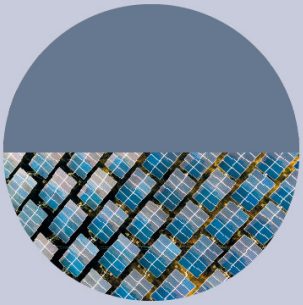
ENVIRONMENTAL RESEARCH
LETTERS

TOPICAL REVIEW • OPEN ACCESS

Community-based monitoring of Indigenous food security in a changing climate: global trends and future directions

To cite this article: Steven Lam *et al* 2019 *Environ. Res. Lett.* **14** 073002



Environmental Research Letters

TOPICAL REVIEW

Community-based monitoring of Indigenous food security in a changing climate: global trends and future directions

Steven Lam[1,7], **Warren Dodd**[2,3,7], **Kelly Skinner**[2], **Andrew Papadopoulos**[1], **Chloe Zivot**[1], **James Ford**[3,4], **Patricia J Garcia**[3,5], **IHACC Research Team**[3] and **Sherilee L Harper**[1,3,6,7]

[1] Department of Population Medicine, University of Guelph, Guelph, Ontario, Canada
[2] School of Public Health and Health Systems, University of Waterloo, Waterloo, Ontario, Canada
[3] Indigenous Health Adaptation to Climate Change (IHACC) Research Team, Alberta, Canada
[4] Priestley International Centre for Climate, University of Leeds, Leeds, United Kingdom
[5] Universidad Peruana Cayetano Heredia, Lima, Peru
[6] School of Public Health, University of Alberta, 11405-87 Ave, Edmonton, Alberta T6G 1C9, Canada
[7] Authors to whom any correspondence should be addressed.

E-mail: lams@uoguelph.ca, wdodd@uwaterloo.ca and sherilee.harper@ualberta.ca

Keywords: community-based monitoring, climate change, adaptation, gender, food security, Indigenous, systematic review methodology

Supplementary material for this article is available online

OPEN ACCESS

RECEIVED
23 August 2018

REVISED
15 February 2019

ACCEPTED FOR PUBLICATION
27 March 2019

PUBLISHED
5 July 2019

Abstract

Climate change is expected to exacerbate existing food security challenges, especially in Indigenous communities worldwide. Community-based monitoring (CBM) is considered a promising strategy to improve monitoring of, and local adaptation to climatic and environmental change. Yet, it is unclear how this approach can be applied in food security or Indigenous contexts. The objectives of this paper are to: (1) review and synthesize the published literature on CBM of Indigenous food security; and, (2) identify gaps and trends in these monitoring efforts in the context of climate change. Using a systematic search and screening process, we identified 86 published articles. To be included, articles had to be published in a journal, describe a CBM system, describe any aspect of food security, and explicitly mention an Indigenous community. Relevant articles were thematically analyzed to characterize elements of CBM in the context of climate change. Results show that the number of articles published over time was steady and increased more than two-fold within the last five years. The reviewed articles reported on monitoring mainly in North America (37%) and South America (28%). In general, monitoring was either collaborative (51%) or externally-driven (37%), and focused primarily on tracking wildlife (29%), followed by natural resources (16%), environmental change (15%), fisheries (13%), climate change (9%), or some combination of these topics (18%). This review provides an evidence-base on the uses, characteristics, and opportunities of CBM, to guide future food security monitoring efforts in the context of climate change.

Introduction

Enhancing the resilience of different food systems to climate change via monitoring is an important global health opportunity of the 21st century [1]. Through routine monitoring and assessments of climate-related risks and their interplay with food security, along with linking early warnings to early responses, food and nutrition crises can be better managed [2, 3]. Such efforts are especially crucial now as climate change increasingly challenges food security[8] [4, 5]. Changes in extreme weather events [6, 7], temperature and rainfall variability [8, 9], and sea level [10], threaten food security by decreasing global food production and increasing the risk of hunger and undernutrition [3, 11]. Projections indicate these food-related health

[8] Food security can be defined as 'a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' [15].

impacts will far exceed all other climate-related health risks [12]. The effects of climate change on food systems are expected to be widespread, complex, and variable, both geographically and temporally [13]. Investing in food systems adaptation to climate change across scales, particularly via monitoring, decreases the risks and uncertainties for food and health systems [14].

The impacts of climate change will not be evenly distributed [16], with Indigenous peoples[9] facing complex challenges to their food systems [17, 18]. Food systems encompass a number of activities which give rise to a number of food security outcomes (i.e. stability of food access, utilization, and availability); we use the term 'Indigenous food systems' to refer to systems of production, process, distribution, and consumption, which are specific to particular geographic regions [19, 20]. Several factors make Indigenous food systems particular sensitive to climate change impacts. These include: histories and ongoing pressures of colonialism and land dispossession that have disconnected Indigenous peoples from their land and local knowledge of food practices [21, 22], high burden of existing food security challenges [18], structural inequities characterized by lack of access to land and other resources [23–25], and habitation in areas undergoing rapid environmental change, biodiversity loss, and competing demands for land for food production [26]. Indeed, Indigenous communities in many countries tend to be more food insecure than their non-Indigenous counterparts [27–29]; for example, Indigenous peoples in the United States including American Indians and Alaska Natives were twice as likely to be food insecure compared to non-Indigenous peoples [30]. Around 97% of Indigenous Batwa households in Uganda were found to be food insecure, which was substantially higher than the national Ugandan average of 20% [31]. Furthermore, Indigenous peoples often have close relationships with the environment for subsistence; as such, even subtle changes in the environment can have large impacts on their food security [32, 33], including reducing access to, and availability of, Indigenous foods [34, 35].

A food security monitoring system can help reduce climate change impacts on vulnerable food systems [37]. The information captured by the monitoring system can be used for several purposes: to contribute to monitoring the implementation of international commitments (e.g. Sustainable Development Goals, United Nations Framework Convention on Climate Change, Paris Agreement); to identify vulnerable areas; to serve as an early warning system for impending food crises [38–40]; and, to inform climate change adaptation[10] strategies [41, 42]. However, such monitoring systems currently face several major challenges. Due to the diverse conceptualizations of food security, measurement tools, and intended uses of information, it is often not clear what exactly is being assessed when we measure food security [43]. Secondly, food security monitoring is typically done through population-based surveys at the national level [2, 40, 44]. These surveys are generally not designed to provide nuanced understandings of food security among populations, do not adequately engage with Indigenous communities [44–46], and are not appropriate for understanding food security of certain population groups [39, 47]. For example, a widely used and adapted income-based measure, the Household Food Security Survey Module does not capture Indigenous food cultures [48, 49]; instead, it presents a static snapshot of food security even though Indigenous food systems vary substantially by household and season [17]. Finally, measures of attributing food security challenges to climate change are not well-developed [50, 51]; thus, it is not clear whether challenges are due to climate change or other factors. Yet, overcoming these challenges is key to understanding current and projected food security and climate-related food shocks [2].

Community-based monitoring (CBM) is often considered a promising strategy to improve monitoring of, and local adaptation to, environmental change [52–54]. CBM is an approach whereby groups collaborate to track and respond to issues of common community concern [52]. This approach can take several forms ranging from community-directed monitoring initiatives originating from communities' interests and needs to initiatives that simply involve communities in data collection [55]. Similarly, the potential benefits of CBM also vary, including: improved understanding of long-term trends; reduced cost of research by leveraging existing infrastructure; skills development and employment opportunities for local monitors; and provision of timely and relevant information for local decision-making [53, 56, 57]. Moreover, as many Indigenous communities have been monitoring the environment for centuries [58, 59], there are opportunities to use both Indigenous and Western knowledge systems in CBM to develop a deeper understanding of pressures on the environment as they arise [60]. CBM can be a key component of community-based adaptation by working with Indigenous communities and knowledge systems to prepare for the food-related health impacts of climate change [61].

[9] Indigenous peoples can be defined as 'the assembly of those who have witnessed, been excluded from, and have survived modernity and imperialism. They are peoples who have experienced the imperialism and colonialism of the modern historical period beginning with the Enlightenment. They remain culturally distinct, some with their native languages and belief systems still alive' [36, p. 114].

[10] Climate change adaptation can be defined as: 'In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects' [131].

