community-based monitoring programmes in the Circumpolar North: One term per criterion column was combined in each Internet search*.

	Criterion One	Criterion Two	Criterion Three	Criterion Four
Search Term	Community-based* monitoring	Indigenous Knowledge	Mobile app* technology	Circumpolar North
	Environment* monitoring	Indigenous communities	Web* technology	Arctic
	Health monitoring	Indigenous	Smartphone	Polar regions
	Monitoring climate change*	Inuit	Technology	North
	Monitoring environmental* change	First Nations		

*an asterisk indicates that a variation of the word may have been used

Health Perspectives) was performed in June 2017. Citations were uploaded into Mendeley© and de-duplicated, and then uploaded into Distiller software©. Using Distiller©, a two-stage screening process was conducted to identify relevant articles. First, two independent reviewers screened the titles and abstracts of each citation for relevance; potentially relevant citations proceeded to the second stage, where the full-text of the article was screened for relevance again by two independent reviewers. Inclusion criteria were identified a priori, and articles were included if they: were published in English between 2000–2016; were a primary or secondary study; were conducted in the Arctic or Subarctic; involved some form of environmental monitoring; and included some form of human health monitoring. A secondary screening was then conducted of the eligible articles, searching for CBM programmes that used technology to collect, share or visualise data; articles that met this criterion were then included in this study (Figure 1). The level of agreement between the two independent reviewers was measured using Cohen's Kappa (κ). Conflicts between reviewers were discussed and reconciled regularly throughout the review process.

(5) *Additional peer-reviewed literature search for specific monitoring programme*: To supplement the formal systematic scoping review, an additional search of peer-reviewed literature was used to find out more information about programmes identified from the grey literature review and to identify additional monitoring programmes that were active from September-December 2017. To conduct this search, each programme name identified through the grey literature review was used as a search term to search Primo Central™ – a search engine of online databases – for associated peer-reviewed articles, with no date restrictions on the search. This method allowed for greater insight and context into the various monitoring programmes, such as details on the methods used to select indicators.

Data analysis

Once relevant community-based or community-led monitoring programmes were identified, key information was extracted about the programmes, categorised and characterised to create a database using Microsoft Excel [84]. Key attributes for each programme were recorded in this database, including: region and geographic location; lead organisation; partner organisations; programme goals; level of community involvement, engagement or leadership; key indicators monitored; the methods used to develop the included indicators; information regarding how data were collected, monitored and stored through the programme; and how technology, including both mobile applications and web-based tools, were utilised. Additionally, key quotations found on programmes' websites, in reports and/or publications describing the relevant monitoring programmes were recorded, sorted and thematically analysed to contextualise the information included in the database [84].

After the initial categorisation and characterisation were complete, data were analysed qualitatively through an iterative and constant comparative approach [85,86]. First, a preliminary analysis of each programme was conducted using the information recorded in the database, coding the data for emergent themes categorised by content, approach, methods utilised, outputs and key findings. Based on this thematic analysis, preliminary themes were identified for each programme attribute. A detailed analysis was then conducted, constantly comparing and contrasting programmes to look for similarities and differences, and to define key features, strategies, lessons learned, recommendations and outcomes across the various programmes [85].

To analyse the types of data recorded by monitoring programmes, the indicators monitored (eg water quality, etc.) were listed in a separate database, and divided into emergent categories (eg aquatic, etc.). The frequency of an indicator across monitoring programmes and the number of indicators for each programme were recorded, as well as the most common indicators in each category, and any categories for which indicators were underrepresented or not accounted.

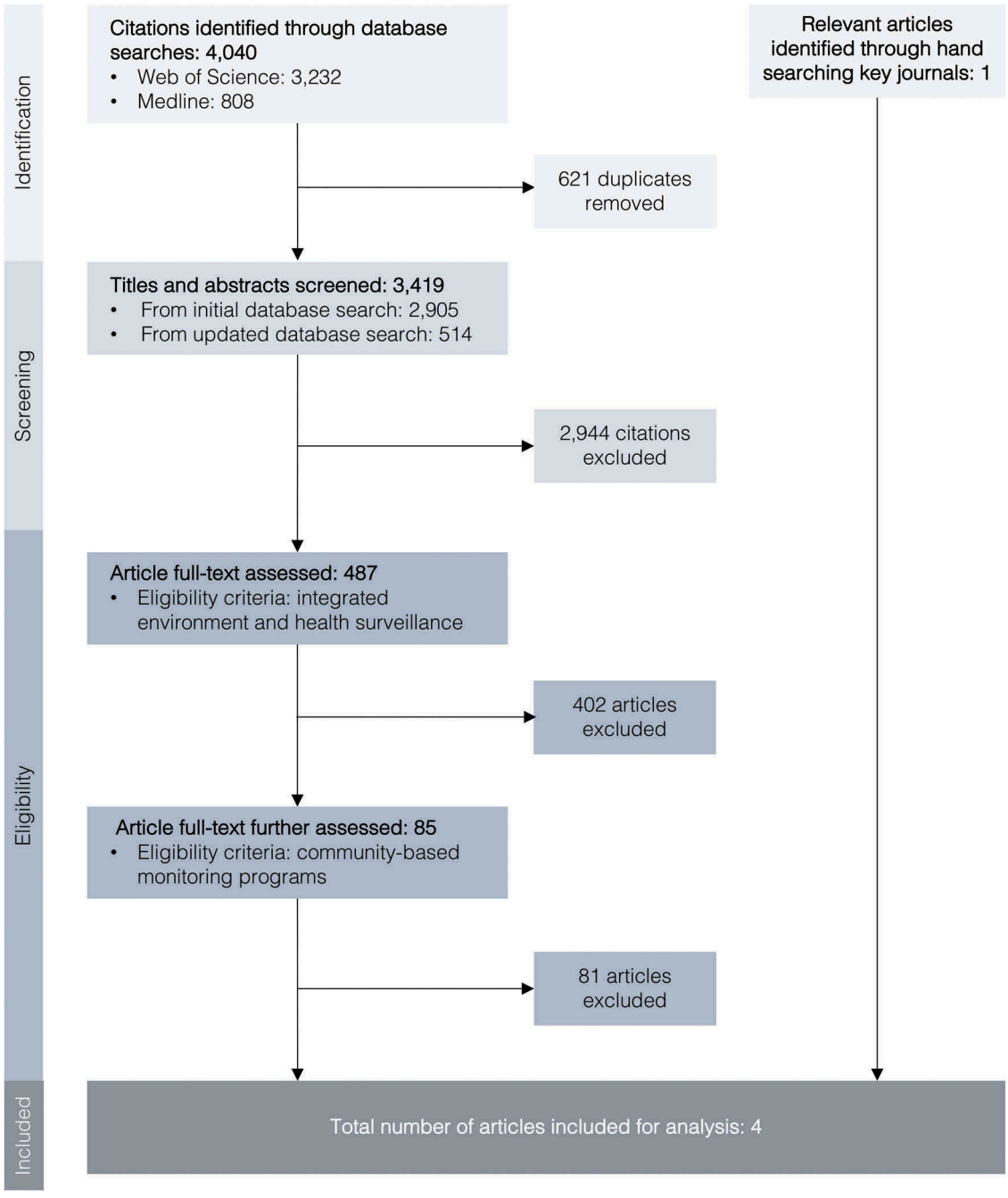

Figure 1. Diagram depicting the flow of identification, screening and eligibility assessment of articles included in this review (n = 3).

Results

In total, 18 monitoring programmes that fit the established criterion in the Circumpolar North were identified from the peer-reviewed and grey-literature searches, and an additional three global app-based climate monitoring programmes were identified and included for further depth (Table 2 and 3). Additionally, 74 distinct indicators/categories were identified and analysed (Table 4–6).

Nine overarching categories developed through the qualitative analysis of these indicators, including: atmosphere, aquatic environment, cryosphere, marine ecology, wildlife ecology, plant ecology, contaminants and human and built environment. The qualitative analysis revealed three key themes: community involvement, indicators chosen for monitoring and use of technology, such as app-based platforms.

Table 2. Identified environment-health monitoring programmes in the Circumpolar North that had some level of involvement with Indigenous communities and used some form of information or communication technology.

Monitoring Programme*	Geographic Region	Associated Organizations
Arctic Borderlands Ecological Knowledge Society (ABEKS)	Porcupine Caribou Herd area and Mackenzie Delta area in Northwest Territories (NWT), Yukon, and Alaska	ABEKS Directors, participants and partners are from Gwich'in and Inuvialuit organizations, governments and are scientists, and community residents
Arctic Monitoring and Assessment Programme (AMAP)	Arctic Wide	Arctic Council
Avativut Program	Nunavik	Centre d'études Nordiques – Université Laval
Circumpolar Biodiversity Monitoring Programme (CBMP)	Circumpolar North	Conservation of Arctic Flora and Fauna (Arctic Council)
Community-Based Water Quality Program (CBWQP)	Northwest Territories Wide	Mackenzie DataStream, NWT Discovery Portal, Government of NWT
Community-Based Wildlife Monitoring Network (CBWMN)	Nunavut Settlement Area	Nunavut Wildlife Management Board
Community Ecological Monitoring Program (CEMP)	Yukon Boreal Forest – Kluane Lake, Mayo, Faro, Watson Lake, and Whitehorse	Arctic Institute Research Station at Kluane Lake, Environment Yukon, the Canadian Wildlife Services and Yukon College
Community Observing Network for Adaptation and Security (CONAS)	Across the Bering Sea in both Alaska and the Russian Far East	Universities of Alaska and Idaho, the Aleut International Association, local community and regional governments in the U. S. and Russia
eNuk Program*** (eNuk)	Rigolet, Nunatsiavut	The Rigolet Inuit Community Government, the University of Guelph, the Labrador Institute of Memorial University, the University of Alberta, Nunatsiavut Government
Inuit Siku Atlas	Baffin Island Nunavut – Cape Dorset, Clyde River, Igloolik, and Pangnirtung	Inuit Sea Ice Use and Occupancy Project
Inuvialuit Settlement Region Community-Based Monitoring Program (ISR-CBMP)	Inuvialuit Settlement Region	ISR Hunters and Trappers Committees, ISR Wildlife Co-Management Boards, Inuvialuit Game Council, the Inuvialuit Regional Corporation, & the Joint Secretariat
Marian Watershed Stewardship Program (MWSP)	Tlicho First Nation in the Northwest Territories	Tlicho Government, Wek'eezhii Land and Water Board and Wilfred Laurier University
Northern Contaminants Program (NCP)	Northern Canada	Aboriginal Affairs & Northern Development Canada
Nunavut Community Aquatic Monitoring Program (NCAMP)	Nunavut Wide	Fisheries and Sealing Division of the Government of Nunavut
PISUNA-net (PISUNA)	Greenland	The Greenland Government, Local Resource Councils, Exchange for Local Observations and Knowledge of the Arctic (ELOKA)
Seasonal Ice Zone Observing Network (SIZONet)	Bering and Chukchi Sea	University of Alaska Fairbanks, Sea-Ice System Services, ELOKA
SIKU**	Eastern Hudson Bay region of Nunavut and Quebec's Nunavik region	The Arctic Eider Society
SmartICE**	Nain, St. John's and Pond Inlet	Memorial University, Nunatsiavut Government, Nain Research Centre

Table 3. Identified global climate change monitoring mobile-phone applications.

Global app-based climate monitoring programmes	Geographic region	Associated organizations
Globe Observer App	Worldwide	National Aeronautics and Space Administration (NASA)
ISeeChange Tracker	Worldwide	NASA's Orbiting Carbon Observatory Mission, National Oceanic and Atmospheric Administration, Community Collaborative Rain, Hail and Snow Network, and more
Local Environmental Observations Network (LEO)	Worldwide	Alaska Native Tribal Health Consortium and Resource Data Inc.

* The monitoring programmes listed are limited to those found during searches performed in English.
** Currently developing or testing mobile-phone applications
*** The indicators used in the eNuk Program are currently being developed in a participatory fashion, in interviews with community members conducted by community researchers; as a result, they were not included in the database designed to analyse indicators

Indicators used to monitor change and how they were used

There were 74 indicators monitored across the different programmes, with the number of indicators/categories monitored by each programme varied. SmartIce monitored the smallest number of indicators, exclusively monitoring sea-ice thickness, while the LEO Network monitored the greatest number, allowing participants to record observations related to approximately 24 different categories of environment/human change. The mean number of indicators collected was nine while the majority of programmes (n = 13) monitored five or fewer indicators/categories.

According to the available data, the different monitoring programmes selected indicators in a variety of ways. Methods for indicator development included:

Table 4. The environment and health indicators captured in monitoring programmes in the Circumpolar North*

CATEGORIES OF INDICATORS MONITORED

	ATMOSPHERIC									AQUATIC								CRYOSPHERIC					
	Indicators Monitored																						
Monitoring Programs	carbon balance in tundra	air temperature	air quality (smog/pollution)	snow (thickness/depth/duration)	precipitation (increase/decrease)	change in seasons	extreme weather conditons (drought,	cloud coverage	wind (speed/ direction/increase)	ocean acidification	appearing/disappearing lakes	current patterns	water temperature	water salinity	water clarity/quality	changing water/ocean conditions	change in water level/flooding	timing of ice freeze-up/break-up	ice thickness	ice edge location	sea-ice extent	sea ice velocity	presence of moving ice
Arctic Borderlands Ecological Knowledge Society		■		■	■	■			■								■						
Arctic Monitoring and Assessment Program	■	■		■						■							■			■	■		
Avativut Project																							
Circumpolar Biodiversity Monitoring Program											■												
Inuvialuit Settlement Region Community Based Monitoring Program																							
Community Based Water Quality Program																							
Community Based Wildlife Monitoring Network																							
Community Ecological Monitoring Program																							
Community Observing Network for Adaptation and Security					■								■	■					■		■	■	
Globe Observer								■															
Inuit Siku Atlas																							
ISeeChange Tracker		■	■	■	■	■	■				■						■		■				
Local Environmental Observations Network Tracker		■	■	■	■	■										■	■		■				
Marian Watershed Stewardship Program															■								
Northern Contaminants Program																							
Nunavut Community Aquatic Monitoring Program															■								
PISUNA Net																			■				
Seasonal Ice Zone Observing Network		■							■												■		
SIKU				■								■	■	■	■	■	■		■				
SmartICE																							
Frequency of Indicator	1	5	2	5	4	3	1	1	2	1	2	1	2	2	3	2	5	5	10	2	5	1	1

* The monitoring programs listed are limited to those found in searches performed in English.