Table 1. Search strategy to identify published articles on Indigenous community-based monitoring of Indigenous food security.

Main terms	Expanded terms
Indigenous[a]	Aasax OR Aboriginal OR 'Aboriginal-Malay' OR Aborigine OR […][a]
Monitoring	Surveillance OR tracking OR monitoring OR reporting OR 'information system' OR 'early warning' OR 'early detection' OR 'early notification' OR 'timely warning' OR 'timely detection' OR 'timely notification'
Food security and climate change	Food OR agriculture OR nutrition OR livestock OR fish* OR animal OR plant OR wildlife OR hunt* OR gather* OR environment* OR ecological OR ecosystem OR 'natural resource' OR 'resource management' OR 'co-management' OR 'cooperative management' OR 'joint management' OR water OR sea OR ocean OR 'climate change' OR 'climate variability' OR 'climate hazard' OR 'extreme weather' OR 'natural hazard' OR disaster OR flood OR drought OR hurricane OR storm OR cyclone OR 'sea level rise' OR 'irregular rainfall' OR 'intense rainfall' OR resilience OR poverty OR livelihood OR welfare OR income
Community-based	'Community-based' OR 'community-centred' OR 'community-centered' OR 'community-engaged' OR 'community-led' OR 'locally-based' OR participatory OR collaborative OR 'citizen-led' OR 'citizen-engaged' OR 'citizen-based' OR 'citizen science'

[a] Search terms used to identify Indigenous peoples globally were adapted from Bishop-Williams *et al* 2017 [63]. A shortened list of expanded search terms was provided here, please see supplementary file for the full list of expanded terms.

Considering the promise of CBM, the disproportionate food security challenges experienced by Indigenous communities, and the high sensitivity of Indigenous food systems to climate change, the goal of our review was to understand and learn from how CBM has been used globally to track and respond to Indigenous food security and climate-related food challenges. Specifically, our objectives were to review and synthesize the published literature on CBM of Indigenous food security in a climate change context. In doing so, we accumulate the knowledge and experiences of developing, implementing, and evaluating CBM systems worldwide. Moreover, we highlight how Indigenous food security monitoring is different from general food security monitoring. This is a step toward informing community-based adaptation efforts for addressing food security challenges of Indigenous communities worldwide.

Methods

We examined the published literature using a systematic review methodology for climate change adaptation outlined by Berrang-Ford *et al* (2015) involving a stepwise process of selection, extraction, analysis, and synthesis of the literature [62]. To guide our review and synthesis of trends and gaps, we posed the following question: What does the published literature tell us about Indigenous CBM of food security in the context of climate change?

Search strategy

The initial search for published articles was performed on 5 November 2017 and later updated on 15 March 2018 using the following databases: AGRICOLA©, PRISMA©, MEDLINE®, CabDirect©, and the Web of Science™ CORE Collection (supplementary file is available online at stacks.iop.org/ERL/14/073002/mmedia). These databases cover agriculture, health, sociology, and environmental disciplines, therefore providing the opportunity to capture the broad literature as well as approach the research question from different perspectives. No search restrictions were placed (e.g. language, date). Each database search used Boolean operators to pair keywords (Indigenous, monitoring systems, food security/climate change, community-based) with their synonyms (table 1).

Citation management

All citations were imported into the web-based application DistillerSR© (Evidence Partners Incorporated, Ottawa, ON, Canada). Duplicate citations were removed using the duplicate removal function.

Relevance screening and eligibility

A two-step relevance screening strategy was employed by two independent reviewers (SL, CZ). First, the titles and abstracts of articles were screened. Next, all citations deemed potentially relevant went through a review of the full-text. We included articles that: (1) were published in journals; (2) described a CBM system; (3) described any aspect of food security or food-related climate change impacts; and (4) explicitly mentioned an Indigenous community (table 2). The reference lists of all relevant articles were hand-searched to identify any further relevant studies not captured in the database search. Reviewers met throughout the screening process to resolve conflicts and discuss any uncertainties related to study selection. The degree of agreement between reviewers (i.e. interrater reliability) was assessed using Cohen's kappa at both stages of screening [64].

Data extraction and synthesis

A charting form was developed by the authors to capture both count data and information on the study [65]. Information extracted from the paper included the last name of the first author, year of publication,

Table 2. Inclusion and exclusion criteria to identify published articles on community-based monitoring of Indigenous food security and climate change.

Inclusion	Exclusion
Original research published in a journal	Conference abstracts or proceedings, letters to the editor, reports, news articles, dissertations
Study described community-based monitoring or synonyms (e.g. community-led surveillance)	Community-based research without a monitoring component, monitoring study without community engagement
Study discusses some aspect of food security, drivers of food security (e.g. climate change, poverty), or synonyms (e.g. wildlife, natural resource)	Study did not discuss food security in any way, study discussed climate change with no reference to food security
Study explicitly mentioned an Indigenous community	Studies of Indigenous plants, animals, or knowledge without reference to an Indigenous community, studies of non-Indigenous communities

Table 3. Summary of information extracted from articles on community-based monitoring of Indigenous food security.

Categories	Information extracted
Information on the article	- Last name of the first author - Author affiliation with an Indigenous organization or community (Y/N) - Year of publication
Community-based monitoring characteristics	- Study country - Indigenous community - Methods used - Explicit mention of 'food security' (Y/N) - Discussion on food access, availability, or use - Provided gender-disaggregated data (Y/N) - Themes surrounding gender (e.g. gender perspectives and participation) - Explicit mention of climate change (Y/N) - Explicit mention of Indigenous knowledge and/or traditional knowledge (Y/N)
Community-based monitoring focused on implementation	- Monitoring approach (autonomous, collaborative, consultative, externally-driven) - Evaluation component (Y/N)

and whether an author was affiliated with an Indigenous organization or community (table 3). Descriptions of the CBM system were charted, including the target country, target community, and methods, as well as food security, Indigenous knowledge, climate change, and gender considerations. We counted whether the CBM system explicitly mentioned 'food security' as well as explicitly mentioned one of the food security pillars (e.g. access, availability, utilization, stability) [15]. We also extracted information on the type of food source and driver of food security challenges monitored. We counted whether Indigenous knowledge and climate change were explicitly mentioned. Considering that climate change impacts will not be gender-neutral [17, 66], it is important that responses to climatic stresses not be limited in the agri-food sector by gender-based constraints. As such, we assessed for gender considerations in CBM by adapting questions based on a quantitative tool that supports standardization of sex and gender reporting in publications [67]. We also explored the nature of gender discourse through thematic analysis techniques [68]. Specifically, each of these articles were coded to capture how gender was framed, focusing on gender perspectives and participation. We also categorized the CBM study broadly as having described: (1) the development of the monitoring system; or (2) the implementation/evaluation of the monitoring system. For the latter, we examined each article for evidence to suggest that it could be classified into one of four general CBM categories: autonomous local monitoring; collaborative monitoring; consultative monitoring; and externally driven monitoring [69, 70]. Finally, we characterized these articles as having an evaluation component if they assessed the process/implementation, outcome, or impact of the monitoring system.

Results

Overview of relevant articles

There were 3986 articles identified through the database search (figure 1). After removal of duplicates and non-relevant articles, and the addition of articles from reference lists, a total of 86 articles were included. See supplementary file for the full list of included articles and selected article characteristics. The inter-rater reliability for title/abstract article screening and

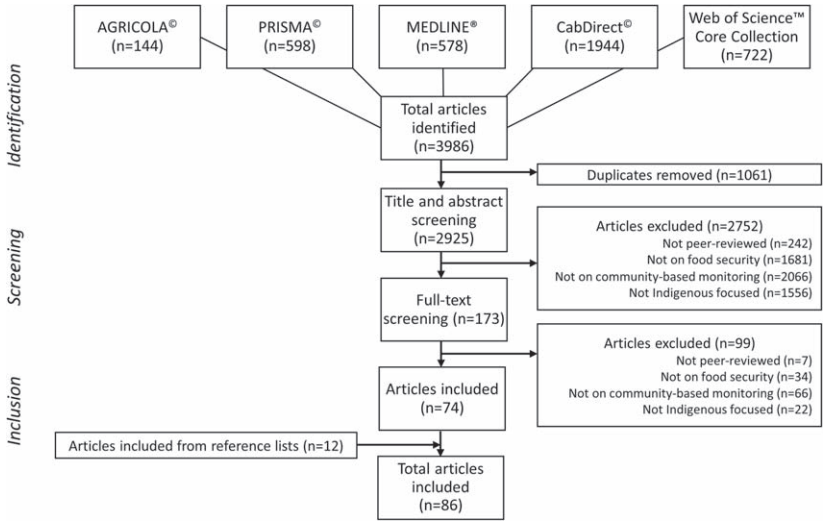


Figure 1. Flow chart of the selection of studies that explored community-based monitoring of Indigenous food security.

full-text article screening was 0.80 and 0.71, respectively, indicating 'substantial agreement' [64].