Table 5. The environment and health indicators captured in monitoring programmes in the Circumpolar North.

	CATEGORIES OF INDICATORS MONITORED																					
	MARINE						WILDLIFE ECOLOGY									PLANT ECOLOGY						
	Indicators Monitored																					
Monitoring Programs	changing distribution of fish	sea ice ecosystem	phytoplankton/marine algae	distribution of marine/aquatic species	aquatic habitat	human behaviour on benthic habitat	wildlife distribution	change in reptiles/amphibians	presence of insects/invertebrates	change in wildlife behavior	change in wildlife migration	wildlife abundance/population	body condition of fauna	invasive/unfamiliar species	genetic diversity	entrapment in ice (severity/frequency)	vegetation changes	greening of the arctic	unfamiliar flora (occurrence/distribution)	familiar flora (productivity/condition)	productivity of berries	biodiversity
Arctic Borderlands Ecological Knowledge Society	■			■	■		■			■	■	■	■	■			■				■	
Arctic Monitoring and Assessment Program																						
Avativut Project																					■	
Circumpolar Biodiversity Monitoring Program	■	■				■						■		■	■			■				
Inuvialuit Settlement Region Community Based Monitoring Program							■				■	■						■				
Community Based Water Quality Program	■	■				■																
Community Based Wildlife Monitoring Network							■				■	■										
Community Ecological Monitoring Program							■										■				■	
Community Observing Network for Adaptation and Security			■				■			■		■	■	■					■	■		■
Globe Observer									■													
Inuit Siku Atlas																						
ISeeChange Tracker				■			■		■	■	■	■					■					
Local Environmental Observations Network Tracker	■			■			■	■	■	■	■	■					■					
Marian Watershed Stewardship Program	■				■																	
Northern Contaminants Program																						
Nunavut Community Aquatic Monitoring Program	■																					
PISUNA Net	■			■			■					■										
Seasonal Ice Zone Observing Network																						
SIKU							■					■				■						
SmartICE																						
Frequency of Indicator	7	2	1	4	2	2	9	1	3	4	5	9	2	3	1	1	4	2	1	1	3	1

* The monitoring programs listed are limited to those found in searches performed in English.

Table 6. The environment and health indicators captured in monitoring programmes in the Circumpolar North.

	CATEGORIES OF INDICATORS MONITORED																												
	LAND						HUMAN/BUILT ENVIRONMENT															CONTAMINANT								
	Indicators Monitored																												
Monitoring Programs	permafrost	changes to the land	arctic peatlands	coastline change	wetland surface drying/surface moisture	ground/soil temperature	road/buildings and ports	sanitation infrastructure	changing traditional ice routes	changes to agriculture	changes in protected areas	consumption/harvest traditional foods	common causes of death	linguistic diversity	traditional knowledge/culture	harvest of marine animals	reindeer herding	air/marine transit	human health	infant mortality	contaminants in humans	level of contaminants in marine life	freshwater/terrestrial contaminants	atmospheric contaminant level	marine debris	oil in unfamiliar places	microbes	contaminant levels in wildlife
Arctic Borderlands Ecological Knowledge Society				■								■																	
Arctic Monitoring and Assessment Program	■					■						■	■							■		■	■	■					
Avativut Project																													
Circumpolar Biodiversity Monitoring Program			■								■	■		■		■	■												
Inuvialuit Settlement Region Community Based Monitoring Program				■								■			■			■										■	
Community Based Water Quality Program																													
Community Based Wildlife Monitoring Network												■																	
Community Ecological Monitoring Program																													
Community Observing Network for Adaptation and Security				■	■		■		■																■	■	■		
Globe Observer																													
Inuit Siku Atlas																													
ISeeChange Tracker				■			■			■									■										
Local Environmental Observations Network Tracker		■					■	■		■									■								■	■	
Marian Watershed Stewardship Program																													
Northern Contaminants Program																						■	■	■				■	
Nunavut Community Aquatic Monitoring Program																													
PISUNA Net																													
Seasonal Ice Zone Observing Network																													
SIKU																						■							
SmartICE																													
Frequency of Indicator	1	1	1	4	1	1	3	1	1	2	1	5	1	1	1	1	1	1	1	1	1	3	2	2	1	1	2	3	

* The monitoring programs listed are limited to those found in searches performed in English.

consultation involving international and regional workshops (eg ABEKS, CBMP, PISUNA); the development of a peer-reviewed indicator strategy (eg CBMP); co-developed surveys and questionnaires (eg CONAS); discussions with natural resource councils (eg PISUNA); semi-structured interviews and interactive community events with community members (eg eNuk); examining regional priorities (eg CBMP, ISR CBMP); decision-making by programme staff (eg Globe Observer, ISeeChange); and indicators suggested by those collecting data (eg eNuk, ISeeChange, LEO Network, PISUNA). Although these various methods provided insight into the processes some programmes used to select indicators, the majority of programmes (n = 13) did not explicitly state how indicators were selected, based on the identified grey and peer-reviewed literature.

Of the 74 identified indicators/categories (Table 4), the most commonly monitored were: ice thickness, wildlife distribution, wildlife abundance/population, changing fish distribution, change in water level/flooding, change in wildlife migration, consumption/harvest of traditional food, sea-ice extent, timing of ice freeze-up/break-up, snow depth/duration and air temperature (Figure 2). Many of the monitoring programmes explicitly monitored indicators associated with different and changing seasons (eg timing of ice freeze-up/break-up); however, not all monitoring programmes explicitly stated whether or not monitoring occurred year-round.