Diversity of approaches to CBM of Indigenous food security

The reviewed studies used several methodological approaches including quantitative ($n = 8$), qualitative ($n = 13$), mixed methods ($n = 42$), review ($n = 21$), and other ($n = 42$) methodologies[11]. Other methodologies included the use of technology, including GIS mapping, GPS tracking, or use of drones and aerial surveys. Around 42% of articles ($n = 36$) had at least one author with an affiliation to an Indigenous organization or community with no clear trend on Indigenous co-authorship over time. The majority of articles ($n = 74$) explicitly mentioned 'Indigenous knowledge' or 'traditional knowledge' in the context of the study.

Most studies were published in the past decade and were primarily from Canada

Initially, there was a limited the number of articles published following 2001, when articles were first found. The number of publications increased more than two-fold from 2013 onwards. The majority of reviewed articles reported on CBM in North America ($n = 32$), followed by South America ($n = 24$), Australia and Oceania ($n = 11$), Africa ($n = 6$), and Asia ($n = 4$) (figure 2). Several studies were conducted across multiple continents ($n = 9$). Among the 31 studies published in North America, most were from Canada ($n = 28$). There was also a varied distribution of Indigenous group representation, with most studies focused on Indigenous groups in Canada ($n = 28$), specifically First Nations ($n = 12$), Inuit ($n = 10$), and multiple groups ($n = 6$). Studies also focused on Indigenous groups of South America ($n = 25$), specifically multiple groups ($n = 10$), Kaxinawa ($n = 3$), Isoseno-Guarani ($n = 3$), Waiwai ($n = 1$), Xerente ($n = 1$), Makushi ($n = 1$), Matsigenka ($n = 1$), Kitchwa ($n = 2$), Purepecha ($n = 1$), Andean ($n = 1$), and Amerindian ($n = 1$). There were some articles on multiple groups from different continents ($n = 9$), Indigenous groups of Oceania ($n = 11$), Indigenous groups of Africa ($n = 6$), Indigenous groups of Asia ($n = 4$), and Native Americans ($n = 3$).

Wildlife was a prominent type of food monitored

A wide variety of food sources were monitored, including wildlife ($n = 25$), natural resources ($n = 14$), and fisheries ($n = 11$). Drivers of food security were also explored, including environmental change ($n = 13$) and climate change ($n = 8$). Several articles explored a combination of food sources and food security drivers ($n = 15$). The term 'food security' was explicitly mentioned in 33 articles (38%), while the specific food security pillars reported included food availability ($n = 16$), food access ($n = 11$), and food utilization ($n = 6$), or some combination of these pillars ($n = 17$). No articles explored food stability.

More articles focused on men's participation in monitoring

A total of 29 articles (34%) provided gender-disaggregated data. Although 2017 had the highest proportion of articles that provided gender-disaggregated data, there was no distinguishable trend suggesting an increase or decrease in active gender considerations over time. For articles that provided gender-disaggregated data and described the development of the monitoring system ($n = 14$), all articles considered perspectives of both men and women. The importance of considering the perspectives of women was

[11] Numbers do not add up to 86 studies as more than one approach was used in some studies.

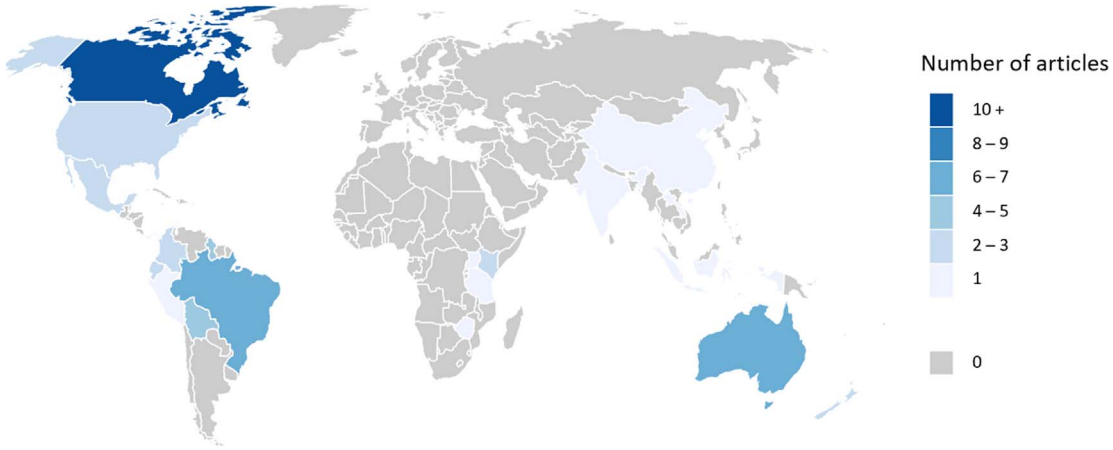


Figure 2. Geographic distribution of articles on community-based monitoring of Indigenous food security.

emphasized in a study in Nunavik, Canada, aimed to understand Elders' and hunters' observations and knowledge: 'Women were included upon the recommendation of their expert knowledge of ice conditions or their frequency of travel' [71, p. 30]. For the articles that provided gender-disaggregated data and described the implementation of the monitoring system ($n = 15$), all articles mentioned the participation of men, while some of these articles ($n = 9$) also mentioned the participation of women. One article actively encouraged the participation of women in monitoring 'as a way to acknowledge internally marginalized groups and alleviate social inequality' [72, p. 22]. Although some studies aimed to include equal participation of men and women, they noted that participants tended to be men [71, 73, 74].

Climate change indicators were rarely assessed in CBM

More than half (56%) of studies ($n = 48$) explicitly mentioned climate change in the context of food security (figure 3). There was no clear trend over time to suggest a general movement towards increasing consideration of climate change in articles. While the majority of articles mentioned climate change as justification for pursuing CBM, a limited number of articles ($n = 8$) described the implementation/evaluation of a community-based food security monitoring system including climate change indicators. The studies that did consider climate change were mostly situated in Arctic regions [71, 75–78]; for example, a study in Alaska employed a participatory CBM system to explore environmental conditions likely associated with climate change, health, and food security outcomes [76]. In another study, an integrated CBM system in Nunavik, Canada tracked climatic and ice conditions to support safe access to land and other resources [71].

Varying degrees of Indigenous community engagement in monitoring

Of the 86 included articles, 37 articles (43%) described work that recommended or informed the development of CBM approaches. For example, Wesche *et al* (2011) stated that their research project 'led to the process of establishing a community-based environmental monitoring program' [75, p. 403]. Most articles ($n = 49$) described the implementation of an existing CBM system. Among these 49 articles, we documented whether the authors evaluated the monitoring system. We found that less than half of articles ($n = 22$) reported an evaluation process or outcome [79–81]. These 49 articles were also classified according to the type of CBM approach adopted (table 4). No clear trend on the type of monitoring approach over time was discernable.

Only one article reporting on autonomous local monitoring was identified [82]. The objective of this article was to highlight the existence of local monitoring practices based on observations in three communities in Papua, Indonesia [82]. The authors found that communities would monitor and control their environment and resources, and found evidence of autonomous monitoring activities in each of the three communities.