The majority of monitoring programmes with specified indicators focused exclusively on environmental change, with only seven out of 20 (35%) focusing on the impacts of climate change on human health: The Arctic Borderlands Ecological Knowledge Society; Arctic Monitoring and Assessment Programme; Circumpolar Biodiversity Monitoring Programme; Community-Based Wildlife Monitoring Network; Inuvialuit Settlement Region Community Based Monitoring Program; ISeeChange; and the LEO Network. The Arctic Monitoring and Assessment Programme monitored the greatest number of indicators related to human health (n = 4), including: consumption/harvest of traditional food, common causes of death, infant mortality and contaminants in humans. The remaining three Circumpolar programmes monitored consumption/harvest of traditional food as the sole indicator of human health, while the two global monitoring apps allowed users to input any observations related to human health. Notably, mental wellness was not explicitly monitored in any of the listed indicators; however, the eNuk Program, whose indicators were not yet published at the time of this review, was conceptualised as an integrated environment-health monitoring programme with the goal of monitoring a range of environmental conditions and both physical and mental health indicators.

There were a number of reported outcomes and outputs from these monitoring programmes. First, several of the organisations reported using the data to inform community, regional, and national decision-making (eg CBWMN, CONAS, ISR CBMP, NCP, PISUNA and SmartICE). For example, data collected through PISUNA were submitted to local authorities and central governments to take action and inform regional management decisions, such as changes to harvesting seasons, quotas and local laws and bylaws related to fishing methods and equipment [87]. Second, programmes reported using the information to develop tools for data sharing, education, and skill development (eg Avativut, ISR CBMP, Inuit Siku

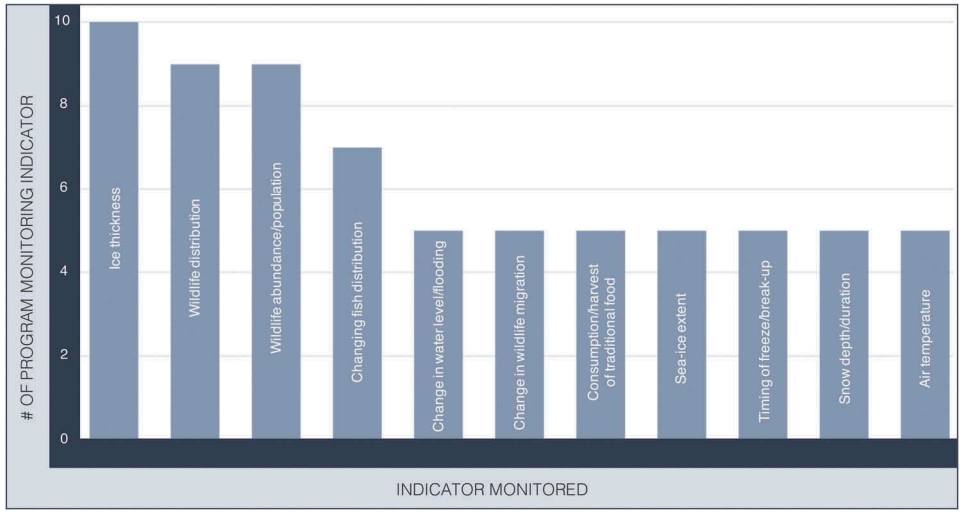

Figure 2. Indicators commonly monitored by environment-health monitoring programmes in the Circumpolar North and global climate change monitoring mobile applications.

Atlas, PISUNA, SIZONet and SmartICE). These tools included interactive maps, databases and archives, online resources for harvesters and interactive multimedia outputs such as audio, video and photographs of observations and educational resources for Northern schools (eg CBMP; Inuit Siku Atlas; ISR PISUNA and SIZONet). Finally, these programmes reported producing community, regional, national and/or international publications, reports and press releases to communicate the results of their programmes at various scales (eg AMAP, CBMP, CEMP and CONAS). Through these different outcomes and outputs, it was evident that these monitoring programmes have the potential to further understandings of the impacts of climate change throughout the Circumpolar North.

Community involvement

Although all of the monitoring programmes analysed reported some level of community involvement, the degree to which community members were involved in monitoring efforts varied, and few community-*led* monitoring programmes were identified. Programmes ranged from being developed and implemented by community members (eg eNuk, ISR-CBMP and PISUNA), to outside organisations consulting with community members (eg SmartICE, and NCAMP), to community members involved in the data collection phases of programmes (eg CBWMN and CEMP). Of the 21 monitoring programmes analysed, less than a quarter were classified as community-led (n = 5). The remaining programmes either partnered with communities (n = 6) or engaged with communities in another way (n = 7) (eg consultation or data collection).

In programmes identified as community-led or community-based, community members played a key role in determining what indicators should be monitored. For example, on PISUNA's website, they explained the process used for determining what would be monitored, stating: "Local Resource Councils, established at the community level and comprising hunters, fishers and other individuals with an interest in the environment, decide what will be monitored based on the relevance for their community" [87]. The Marian Watershed Stewardship Program, another community-led programme, discussed taking a similar approach to determining what to monitor, explaining, "[Our program] is a community-based monitoring program that is being developed based on the questions and needs of the Tlicho people" [88].

Although involving community members in monitoring is an integral part of CBM, aside from the three global-monitoring apps – which allowed anyone who had access to a mobile-phone to collect data – the majority of programmes were not open to the public and dedicated monitors were selected. These monitors often included: harvesters (ie hunters and fishers) (eg CBWMN, CONAS, ISR-CBMP, PISUNA and SIKU); Elders (eg CONAS); local experts (ie sea ice and wildlife experts) (eg ABEKS and SIZONet); and trained community members (eg CBWMN, CONAS and MWSP).

Use of technology

All of the programmes included in this review used some form of web-based technologies to: visualise, analyse, store and share data that were collected (n = 12); promote the programme via a webpage (n = 21); and collect data (n = 6). For example, The Inuit Siku Atlas had an online platform that allowed stories and data to be shared in the form of maps, audio, video, picture and text across Nunavut and beyond, allowing for information to be more easily accessed and updated [89]. PISUNA also had a web-based application, where the observations made by local communities were stored, publicly available and searchable [87]. Similarly, the Avativut Program had a web portal, which allowed data to be inputted, accessed and archived [90]. The Avativut portal also enabled consultation of scientific protocols, sharing video clips and photographs and communication across data collection locations [90].

The results of this environmental scan indicated that, in large part, advanced web-based technology, such as mobile-phone applications, or tablets, were not used in the data collection process of most monitoring programmes in the Circumpolar North (n = 3/18). For example, data collectors for the Community-Based Wildlife Monitoring Network used hand-held computers to record their observations when out on the land; once they returned home trained data clerks transferred information from the hand-held devices to a regional database [91]. In other monitoring programmes, data were collected using hand written notes, or through paper surveys.

This research identified only three programmes in the Circumpolar North that were developing apps for community-based monitoring in the region at the time of this study. The first programme, SmartICE, was designed to observe and disseminate knowledge on sea-ice (ie thickness and surface characteristics), and was developing a mobile-phone application to provide the most up-to-date sea-ice information to community members and to allow for the recording of observations by people travelling on the sea-ice [92]. The second programme, SIKU, focused on monitoring ice conditions

and wildlife and was developing an app and associated web-based tools with the goal of helping to facilitate knowledge transfer, sea-ice safety, participatory mapping, language preservation, education, training and environmental stewardship [93]. The third, and final programme, eNuk, was developing the eNuk app to allow community members to record and respond to both environment and/or health indicators of climate change via online posts, photos or video uploads. As mentioned, internationally, this research identified three additional monitoring programmes that used app-based technologies to track environmental change: Globe Observer, ISeeChange and LEO Network. These programmes allowed individuals to document different changes they saw in their everyday lives through an app platform, and consolidate these observations and inputs into aggregate information centres. There are therefore many opportunities to incorporate new technologies and innovations into environment-health monitoring systems in the Circumpolar North.

This research found that internet and cellular phone connectivity was often limited or non-existent in the North, which has the potential to negatively impact the timeliness of these mobile-phone applications. These app-based monitoring programmes were exploring new and innovative ways to address these concerns. An example of a programme attempting to bridge this digital divide is the SmartICE programme. SmartICE used stationary sensors (SmartBUOYs) to provide timely information about sea ice to community members via satellites, as well as through a mobile, sled-based technology pulled by snowmobiles (SmartQAMUTIK) to measure sea ice thickness [94]. This information was gathered by community researchers and shared through a cloud-based interface, the SmartICE App itself, and paper reports [94]. This example shows how innovative technology can be used to meet the unique context of environmental-health monitoring in the North.

Discussion

As evidenced by this research and outlined in the literature [35], Indigenous communities across the North are increasingly involved in the design, development and implementation of monitoring programmes in order to observe, record, and respond to climate change. As this synthesis indicates, several important opportunities exist with regard to Indigenous communities monitoring the health effects of climate change, including the need for programmes to: (1) be community-led and community-based; (2) holistically incorporate health and environment; and (3) make use of innovative technologies that are locally appropriate and usable.

In many Indigenous communities across the North, environment-health monitoring programmes that engage community members have been identified as being more successful than other programmes [95]. Specifically, these programmes are recognised in the literature for their ability to combine cultural knowledge surrounding environmental changes with environmental observations, leading to important community adaptation and emergency response strategies [96]. This research found that although Indigenous communities were increasingly involved in the monitoring of environment and health through community-based and community-led monitoring, the extent of community involvement varied and was often limited. Although research has identified the benefits of CBM for Indigenous communities, the data analysed in this environmental scan were not sufficient to determine the success of community-led versus community-based monitoring programmes. More research is needed to determine the relative effectiveness of increased community involvement in monitoring initiatives.

Analysing the indicators used by monitoring programmes provided insight into what indicators were used to monitor climate change within the North. Although climate change is recognised as having numerous effects on health and wellbeing [1–10], this research discovered that few monitoring programmes integrated both environment and health indicators in their programmes in a holistic way. The lack of integration between environmental and health indicators may point to a lack of integration between environmental and health monitoring more broadly, which is particularly problematic for Indigenous communities that conceptualise wellbeing as closely tied to the environment and land [10–12,21,27,30,65]. Additionally, the analysis of indicators revealed a paucity of community-based monitoring programmes focused on mental wellbeing, which should be addressed for many reasons, including the intimate connections between climate change and Indigenous mental wellbeing that have been identified by community members and researchers alike [2–6].

Existing literature on monitoring health impacts of climate change has highlighted challenges associated with collecting these health indicators, including: (1) identifying relevant health indicators is often dependent on a population's vulnerability and adaptive capacity, as well as many other determinants; (2) accessing and analysing health data from multiple sources is difficult; (3) determining relationships between complex and often distal climate related risk factors and their health consequences is methodologically challenging;

and, (4) identifying, collecting and analysing health data for health practitioners, as well as local and regional governments requires resources and capacity [30,97–99]. These challenges may explain why environmental indicators associated with climate change were more frequently monitored than health indicators, and why there were no indicators of mental health monitored in the literature included in this review.

The way technology was used by the majority of identified monitoring programmes (ie data visualisation, storage and sharing) has potential to help organise and share information in a way that is accessible beyond research institutions. This research indicated, however, that important challenges remain for programmes with regard to using advanced technology in the data collection phases of monitoring programmes. Similar to existing research [35,95], the data revealed that programmes often used low-tech approaches to data collection as a result of poor bandwidth in higher latitudes and minimal computer access, leading to potentially problematic delays in reporting and data errors. As highlighted above, internet and cellular network connectivity issues in the North can often delay time-sensitive information recorded in mobile applications from being uploaded in real-time. Innovative solutions, such as the mobile phone application being developed by the eNuk programme, as well as the stationary and mobile sensors (SmartBOUYs and SmartQAMUTIK), and the satellite technology used by SmartICE [94] are beginning to address these challenges and bridge the technological gap that exists in many communities in the North.

This review revealed several limitations to existing community-based monitoring programmes in the Circumpolar North. Although the reviewed programmes all had some level of community involvement, only a few programmes were actually *led* by community members. Further, through examining the indicators monitored by these programmes, it was evident that there is a gap in monitoring the health implications of climate change for communities in this region. Finally, this research revealed that low-tech tools were often used to gather data and monitor indicators, and the need for innovative solutions to gathering this data and improving internet connectivity issues in the North.

Despite the information gleaned from this environmental scan and subsequent analysis, there were several limitations to this research. An environmental scan is designed to be an efficient way of providing a "snapshot" of existing monitoring programmes in the Circumpolar North rather than a comprehensive review [73]. The searches were conducted in English, which may have limited the majority of identified programmes to English-speaking regions of the Circumpolar North. Additionally, some CBM programmes may not have a presence on the internet, inadvertently excluding them from this study.

A challenge involved in categorising and analysing the indicators monitored by environment-health monitoring programmes, which is perhaps indicative of a greater challenge in monitoring, was that the indicators of environment and human health were often different for each programme. For example, some programmes stated that they monitored the broad category of "sea ice," while others monitored more specific elements of sea ice including "thickness, colour, time of break-up, incidents of animal entrapment in sea ice, etc". Although this information was useful as it revealed the types of indicators being monitored, it made comparability across programmes difficult.

Conclusion

This review indicated that there are many opportunities for growth within community-based monitoring in this region. Increased community leadership throughout the design and delivery of monitoring programmes has the potential to enable community prioritisation of needs in regional decision making, for the development of relevant indicators of change that reflect Indigenous connections between environment and wellbeing, and for the creation of locally and culturally useful technological innovation [100]. Supporting monitoring programmes in the North, which are community-led, integrated and make use of culturally appropriate technology, can help fill the gaps in existing programming outlined throughout this article, potentially leading to more robust and meaningful monitoring of health-related impacts of climate change in and across Indigenous communities in the Circumpolar North.