More than half of the reviewed articles (51%) were classified as collaborative monitoring. This approach encouraged project co-creation, transfer of ownership, and knowledge sharing with community members. An example of this approach was illustrated by Cummings *et al* (2017). The authors described steps taken to introduce drones in two Indigenous villages in Southern Guyana and portrayed the extent of community engagement through the following statement: 'When the participants collect data on their missions, they have the first access to these, and can decide whether to share the data with the non-indigenous [*sic*] project team members' [92, p. 13]. In another example, the authors described: 'A CyberTracker was

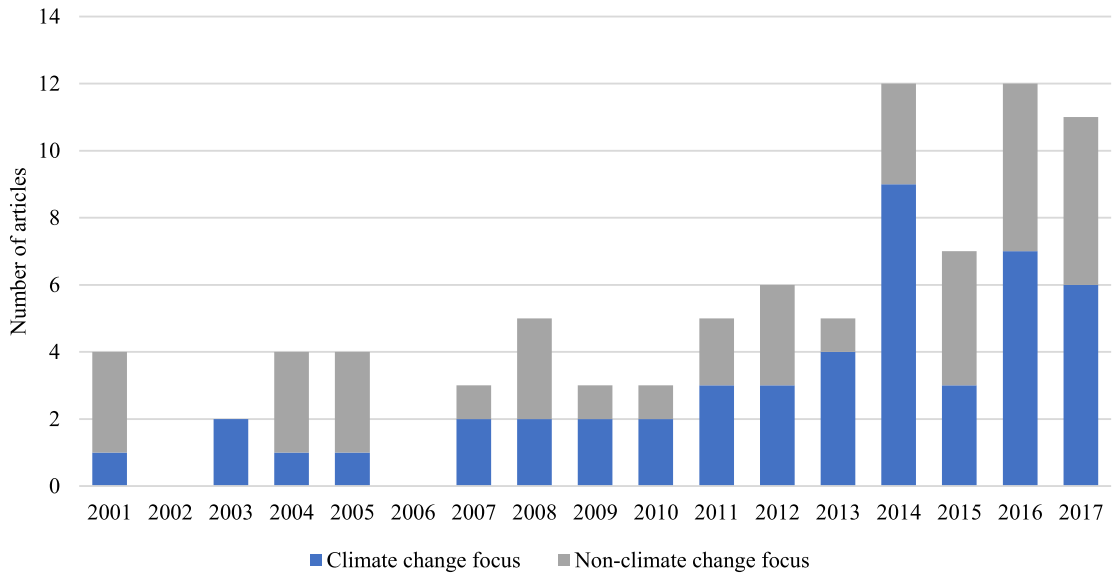


Figure 3. Articles on community-based monitoring of Indigenous food security with and without climate change considerations, over time.

Table 4. Types of community-based monitoring approaches described in articles that reported the implementation of a monitoring system (adapted primarily from Kouril *et al* 2015, Danielsen *et al* 2009).

Category	Characteristics	Number of articles	Example references
Autonomous local monitoring	Community members are involved in the whole monitoring process and make all decisions	1	[82]
Collaborative monitoring	Community members are involved in data collection, analysis, and interpretation; researchers and community members make decisions together	25	[71, 83–86]
Consultative monitoring	Community members are involved in data collection and are c onsulted; researchers make decisions	5	[87–89]
Externally driven monitoring	Community members are involved only in data collection or as research assistants, researchers make all decisions	18	[76, 90, 91]

developed and used by the Naskapi Nation to verify forest-dwelling caribou presence in collaboration with New Millennium Capital Corporation' [93, p. 39].

Compared to the other monitoring approaches discussed by articles, a relatively low number of articles describing consultative monitoring were identified (10%). This CBM approach involved some degree of decision-making by the community. An example of this approach was described by Shaffer *et al* (2017) where the authors 'established a hunter self-monitoring program in consultation with the Waiwai in July of 2014' [87, p. 1121]. In the context of participatory monitoring in the Amazon, the authors 'provided technical support for the development of a hunting monitoring system aimed at informing adaptive management processes for sustainability' [88, p. 55]. In both cases, community members were involved in identifying monitoring goals and collecting data, while analysis was performed entirely by the researchers.

The proportion of publications classified as externally driven monitoring schemes was 37%. This CBM approach involved community members only in data collection with no decision-making by community members. For example, in one study: 'All of the data in the study were collected by locally recruited and trained indigenous [*sic*] technicians and most of the data-collection process was established *a priori*, without local input' [90, p. 771]. The same authors also emphasized the importance of knowledge sharing back to the community: 'However, we sought substantial input regarding the format and content of research results to be returned to collaborating communities' (p. 772). In another study categorized as externally-driven, hunters were invited to participate on a voluntary basis, and those who accepted were trained to fill monitoring data sheets [91].

Discussion

This paper systematically examines trends in peer-reviewed publications on CBM. We found the number of articles on CBM of Indigenous food security were limited but growing. Since 2013, there has been an

increase in the number of publications on this topic by more than two-fold. This trend is consistent with previous studies on broader environmental CBM [52, 69] and reflects the need to include different sources of knowledge and different knowledge users in monitoring efforts, instead of conventional monitoring approaches which are typically externally driven [55, 94]. Furthermore, the increasing interest in CBM is part of a broader trend around the need to address the disproportionate food security and climate change impacts often experienced by Indigenous communities globally [18, 27–29]. The articles captured in this review mainly reported on CBM in North America, and specifically Canada. This finding could be explained by the current and projected severity of climate change impacts in the Arctic (such as Arctic Canada) compared to the rest of world [95], and the need to understand and address such impacts through CBM. Indeed, there has been a significant growth in research on, and funding for climate change in Canada's North [33]. This geographic distribution of articles also highlights gaps in CBM research in many regions where community-level vulnerability is thought to be significant, particularly in low- and middle-income regions such as Africa and Asia. Gaps could point to a lack of resources or priority for CBM research in these regions; however, it is possible that CBM is occurring in these regions, but do not engage with Indigenous communities specifically, nor include research components to CBM, and thus may not be documented in published journals. Nevertheless, climate change impacts on Indigenous food systems is a global phenomenon [17], and this review highlights potential gaps where CBM could be further developed and implemented.

Approximately one third of the reviewed articles provided gender-disaggregated data; this research gap results in an incomplete understanding of how Indigenous women, men, and gender-diverse people may differentially participate in, and experience CBM. We encourage authors and journal editors to integrate assessment of gender into all manuscripts [67]. Among the articles that provided gender-disaggregated data, all articles highlighted the perspectives of both women and men in the design of the monitoring system. When examining the implementation of the monitoring system, articles generally emphasized participation of men only or both men and women. The quality of participation or reasons for participation were unclear due to lack of reporting in these articles; however, the predominant focus on men in monitoring efforts could be due to the role of many Indigenous men in hunting, fishing, and natural resource management in several contexts [85, 87, 91]. Challenges to women's participation in, and benefit from, monitoring efforts could be due to failure to recognize and address gendered power imbalances in project objectives or inadequate considerations of gender in the program design [96, 97]. A better understanding of the gendered nature of CBM, as well as the relationship between climate, food, and gender, are important for planning and designing a CBM system that reflect gender equity. Critically, an examination of the underlying social-cultural-political processes that determine differential gender exposure and sensitivity to climate change and adaptive capacity, as well as gender equity in monitoring is recommended [98].

Considering the history of unethical research conducted on and not with Indigenous communities [99, 100], there is increasing demand for the recognition of Indigenous peoples' contributions and knowledge in the context of research [101], including climate change research [102, 103]. Prioritizing collaborative publications is an emerging avenue for acknowledging Indigenous peoples' contributions to research [104]. While Indigenous peoples' observations of climate change are increasingly reported in the published literature [105], we found the inclusion of Indigenous peoples as co-authors did not appear to follow the same trend. We found less than half (42%) of reviewed articles on CBM had a co-author with an affiliation to an Indigenous organization or community. If a monitoring system is community-led and community-based, there is a need to consider whether co-authorship is appropriate, recognizing that some community members may request not to be authors for a variety of reasons. Nevertheless, steps need to be taken to avoid risks including tokenistic inclusion, implied support for findings, and misappropriation of knowledge [104, 106]. Multiple evidence-based (MEB) approaches offer a way forward for Indigenous and non-Indigenous collaborators to work together in developing CBM systems that respects and reflects different contributions [107]. MEB approaches view Indigenous, local, and scientific knowledge systems as generating different manifestations of knowledge, that when viewed as complementary, can generate new insights to support decision-making and action [59]. MEB approaches are recognized under the Convention for Biodiversity as a way of ensuring equitable participation of diverse knowledge systems in monitoring biodiversity targets [59], as well as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services to enhance understanding of governance of biodiversity and ecosystems [108]. The Paris Agreement article 7.5 also supports MEB approaches by acknowledging adaptation action 'should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous [*sic*] peoples and local knowledge systems, with a view to integrating adaptation into relevant socio-economic and environmental policies and actions, where appropriate' [109, p. 25].