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ORCID

Amy Kipp http://orcid.org/0000-0001-7298-8765
Daniel Gillis http://orcid.org/0000-0002-7646-259X
Sherilee L. Harper http://orcid.org/0000-0001-7298-8765

References

[1] Harper SL, Edge VL, Cunsolo Willox A., et al. "Changing climate, changing health, changing stories" profile: using an EcoHealth approach to explore impacts of climate change on Inuit health. Ecohealth. 2012;9:89–101.
[2] Petrasek MacDonald J, Harper SL, Cunsolo Willox A, et al. A necessary voice: climate change and lived experiences of youth in Rigolet, Nunatsiavut, Canada. Glob Environ Chang. 2013;23:360–371.
[3] Cunsolo Willox A, Harper SL, Ford JD, et al. Climate change and mental health: an exploratory case study from Rigolet, Nunatsiavut, Canada. Clim Change. 2013;121:255–270.
[4] Cunsolo Willox A, Harper SL, Edge VL, et al. The land enriches the soul: on climatic and environmental change, affect, and emotional health and well-being in Rigolet, Nunatsiavut, Canada. Emot Sp Soc. 2013;6:14–24.
[5] Cunsolo Willox A, Harper SL, Ford JD, et al. "From this place and of this place:" climate change, sense of place, and health in Nunatsiavut, Canada. Soc Sci Med. 2012;75:538–547.
[6] Ostapchuk J, Harper SL, Willox AC, et al. Exploring elders' and seniors' perceptions of how climate change is impacting health and well-being in Rigolet, Nunatsiavut. Int J Indigenous Health. 2015;9:6–24.
[7] Jay M, Marmot M. Health and climate change. BMJ. 2009;339:645–646.
[8] Parkinson AJ, Butler JC. Potential impacts of climate change on infectious diseases in the Arctic. Int J Circumpolar Health. 2005;64:478–486.
[9] Haines A, Kovats RS, Campbell-Lendrum D, et al. Climate change and human health: impacts, vulnerability and public health. Public Health. 2006;120:585–596.
[10] Ford JD. Indigenous health and climate change. Am J Public Health. 2012;102:1260–1266.
[11] Ford J, Cunsolo Willox A, Chatwood S, et al. Adapting to the effects of climate change on Inuit health. Am J Public Health. 2014;104:9–17.
[12] Harper SL, Edge VL, Schuster-Wallace CJ, et al. Weather, water quality and infectious gastrointestinal illness in two Inuit communities in Nunatsiavut, Canada: potential implications for climate change. Ecohealth. 2011;8:93–108.
[13] Harper SL, Edge VL, Ford JD, et al. Acute gastrointestinal illness in two Inuit communities: burden of illness in Rigolet and Iqaluit, Canada. Epidemiol Infect. 2015;143:3048–3063.
[14] Harper SL, Edge VL, Ford J, et al. Lived experience of acute gastrointestinal illness in Rigolet, Nunatsiavut: "Just suffer through it.". Soc Sci Med. 2015;126:86–98.
[15] Harper SL, Edge VL, Ford J, et al. Climate-sensitive health priorities in Nunatsiavut, Canada. BMC Public Health. 2015;15:605.
[16] Harper SL, Edge VL, Ford J, et al. Healthcare use in two Inuit communities: acute gastrointestinal illness in Rigolet and Iqaluit, Canada. Int J Circumpolar Health. 2015;74:26290.
[17] Cunsolo Willox A, Shiwak I, Wood M. "You need to be a well-rounded cultural person": youth mentorship programs for cultural preservation, promotion, and sustainability in the Nunatsiavut Region of Labrador. In: Fondahl G, Wilson G, editors. Northern sustainabilities: understanding and addressing change in the circumpolar world. Springer, Cham: Springer Polar Sciences; 2017. p. 285–303.
[18] Petrasek MacDonald J, Cunsolo WA, Ford J, et al. Protective factors for mental health and well-being in a changing climate: perspectives from Inuit youth in Nunatsiavut, Labrador. Soc Sci Med. 2016;141:133–141.
[19] Petrasek MacDonald J, Ford J, Cunsolo Willox A, et al. Youth-led participatory video as a strategy to enhance inuit youth adaptive capacities for dealing with climate change. Arctic. 2015;68:486–499.
[20] Ford JD, Smit B, Wandel J, et al. Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada. Geogr J. 2008;174:45–62.
[21] Ford JD, Furgal C. Foreword to the special issue: climate change impacts, adaptation and vulnerability in the Arctic. Polar Res. 2009;28:1–9.
[22] Lardeau M-P, Healey G, Ford J. The use of photovoice to document and characterize the food security of users of community food programs in Iqaluit, Nunavut. Rural Remote Health. 2011;11:1680.
[23] Ford J, McDowell G, Shirley J, et al. The dynamic multiscale nature of climate change vulnerability: an Inuit harvesting example. Ann Assoc Am Geogr. 2013;103:1193–1211.
[24] Ford JD, Pearce T, Gilligan J, et al. Hazards associated with ice use in Northern Canada. Arctic, Antarct Alp Res. 2008;40:647–659.
[25] Ford J, Gough W, Laidler G, et al. Sea ice, climate change, and community vulnerability in northern Foxe Basin, Canada. Clim Res. 2009;38:137–154.
[26] Pardhan-Ali A, Wilson J, Edge VL, et al. Community-level risk factors for notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991–2008. BMC Public Health. 2013;13:63.
[27] Pardhan-Ali A, Wilson J, Edge VL, et al. A descriptive analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991–2008. BMJ Open. 2012;2:e000732.
[28] Tremblay M, Furgal C, Larrivée C, et al. Climate change in Northern Quebec : adaptation strategies from community-based research. Arctic. 2008;61:27–34.
[29] Pardhan-Ali A, Berke O, Wilson J, et al. A spatial and temporal analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. Int J Health Geogr. 2012;11:17.