Variations in the level of Indigenous community engagement in CBM were observed. Articles on CBM of Indigenous food security were mostly classified as either collaborative monitoring (51%) or externally

driven monitoring (37%). This finding is consistent with a review of environmental CBM in the Arctic region which found that 47% of systems involved community members in collaboration while 30% involved community members in data collection only [53]. The higher number of articles describing collaborative monitoring could be explained by the broader trend of engaging Indigenous communities in research and monitoring practices, whereas externally-driven monitoring is likely influenced by conventional, government or researcher implemented monitoring approaches [110], as well as requests by Indigenous communities for external monitoring support [53, 94]. However, successful CBM generally occurs when communities monitor things they personally connect with and care about, rather than for externally-driven needs [111, 112]. Moreover, in the context of climate research, studies initiated with and by Indigenous community members tend to indicate more responsible community engagement than studies initiative by outside researchers alone [113]. Community engagement is also important for generating local ownership and understandings of environmental change, and to facilitate the development of local climate change adaptation responses [114].

We reviewed the articles that described the implementation of CBM and found less than half of these articles reported evaluation findings. The limited focus on evaluation could be explained by challenges of evaluating climate change adaptation programs and policies including assessing attribution, creating baselines, absence of measurable outcomes, and monitoring over long time horizons [51, 115]. Climate change adaptation is also a relatively new field with little consensus on what constitutes effective adaptation, and how the success of adaptation efforts should best be measured [116]. Nevertheless, in the context of CBM, it is important that communities and researchers work together towards a consensus to ensure that CBM is translated into responses to address climate change impacts and enhance food systems resilience. Evaluations of CBM can also help identify monitoring gaps, inform governance systems on monitoring progress, and justify continued support for CBM [117, 118]. Moreover, a better understanding of CBM processes and outcomes can serve to develop an evidence base that will inform future climate change adaptation efforts [119].

Only one formal autonomous monitoring scheme was reported in the published literature [82]. This finding is consistent with a recent review of environmental CBM approaches which found no formal autonomous monitoring schemes [69]. It is likely that monitoring is carried out without documentation in the published literature, as many Indigenous communities often monitor environmental changes and the health of their land [53]. Further, communities participating in monitoring may not be interested in research related to CBM nor publishing in the literature, but instead interested in mobilizing CBM to support local decision-making [69]. There may also be challenges in understanding autonomous monitoring stemming from disciplinary obstacles and difficulties describing and characterizing such systems [82, 120]. Nevertheless, greater research attention to autonomous climate change monitoring and adaptation—case studies outlining the process and outcomes of such activities—could provide important insights to inform climate change adaptation strategies along with a strong foundation for further documentation of CBM efforts [82].

Four pillars are often referred to when explaining the concept of food security: availability, access, utilization, and stability [15]. For most of articles on CBM of Indigenous food security reviewed in this paper the specific pillar of food security was not explicitly mentioned, and food stability was not mentioned at all. The absence of focus on specific food security pillars could be due to articles focusing on proxies or indicators of food security (e.g. wildlife, climate change). Moreover, the objectives of CBM may be to address conservation or natural resource management goals rather than addressing food security challenges directly [52, 84, 85, 121]. This finding highlights the need to clarify what is being assessed when food security is being monitored (e.g. which food security pillar is being addressed), so that monitoring approaches can be coordinated and allow comparisons to be made across studies and contexts. Where the food security pillar was specified, we found that CBM typically focuses on food availability and access, consistent with studies on impacts of climate change on food security [11, 122]. Less is known about the role of climate change on food stability and utilization. Considering and specifying broader determinants of food security in monitoring systems, together with climate change indicators (e.g. seasonality, rain variability), could support more accurate, transparent, and consistent monitoring of food system resilience to climate change.

Conventional food security monitoring tends to fail to probe for information that may be relevant to Indigenous food security, such as the status of Indigenous food systems or environmental change [2, 38, 39]. This review found articles focused on food security themes that extended beyond common metrics of food security (e.g. market foods, poverty) including wildlife, natural resources, environmental change, and fisheries. However, not all aspects of food security considered important to Indigenous peoples were captured in CBM systems such as land and knowledge of local food practices [21, 22]. This review, then, begs the following questions: who is CBM of Indigenous food security serving? Does a conventional definition of food security (i.e. four pillars including availability, access, utilization, and stability) adequately capture the dynamic nature of Indigenous food systems? If a conventional definition of food

security is used to guide the development of a CBM system with Indigenous communities, does this definition lead to the creation of systems that overlook critical components of Indigenous food systems? We encourage researchers to grapple with these questions when developing food security monitoring systems with Indigenous communities. Where food security was defined broadly, we argue that definitions and metrics should consider components highlighted above that are important for Indigenous communities. Furthermore, given the diverse Indigenous groups, food systems, and food practices, it is necessary to incorporate race, ethnicity, and culture when exploring food security [123]. Indeed, Indigenous food security can be better understood by considering the social and economic benefits that Indigenous food systems provide [124]. The importance of monitoring Indigenous food security, and having an inclusive definition of food security, is only increasing given the current and projected changes in climate and its disproportionate impact on Indigenous food systems [35]. Supporting Indigenous communities in defining and monitoring food security, and linking monitoring responses to decision-making and action, will be crucial for community-based adaptation.

Climate change was explicitly mentioned in more than half of the reviewed articles with climatic indicators explored in only a few articles. The limited consideration of climatic indicators could be explained by the lack of consensus on how food systems resilience to climate change should be assessed [125, 126]. Food system resilience can be defined as the 'capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances' [127, p. 19]. Measuring resilience in this context is challenging because the concept of food system resilience has not been well defined for climate change [128] and the links between resilience of food systems and climate change are not straight forward [125]. Moreover, limited conceptual tools and frameworks are available to guide such assessments [128, 129]. However, many Indigenous communities have knowledge of climate and weather, and have developed adaptation strategies for ensuring food security. For example, Indigenous knowledge systems such as sky and astronomical observations, animal behaviours, and wind direction played a key role in determining when farmers prepare the fields and the nature of crops they plant in a particular season [130]. As such, incorporating Indigenous knowledge in the design of food security and climate change metrics could help improve our understanding of how climate change impacts on food systems can be assessed over time.

Our review and synthesis highlight examples of how CBM is being used worldwide to address food-related climate change impacts. The analysis of trends shows a growing interest in CBM over time, with steady interest in considerations of climate change. The gaps identified in this study might be useful for communities, researchers, and decision-makers in developing, refining, or evaluating similar monitoring efforts. While our paper is comprehensive and systematic, we note several important limitations. First, to examine *research* that has been conducted on CBM, we included only published articles. We acknowledge that a substantial body of work may be found in the grey literature [69]. Analyzing the grey literature is recommended for future research to better understand the full spectrum of CBM *practice* occurring within Indigenous communities, especially of autonomous monitoring systems which may be investigated or evaluated outside of research and the published literature. Secondly, the categorization of the monitoring approach of articles, along with considerations of gender, were based on the information presented in each article. We acknowledge the articles themselves may not fully elaborate on the extent to which community engagement was considered. Greater elaboration on these processes of community engagement in articles will benefit knowledge sharing among Indigenous and scholarly communities. Finally, reporting and synthesizing evaluative findings can provide further insights into the effectiveness, impact, and sustainability of CBM systems. Overall, this study provides important insights into the trends and future directions in CBM of Indigenous food security based on experiences from around the world and as reported in the published literature.