[30] Furgal C, Seguin J. Climate change, health, and vulnerability in Canadian northern Aboriginal communities. Environ Health Perspect. 2006;114:1964–1970.
[31] Ebi KL, Ogden NH, Semenza JC, et al. Detecting and attributing health burdens to climate change. Environ Health Perspect. 2017;125:085004.
[33] Parkinson AJ, Berner J. Climate change and impacts on human health in the Arctic: an international workshop on emerging threats and the response of Arctic communities to climate change. Int J of Circumpolar Health. 2009;68:84–91.
[34] Ford JD, Berrang-Ford L, King M, et al. Vulnerability of Aboriginal health systems in Canada to climate change. Glob Environ Change. 2010;20:668–680.
[35] Kouril D, Furgal C, Whillans T. Trends and key elements in community-based monitoring: a systematic review of the literature with an emphasis on Arctic and Subarctic regions. Environ Reviews. 2015;24:151–163.
[36] Parkinson AJ, Bruce MG, Zulz T. International circumpolar surveillance, an Arctic network for the surveillance of infectious diseases. Emerg Infect Dis. 2008;14:18–24.
[37] Driscoll DL, Sunbury T, Johnston J, et al. Initial findings from the implementation of a community-based sentinel surveillance system to assess the health effects of climate change in Alaska. Int J Circumpolar Health. 2013;72:21405.
[38] Ebi KL, Schmier JK. A stitch in time: improving public health early warning systems for extreme weather events. Epidemiol Rev. 2005;27:115–121.
[39] IPCC. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. Field CB, Barros V, Stocker TF, et al. eds. Cambridge: Cambridge University Press; 2012.
[40] IPCC. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Parry ML, Canziani OF, Palutikof PJ, et al., editors. Cambridge, UK: Cambridge University Press; 2007.
[41] Ebi KL, Kovats RS, Menne B. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. Environ Health Perspect. 2006;114:1930–1934.
[42] Brubaker M, Berner J, Chavan R, et al. Climate change and health effects in Northwest Alaska. Glob Health Action. 2011;4:8445.
[43] Scheraga JD, Ebi KL, Furlow J, et al. From science to policy: developing responses to climate change. In: McMichael AJ, Campbell-Lendrum DH, Corvalán CF, Ebi KL, Githeko AK, Scheraga JD, Woodward A, editors. Climate change and human health. Geneva (Switzerland): World Health Organization; 2003. p. 237–266.
[44] Greer A, Ng V, Fisman D. Climate change and infectious diseases in North America: the road ahead. Can Med Assoc J. 2008;178(6):715–722.
[45] Parkinson AJ, Evengård B. Climate change, its impact on human health in the Arctic and the public health response to threats of emerging infectious diseases. Glob Health Action. 2009;2:1–3.
[46] McMichael AJ, Campbell-Lendrum D, Corvalan C, et al. Climate change and human health: risks and responses. Geneva, Switzerland: World Health Organization; 2003.
[47] Confalonieri U, Menne B, Akhtar R, et al. Human Health. In: Parry ML, Canziani OF, Palutikof JP, et al., editors. Climate change 2007: impacts, adaptation and vulnerability. contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge (UK): Cambridge University Press; 2007. p. 391–431.
[48] Few R. Health and climatic hazards: framing social research on vulnerability, response and adaptation. Glob Environ Chang. 2007;17:281–295.
[49] Lesnikowski AC, Ford JD, Berrang-Ford L, et al. Adapting to health impacts of climate change: a study of UNFCCC Annex I parties. Environ Res Lett. 2011;6:44009.
[50] McMichael AJ. Globalization, climate change, and human health. N Engl J Med. 2013;368:1335–1343.
[51] Ebi KL, Lewis ND, Corvalan C. Climate variability and change and their potential health effects in small island states: information for adaptation planning in the health sector. Environ Health Perspect. 2006;114:1957–1963.
[52] Evengård B, Sauerborn R. Climate change influences infectious diseases both in the Arctic and the tropics: joining the dots. Glob Health Action. 2009;2:1–8.
[53] Ebi KL, Smith J, Burton I, et al. Some lessons learned from public health on the process of adaptation. Mitig Adapt Strateg Glob Chang. 2006;11:607–620.
[54] Kovats RS, Menne B, Ahern MJ, et al. National assessments of health impacts of climate change: a review. In: McMichael AJ, Campbell-Lendrum DH, Corvalán CF, Ebi KL, Githeko AK, Scheraga JD, Woodward A, editors. Climate change and human health. Geneva, Switzerland: World Health Organization; 2003. p. 181–203.
[56] Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health. 2008;98:435–445.
[57] Füssel HM. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustain Sci. 2007;2:265–275.
[58] Ebi KL, Burton I. Identifying practical adaptation options: an approach to address climate change-related health risks. Environ Sci Policy. 2008;11:359–369.
[59] Ebi KL, Semenza JC. Community-based adaptation to the health impacts of climate change. Am J Prev Med. 2008;35:501–507.
[60] Blashki G, Armstrong G, Berry HL, et al. Preparing health services for climate change in Australia. Asia-Pacific J Public Health. 2011;23:133S–43.
[61] McMichael A. Global climate change and health: an old story writ large. In: McMichael AJ, Campbell-Lendrum D, Corvalan C, et al., editors. Climate change and human health. Risks and responses. Geneva, Switzerland: World Health Organization; 2003. p. 1–17.
[62] Campbell-Lendrum D, Bertollini R, Neira M, et al. Health and climate change: a roadmap for applied research. Lancet. 2009;373:1663–1665.
[63] Smylie J, Anderson M. Understanding the health of indigenous peoples in Canada: key methodological and conceptual challenges. Can Med Assoc J. 2006;175(6):602.
[64] Gracey M, King M. Indigenous health part 1: determinants and disease patterns. The Lancet. 2009;374:65–75.
[65] Harper SL, Edge VL, Schuster-Wallace CJ, et al. Improving aboriginal health data capture: evidence from a health registry evaluation. Epidemiol Infect. 2011;139:1774–1783.