Conclusion

The monitoring of food security with, for, and by Indigenous communities is a growing area of research and practice. This trend follows the recent global trend of engaging Indigenous communities, integrating diverse sources of knowledge, and addressing the disproportionate food security and climate change challenges experienced by Indigenous communities. The reviewed articles highlight the importance of considering indicators of wildlife and environmental change in food security monitoring systems, considerations that are typically excluded in conventional food security monitoring efforts. While many articles acknowledged the impact of climate change on food security, few articles explicitly explored climatic indicators. This finding is reflective of the limited understanding of how food systems resilience to climate change should be assessed. We also found many examples of collaborative CBM but limited examples of autonomous CBM. Exploring these trends highlight key research opportunities for supporting monitoring and adaptation of food systems. First, we encourage articles to reflect and report on the processes and outcomes of CBM. Furthermore, the development and inclusion of food security and climate change

metrics in CBM are also recommended. Finally, a greater attention to autonomous monitoring and adaptation could help inform more effective responses to climate change. When viewed as a whole, our findings provide an evidence-base of research on CBM worldwide to address Indigenous food security challenges, serving as a resource to inform future community-based adaptation efforts.

Acknowledgments

Funding contributions were provided by the Graduate Student Excellence Entrance Scholarship (to SL), the Ontario Veterinary College PhD Scholarship (to SL), the Canadian Institutes of Health Research (CIHR), and the Network of Centres of Excellence of Canada (ArcticNet). Thank you to Hannah Tait Neufeld and Erin Nelson for helpful feedback on earlier drafts.

Author contributions

SL led all stages of the review including developing the research question; designing the search strategy; extracting, analyzing, and interpreting the data; and writing the paper. WD and SLH supervised and contributed to all stages of the review. KS, AP, JF and PJG contributed to data interpretation and manuscript editing. CZ contributed as a secondary reviewer and to the design of the screening tool. The IHACC Research Team contributed to the conceptualization and development of the broader research questions and contributed to manuscript editing. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

ORCID iDs

Steven Lam https://orcid.org/0000-0001-7279-6165
Warren Dodd https://orcid.org/0000-0003-0774-7644
Kelly Skinner https://orcid.org/0000-0003-0989-8841
Sherilee L Harper https://orcid.org/0000-0001-7298-8765

References

[1] Watts N *et al* 2017 The lancet countdown: tracking progress on health and climate change *Lancet* **389** 1151–64
[2] World Food Programme 2018 Food Security Monitoring Systems Technical Guidance Sheet (Rome: WFP)
[3] Lake I R *et al* 2012 Climate change and food security: health impacts in developed countries *Environ. Health Perspect.* **120** 1520–6
[4] Wheeler T and von Braun J 2013 Climate change impacts on global food security *Science* **341** 508–13
[5] Tai A P K, Martin M V and Heald C L 2014 Threat to future global food security from climate change and ozone air pollution *Nat. Clim. Change* **4** 817–21
[6] Gbegbelegbe S, Chung U, Shiferaw B, Msangi S and Tesfaye K 2014 Quantifying the impact of weather extremes on global food security: a spatial bio-economic approach *Weather Clim. Extrem.* **4** 96–108
[7] Devereux S 2007 The impact of droughts and floods on food security and policy options to alleviate negative effects *Agric. Econ.* **37** 47–58
[8] Niles M T and Brown M E 2017 A multi-country assessment of factors related to smallholder food security in varying rainfall conditions *Sci. Rep.* **7** 16277
[9] Myers S S *et al* 2017 Climate change and global food systems: potential impacts on food security and undernutrition *Annu. Rev. Public Health* **38** 259–77
[10] Chen C C, McCarl B and Chang C C 2012 Climate change, sea level rise and rice: global market implications *Clim. Change* **110** 543–60
[11] Schmidhuber J and Tubiello F N 2007 Global food security under climate change *Proc. Natl Acad. Sci. USA* **104** 19703–8
[12] Hales S, Kovats S, Lloyd S and Campbell-Lendrum D 2014 Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s (Geneva: WHO)
[13] Vermeulen S J, Campbell B M and Ingram J S I 2012 Climate change and food systems *Annu. Rev. Environ. Resour.* **37** 195–222
[14] Conevska A, Ford J, Lesnikowski A and Harper S 2018 Adaptation financing for projects focused on food systems through the UNFCCC *Clim. Policy* **19** 1–16
[15] FAO 2001 *The State of Food Insecurity in the World 2001* (Rome: FAO)
[16] Dennig F, Budolfson M B, Fleurbaey M, Siebert A and Socolow R H 2015 Inequality, climate impacts on the future poor, and carbon prices *Proc. Natl Acad. Sci* **112** 15827–32
[17] FAO 2013 Indigenous Peoples' food systems & well-being: Interventions & policies for healthy communities (Rome: FAO)
[18] Ford J D 2012 Indigenous health and climate change *Am. J. Public Health* **102** 1260–6
[19] Keleman Saxena A, Cadima Fuentes X, Gonzales Herbas R and Humphries D L 2016 Indigenous food systems and climate change: impacts of climatic shifts on the production and processing of native and traditional crops in the Bolivian Andes *Frontiers Public Health* **4**
[20] FAO 2019 INDIGENOUS PEOPLES' FOOD SYSTEMS: the many dimensions of culture, diversity and environment for nutrition and health (Rome: FAO)
[21] Reading C L and Wein F 2009 1–47 Health inequalities and social determinants of Aboriginal people's health (Prince George, BC: National Collaborating Centre for Aboriginal Health)(http://nccah-ccnsa.ca/docs/social%20determinates/nccah-loppie-wien_report.pdf)
[22] Coté C 2016 'Indigenizing' food sovereignty. Revitalizing indigenous food practices and ecological knowledges in Canada and the United States *Humanities* **5** 57
[23] Skinner K, Hanning R M, Desjardins E and Tsuji L J S 2013 Giving voice to food insecurity in a remote indigenous community in subarctic Ontario, Canada: traditional ways, ways to cope, ways forward *BMC Public Health* **13** 427
[24] Elliott B, Jayatilaka D, Brown C, Varley L and Corbett K K 2012 'We are not being heard': aboriginal perspectives on traditional foods access and food security *J. Environ. Public Health* **2012** 130945
[25] Richmond C A M and Ross N A 2009 The determinants of first nation and inuit health: a critical population health approach *Health Place* **15** 403–11
[26] Lemke S and Delormier T 2017 Indigenous peoples' food systems, nutrition, and gender: conceptual and methodological considerations *Maternal Child Nutr.* **13** 12499

[27] Hoover E et al 2015 Indigenous peoples of north America : environmental exposures and reproductive justice *Environ. Health Perspect.* **120** 1645–9
[28] Ford J D, Macdonald J P, Huet C, Statham S and MacRury A 2016 Food policy in the Canadian North: is there a role for country food markets? *Soc. Sci. Med.* **152** 35–40
[29] Council of Canadian Academies 2014 Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge (Ottawa: CCA)
[30] Jernigan V B B, Huyser K R, Valdes J and Simonds V W 2017 Food insecurity among american indians and alaska natives: a national profile using the current population survey–food security supplement *J. Hunger Environ. Nutr.* **12** 1–10
[31] Patterson K et al 2017 Seasonal variation of food security among the Batwa of Kanungu, Uganda *Public Health Nutr.* **20** 1–11
[32] Barber M, Jackson S, Dambacher J and Finn M 2015 The persistence of subsistence: qualitative social-ecological modeling of indigenous aquatic hunting and gathering in tropical Australia *Ecol Soc.* **20** 60
[33] Furgal C and Seguin J 2006 Climate change, health, and vulnerability in Canadian northern aboriginal communities *Environ. Health Perspect.* **114** 1964–70
[34] Lynn K et al 2013 The impacts of climate change on tribal traditional foods *Clim. Change* **120** 545–56
[35] Furgal C and Seguin J 2006 Climate change, health, and vulnerability in Canadian northern aboriginal communities *Environ. Health Perspect.* **114** 1964–70
[36] Smith L T 2005 On tricky ground: Researching the native in the age of uncertainty *The SAGE Handbook of Qualitative Research* 3rd edn (Thousand Oaks, CA: Sage) pp 85–107
[37] Beddington J R et al 2012 The role for scientists in tackling food insecurity and climate change *Agric Food Secur.* **1** 10
[38] FAO, IFAD, WFP 2016 *Monitoring Food Security and Nutrition in Support of the 2030 Agenda for Sustainable Development: Taking Stock and Looking Ahead* (Rome: FAO, IFAD, WFP)
[39] Babu S C 2015 Evidence-informed policymaking: lessons from food security and nutrition monitoring systems during food crises ed D E Sahn *The Fight Against Hunger and Malnutrition: The Role of Food, Agriculture, and Targeted Policies* (Oxford: Oxford University Press)
[40] World Health Organization 2013 Food and nutrition surveillance systems: technical guide for the development of a food and nutrition surveillance system (Geneva: WHO)
[41] Canadian Polar Comission 2015 State of Environmental Monitoring in Northern Canada (Ottawa: Canadian Polar Commission)
[42] High Level Task Force on the Global Food Security Crisis 2010 Updated Comprehensive Framework for Action (Rome: FAO)
[43] Jones A D, Ngure F M, Pelto G and Young S L 2013 What are we assessing when we measure food security? A compendium and review of current metrics *Adv. Nutr. Int. Rev. J.* **4** 481–505
[44] Ford J D, Berrang-Ford L, King M and Furgal C 2010 Vulnerability of aboriginal health systems in Canada to climate change *Glob. Environ. Change* **20** 668–80
[45] Smylie J, Anderson I, Ratima M, Crengle S and Anderson M 2006 Indigenous health performance measurement systems in Canada, Australia, and New Zealand *Lancet* **367** 2029–31
[46] Anderson M J and Smylie J K 2009 Health systems performance measurement systems in canada: how well do they perform in first nations, inuit, and métis contexts? *Pimatisiwin* **7** 99–115
[47] Bilukha O, Prudhon C, Moloney G, Hailey P and Doledec D 2012 Measuring anthropometric indicators through nutrition surveillance in humanitarian settings: options, issues, and ways forward *Food Nutr. Bull.* **33** 169–76
[48] Statistics NC for H 2008 US Household Food Security Survey Module: Six-Item Short Form (https://www.ers.usda.gov/media/8282/short2012.pdf)
[49] Bickel G, Nord M, Price C, Hamilton W and Cook J 2000 *Guide to Measuring Household food Security* (Alexandria, VA: USDA)
[50] Ebi K L and Del Barrio M O 2017 Lessons learned on health adaptation to climate variability and change: experiences across low- and middle-income countries *Environ. Health Perspect.* **125** 065001
[51] Ford J D, Berrang-Ford L, Lesnikowski A, Barrera M and Jody Heymann S 2013 How to track adaptation to climate change: a typology of approaches for national-level application *Ecol. Soc.* **18** 40
[52] Pollock R M and Whitelaw G S 2005 Community-based monitoring in support of local sustainability *Local Environ.* **10** 211–28
[53] Johnson N, Behe C, Danielsen F, Nickels S and Pulsifer P L Community-based monitoring and indigenous knowledge in a changing Arctic (Ottawa: Inuit Circumpolar Council)
[54] Kipp A, Cunsolo A, Gillis D, Sawatzky A and Harper S 2018 The need for community-led, integrated, and innovative monitoring programs when responding to the health impacts of climate change *Int. J. Circumpolar Health* **78** 1517581
[55] Danielsen F et al 2005 Does monitoring matter? A quantitative assessment of management decisions from locally-based monitoring of protected areas *Biodivers. Conserv.* **14** 2633–52
[56] Berner J, Brubaker M, Revitch B, Kreummel E, Tcheripanoff M and Bell J 2016 Adaptation in Arctic circumpolar communities: food and water security in a changing climate *Int. J. Circumpolar Health* **75** 33820
[57] Danielsen F et al 2014 Counting what counts: using local knowledge to improve arctic resource management *Polar Geogr.* **37** 69–91
[58] Farhan Ferrari M, de Jong C and Belohrad V S 2015 Community-based monitoring and information systems (CBMIS) in the context of the convention on biological diversity (CBD) *Biodiversity* **16** 57–67
[59] Tengö M et al 2017 Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability *Curr. Opin. Environ. Sustain.* **26–27** 17–25
[60] Johnson N et al 2015 The contributions of community-based monitoring and traditional knowledge to arctic observing networks: reflections on the state of the field *Arctic* **68** 1–13
[61] Ebi K and Semenza J C 2008 Community-based adaptation to the health impacts of climate change *Am. J. Prev. Med.* **35** SP-501–7
[62] Berrang-Ford L, Pearce T and Ford J D 2015 Systematic review approaches for climate change adaptation research *Reg. Environ. Change* **15** 755–69
[63] Bishop-Williams K, Sargeant J M, Berrang-Ford L, Edge V, IHACC Research Team, Harper S L 2017 A protocol for a systematic narrative synthesis review: the global impact of environment on acute respiratory infections in Indigenous populations *BMC Syst. Rev.* **6** 19
[64] Landis J R and Koch G G 1977 The measurement of observer agreement for categorical data *Biometrics* **33** 159–74
[65] Levac D, Colquhoun H and O'Brien K K 2010 Scoping studies: advancing the methodology *Implement Sci.* **5** 69
[66] Habtezion S 2012 *Gender, Climate Change and Food Security* (New York: UNDP)
[67] Heidari S, Babor T F, De Castro P, Tort S and Curno M 2018 Sex and gender equity in research: rationale for the SAGER guidelines and recommended use *Res. Integr. Peer Rev.* **1** 2
[68] Braun V and Clarke V 2006 Using thematic analysis in psychology using thematic analysis in psychology *Qual. Res. Psychol.* **3** 77–101
[69] Kouril D, Furgal C and Whillans T 2016 Trends and key elements in community-based monitoring: a systematic review of the literature with an emphasis on Arctic and Subarctic regions *Environ. Rev.* **24** 151–63
[70] Danielsen F et al 2009 Local participation in natural resource monitoring: a characterization of approaches *Conserv. Biol.* **23** 31–42