[70] Government of Canada. Canadian National Enteric Pathogen Surveillance System: C-EnterNet 2009 Annual Report: Guelph, ON: Public Health Agency Can; 2011, p. 84.
[71] Keegan VA, Majowicz SE, Pearl D, et al. Epidemiology of enteric disease in C-EnterNet's pilot site – waterloo region, Ontario, 1990 to 2004. Can J Infect Dis Med Microbiol. 2009;20:79–87.
[72] EMAN. 2003. Improving local decision-making through community based monitoring: toward a Canadian community monitoring network. Environ Can. En40-883/2003E. accessed 2012 Feb 3. http://publications.gc.ca/site/eng/242989/publication.Html
[73] Rowel R, Moore ND, Nowrojee S, et al. The utility of the environmental scan for public health practice: lessons from an urban program to increase cancer screening. J Natl Med Assoc. 2005;l97:527.
[74] Graham P, Evitts T, Thomas-MacLean R. Environmental scans: how useful are they for primary care research? Can Fam Physician. 2008;54(7):1022–1023.
[75] Skinner K, Hanning R, Tsuji L. Barriers and supports for healthy eating and physical activity for first nation youths in Northern Canada. Int J Circumpolar Health. 2006;65:148–161.
[76] Mew EJ, Ritchie SD, VanderBurgh D, et al. An environmental scan of emergency response systems and services in remote first nations communities in Northern Ontario. Int J Circumpolar Health. 2017;76:1320208.
[77] Young TK, Ng C, Chatwood S. Assessing health care in Canada's North: what can we learn from national and regional surveys? Int J Circumpolar Health. 2015;74:28436.
[78] Muttitt S, Vigneault R, Loewen L. Integrating telehealth into aboriginal healthcare: the Canadian experience. Int J Circumpolar Health. 2004;63:401–414.
[79] Wakegijig J, Osborne G, Statham S, et al. Collaborating toward improving food security in Nunavut. Int J Circumpolar Health. 2013;72:21201.
[80] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol. 2005;8:19–32.
[81] Pham MT, Rajić A, Greig JD, et al. A scoping review of scoping reviews: advancing the approach and enhancing the consistency. Res Methods Synth. 2014;5:371–385.
[82] Colquhoun HL, Levac D, O'Brien KK, et al. Scoping reviews: time for clarity in definition, methods, and reporting. J Clin Epidemiol. 2014;67:1291–1294.
[83] Peters MD, Godfrey CM, Khalil H, et al. Guidance for conducting systematic scoping reviews. Int J Evid-Based Healthc. 2015;13(3):141–146.
[84] Thorne S. Data analysis in qualitative research. Evid-Based Nurs. 2000;3:68–70.
[85] Srivastava P, Hopwood N. A practical iterative framework for qualitative data analysis. Int J Qual Methods. 2009;8:76–84.
[86] Boeije H. A purposeful approach to the constant comparative method in the analysis of qualitative interviews. Qual Quant. 2002;36:391–409.
[87] IUCN.org [Internet]. PISUNA – community-based monitoring to management Accessed 2017 Dec. https://www.iucn.org/news/marine-and-polar/201701/pisuna-community-based-monitoring-management
[88] NWTGeoScience.ca. [Internet]. Environmental monitoring and research: Marian Watershed Stewardship Program. [Accessed November 2017]. http://www.nwtgeoscience.ca/forum/session/marian-watershed-stewardship-program
[89] SikuAtlas.ca [Internet]. Inuit Siku Atlas. Accessed 2017 Dec. https://sikuatlas.ca/index.html?module=module.sikuatlas.home.welcome
[90] Cen.Ulaval.ca [Internet]. Avativut – science in Nunavik Accessed 2017 Dec. http://www.cen.ulaval.ca/avativut/en_accueil.aspx
[91] NWMB.com [Internet]. Community-based wildlife monitoring network. Accessed 2017 Dec. http://www.nwmb.com/en/cbmn
[92] UNFCC.int [Internet]. SmartICE | canada. Accessed 2017 Dec. http://unfccc.int/secretariat/momentum_for_change/items/10468.php
[93] ArcticEider.com [Internet]. SIKU. Accessed 2017 Dec. www.arcticeider.com/siku
[94] SmartIce.org [Internet]. Enabling resiliency in the face of climate change. Accessed 2017 Dec. https://www.smartice.org/
[95] Johnson N, Behe C, Danielsen F, et al. Community-based monitoring and indigenous knowledge in a changing arctic: a review for the sustaining arctic observing networks. Sustain Arct Observ Net. 2016;9:1–62.
[96] Sawatzky A, Cunsolo A, Gillis D, et al., Profiling the eNuk program. Northern Public Affairs. 2017.
[97] Moulton AD, Schramm P. Climate change and public health surveillance: toward a comprehensive strategy. J Public Health Manag Pract. 2017;23(6):618.
[98] WHO.int [Internet]. Climate change and health. Accessed 2018 Jun. http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[99] UNCClearn.org [Internet]. Resource guide for advanced learning on understanding the climate change and health interface.
[100] Jones J, Cunsolo A, Harper S. Who is research serving? A systematic realist review of circumpolar environment-related indigenous health literature. PLoS One. 2018.

Appendices

Appendix 1. Finalized search strings for Web of Science™ and MEDLINE® aggregator databases to identify articles related to integrated surveillance strategies in Arctic and Subarctic regions of the Circumpolar North that involved considerations for the natural environment, human health, and surveillance (2005–2016).

	Web of Science™	MEDLINE®
Natural environment component	(((((climat* NEAR/2 (change or variabl* or extreme)) or global warm* or ice or disaster* or fire* or cyclon* or storm* or flood* or drought* or rain or snow or (tidal NEAR/2 wave*) or tornado* or (food NEAR/2 (suppl* or safe* or security or quality)) or (water NEAR/2 (suppl* or fresh or drink* or security or quality or pollut*)) or weather or (extreme NEAR/2 (cold or heat)) or (air NEAR/2 (quality or pollut*)) or humidity or temperature* or wind* or "ultraviolet rays" or (environment* NEAR/2 (monitor* or medicine or health or pollut* or exposure*)))))	((((climat* adj2 (change or variabl* or extreme)) or global warm* or ice or disaster* or fire* or cyclon* or storm* or flood* or drought* or rain or snow or (tidal adj2 wave*) or tornado* or (food adj2 (suppl* or safe* or security or quality)) or (water adj2 (suppl* or fresh or drink* or security or quality or pollut*)) or weather or (extreme adj2 (cold or heat)) or (air adj2 (quality or pollut*)) or humidity or temperature* or wind* or ultraviolet rays or (environment* adj2 (monitor* or medicine or health or pollut* or exposure*))))).tw.
Surveillance component	((((((ecological* NEAR/3 monitor*) or (disease NEAR/2 notification) or ((surveillance or monitor* or track* or assess*) NEAR/3 (population or health* or environment*)) or ((prevent* or warn* or prepar* or surveillance or monitor* or track* or assess* or detect*) NEAR/3 (sentinel or health*)) or ((prevent* or warn* or prepar* or surveillance or monitor* or track* or assess* or detect* or adapt*) NEAR/3 system*) or (strateg* NEAR/3 (climat* or environment* or adapt*))))))	((((((ecological* adj3 monitor*) or (disease adj2 notification) or ((surveillance or monitor* or track* or assess*) adj3 (population or health* or environment*)) or ((prevent* or warn* or prepar* or surveillance or monitor* or track* or assess* or detect*) adj3 (sentinel or health*)) or ((prevent* or warn* or prepar* or surveillance or monitor* or track* or assess* or detect* or adapt*) adj3 system*) or (strateg* adj3 (climat* or environment* or adapt*)))))).tw.
Human health component	((((((health or wellbeing OR safe* or injur* or illness* or disease* or infect* or "frost bite*" or burn* or wound*)))))	((((((health or wellbeing OR safe* or injur* or illness* or disease* or infect* or frost bite* or burn* or wound*))))).tw.
Geographic focus	(Circumpolar or polar or "arctic Canada" or Canada or Alberta or "British Columbia" or "New Brunswick" or Manitoba or "Newfoundland and Labrador" or "Northwest Territories" or "Nova Scotia" or Nunavut or "Prince Edward Island" or Ontario or Quebec or Saskatchewan or Yukon or Nunavik or Nunatsiavut or Inuvialuit or Norway or Svalbard or Greenland or Denmark or Alaska or "USA" or Russia or Sweden or Finland or Iceland or Scandinavia or "Nordic countr*" or Arctic or North*)	(Circumpolar or polar or arctic Canada or Canada or Alberta or British Columbia or Manitoba or Newfoundland and Labrador or Northwest Territories or Nunavut or Ontario or Quebec or Saskatchewan or Yukon or Nunavik or Nunatsiavut or Inuvialuit or Norway or Svalbard or Greenland or Alaska or Russia or Sweden or Finland or Iceland or Scandinavia or Nordic countr* or Arctic or North*).tw.