[71] Tremblay M et al 2008 Climate change in northern quebec: adaptation strategies from community-based research Arctic 61 27–34
[72] Constantino P D A L et al 2012 Empowering local people through community-based resource monitoring: a comparison of Brazil and Namibia Ecol. Soc. 17 22
[73] Parlee B L, Goddard E, First Nation ŁKD, Smith M 2014 tracking change: traditional knowledge and monitoring of wildlife health in Northern Canada Human Dimens. Wildl. 19 47–61
[74] Setty R S, Bawa K, Ticktin T and Gowda C M 2008 Evaluation of a participatory resource monitoring system for nontimber forest products: the case of Amla (Phyllanthus spp.) fruit harvest by Soligas in South India Ecol. Soc. 13 19
[75] Wesche S et al 2011 Community-based health research led by the Vuntut Gwitchin first nation Int. J. Circumpolar Health 70 396–406
[76] Driscoll D L, Mitchell E, Barker R, Johnston J M and Renes S 2016 Assessing the health effects of climate change in Alaska with community-based surveillance Clim. Change 137 455–66
[77] Driscoll D L, Sunbury T, Johnston J and Renes S 2013 Initial findings from the implementation of a community-based sentinel surveillance system to assess the health effects of climate change in Alaska Circumpolar Health Suppl. 72 946–54
[78] McClymont Peace D and Myers E 2012 Community-based participatory process—climate change and health adaptation program for Northern first nations and inuit in Canada Int. J. Circumpolar Health 71 1–8
[79] Ens E J, Towler G M and Daniels C 2012 Looking back to move forward: collaborative ecological monitoring in remote Arnhem land Ecol. Manage. Restor. 13 26–35
[80] Kofinas G, Lyver P O B, Russell D, White R, Nelson A and Flanders N 2003 Towards a protocol for community monitoring of caribou body condition Rangifer 23 29–38
[81] Oviedo A F P and Bursztyn M 2017 Community-based monitoring of small-scale fisheries with digital devices in Brazilian Amazon Fish Manage. Ecol. 24 320–9
[82] Sheil D, Boissière M and Beaudoin G 2015 Unseen sentinels: local monitoring and control in conservation's blind spots Ecol. Soc. 20 39
[83] Mateo-Vega J et al 2017 Full and effective participation of indigenous peoples in forest monitoring for reducing emissions from deforestation and forest degradation (REDD+): trial in Panama's Darién Ecosphere 8 e01635
[84] Gill H and Lantz T 2014 A Community-based approach to mapping gwich'in observations of environmental changes in the lower peel river watershed, NT J. Ethnobiol. 34 294–314
[85] Constantino P de AL et al 2008 Indigenous collaborative research for wildlife management in Amazonia: the case of the Kaxinawá, Acre, Brazil Biol. Conserv. 141 2718–29
[86] Brook R K, Kutz S J, Veitch A M, Popko R A, Elkin B T and Guthrie G 2009 Fostering community-based wildlife health monitoring and research in the Canadian North Ecohealth 6 266–78
[87] Shaffer C A, Milstein M S, Yukuma C, Marawanaru E and Suse P 2017 Sustainability and comanagement of subsistence hunting in an indigenous reserve in Guyana Conserv. Biol. 31 1119–31
[88] Van Vliet N, Sandrin F, Vanegas L, L'haridon L, Fa J E and Nasi R 2017 High-tech participatory monitoring in aid of adaptive hunting management in the Amazon Unasylva 68 53–62
[89] Van Rijsoort J and Jinfeng Z 2005 Participatory resource monitoring as a means for promoting social change in Yunnan, China Biodivers. Conserv. 14 2543–73
[90] Luzar J B, Silvius K M, Overman H, Giery S T, Read J M and Fragoso J M V 2011 Large-scale environmental monitoring by indigenous peoples Bioscience 61 771–81
[91] de Paula M, Xerente V and Pezzuti J 2017 Hunting and monitoring: community-based research in xerente indigenous land, Brazilian Cerrado Human Ecol. Rev. 23 23–44
[92] Cummings A et al 2017 Developing a UAV-based monitoring program with indigenous peoples J. Unmanned Veh. Syst. 5 115–25
[93] Herrmann T M et al 2014 Effects of mining on reindeer/caribou populations and indigenous livelihoods: community-based monitoring by Sami reindeer herders in Sweden and first nations in Canada Polar J. 4 28–51
[94] Danielsen F et al 2014 Linking public participation in scientific research to the indicators and needs of international environmental agreements Conserv. Lett. 7 12–24
[95] Anisimov O A et al 2007 Polar regions (Arctic and Antarctic) Intergovernmental Panel on Climate Change Working Group ed M L Parry et al (Cambridge: Cambridge University Press) pp 653–85
[96] Nordic Development Fund (NDF) 2004 Gender Equality Study: A Study on Addressing Gender Aspects in Projects Co-Financed by NDF in Developing Countries (Helsinki: NDF)
[97] Fisher S 2014 Tracking Adaptation and Measuring Development Through a Gender Lens (London: IIED)
[98] Bunce A and Ford J 2015 How is adaptation, resilience, and vulnerability research engaging with gender? Environ. Res. Lett. 10 123003
[99] Brant Castellano M 2004 Ethics of aboriginal research J. Aborig. Health 1 98–114
[100] Smith L T 1999 Decolonizing Methodologies (New York: University of Otago Press) pp 28–74
[101] Inuit Tapiriit Kanatami 2018 National Inuit Strategy on Research (Ottawa: Inuit Tapiriit Kanatami)
[102] Ford J D et al 2016 Including indigenous knowledge and experience in IPCC assessment reports Nat. Clim. Change 6 349–53
[103] Ford J D, Vanderbilt W and Berrang-Ford L 2012 Authorship in IPCC AR5 and its implications for content: climate change and indigenous populations in WGII Clim. Change 113 201–13
[104] Castleden H, Morgan V S and Neimanis A 2010 Researchers' perspectives on collective/community co-authorship in community-based participatory indigenous research J. Empir. Res. Human Res. Ethics 5 23–32
[105] Green D and Raygorodetsky G 2010 Indigenous knowledge of a changing climate Clim. Change 100 239–42
[106] Castleden H E et al 2017 Implementing Indigenous and western knowledge systems:II. 'You have to take a backseat' and abandon the arrogance of expertise Int. Indig. Policy J. 8
[107] Gratani M, Royee F and Butler J R A 2016 A research process and criteria indicators framework for developing indigenous freshwater ecosystem health monitoring Cogent Environ. Sci. 2 1–14
[108] Tengö M, Brondizio E S, Elmqvist T, Malmer P and Spierenburg M 2014 Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach Ambio 43 579–91
[109] UNFCCC 2015 Adoption of the Paris Agreement (Paris: UNFCCC)
[110] Chandler M et al 2017 Contribution of citizen science towards international biodiversity monitoring Biol. Conserv. 213 280–94
[111] Wiseman N D and Bardsley D K 2016 Monitoring to learn, learning to monitor: a critical analysis of opportunities for indigenous community-based monitoring of environmental change in Australian Rangelands Geogr. Res. 54 52–71
[112] Staddon S C, Nightingale A and Shrestha S K 2014 The social nature of participatory ecological monitoring Soc. Nat. Resour. 27 899–914
[113] David-Chavez D M and Gavin M C 2018 A global assessment of Indigenous community engagement in climate research Environ. Res. Lett. 13 123005
[114] Bardsley D and Rogers G 2011 Prioritizing engagement for sustainable adaptation to climate change: an example from natural resource management in South Australia Soc. Nat. Resour. 24 1–17

[115] Fisher S, Dinshaw A, Mcgray H, Rai N and Schaar J 2015 Evaluating climate change adaptation: learning from methods in international development *New Dir. Eval.* **2015** 13–35
[116] Hedger M, Greeley M and Leavy J 2012 Evaluating climate change : pro-poor perspectives *Inst. Dev. Stud.* **39** 75–80
[117] Brooks N, Anderson S, Ayers J, Burton I and Tellam I 2011 Tracking adaptation and measuring development (London: IIED)(http://pubs.iied.org/pdfs/10031IIED.pdf)
[118] Ford J D and Berrang-Ford L 2016 The 4Cs of adaptation tracking: consistency, comparability, comprehensiveness, coherency *Mitigation Adaptation Strateg. Glob. Change* **21** 839–59
[119] Ford J D *et al* 2018 Preparing for the health impacts of climate change in Indigenous communities: the role of community-based adaptation *Glob. Environ. Change* **49** 129–39
[120] Sheil D and Lawrence A 2004 Tropical biologists, local people and conservation: new opportunities for collaboration *Trends Ecol. Evol.* **19** 634–8
[121] Constantino P A L 2015 Dynamics of hunting territories and prey distribution in Amazonian Indigenous Lands *Appl. Geogr.* **56** 222–31
[122] Campbell B M *et al* 2016 Reducing risks to food security from climate change *Glob. Food Sec.* **11** 01
[123] Skinner K, Pratley E and Burnett K 2016 Eating in the city: a review of the literature on food insecurity and indigenous people living in Urban spaces *Societies* **6** 7
[124] Neufeld H T and Richmond C A M 2017 Health access centre SOA. Impacts of place and social spaces on traditional food systems in southwestern Ontario *Int. J. Indig. Health* **12** 93
[125] Douxchamps S, Debevec L, Giordano M and Barron J 2017 Monitoring and evaluation of climate resilience for agricultural development—a review of currently available tools *World Dev. Perspect.* **5** 10–23
[126] Schipper E L F and Langston L 2015 A comparative overview of resilience measurement frameworks analysing indicators and approaches. Overseas Dev Inst-Work Pap 422 (London: Overseas Development Institute)
[127] Tendall D M *et al* 2015 Food system resilience: defining the concept *Glob. Food Secur.* **6** 17–23
[128] IISD 2013 Climate Resilience and Food Security A framework for planning and monitoring (Winnipeg: IISD)
[129] Sturgess P 2016 Measuring Resilience (London: Department for International Development)
[130] Ebhuoma E E and Simatele D M 2017 'We know our Terrain': indigenous knowledge preferred to scientific systems of weather forecasting in the Delta State of Nigeria *Clim. Dev.* **11** 1–12
[131] IPCC Summary for policymakers ed V Masson-Delmotte *et al* 2018 *Global Warming of 15°C An IPCC Special Report on the Impacts of Global Warming of 15°C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, In the Context of Strengthening the Global Response to the Threat of Climate Change* (Geneva: World Meteorological Organization) p 32