Mapping Human Dimensions of Climate Change Research in the Canadian Arctic

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Abstract This study maps current understanding and research trends on the human dimensions of climate change (HDCC) in the eastern and central Canadian Arctic. Developing a systematic literature review methodology, 117 peer reviewed articles are identified and examined using quantitative and qualitative methods. The research highlights the rapid expansion of HDCC studies over the last decade. Early scholarship was dominated by work documenting Inuit observations of climate change, with research employing vulnerability concepts and terminology now common. Adaptation studies which seek to identify and evaluate opportunities to reduce vulnerability to climate change and take advantage of new opportunities remain in their infancy. Over the last 5 years there has been an increase social science-led research, with many studies employing key principles of community-based research. We currently have baseline understanding of climate change impacts, adaptation, and vulnerability in the region, but key gaps are evident. Future research needs to target significant geographic disparities in understanding, consider risks and opportunities posed by climate change outside of the subsistence hunting sector, complement case study research with regional analyses, and focus on identifying and characterizing sustainable and feasible adaptation interventions.

Keywords Climate change · Arctic · Inuit · Systematic review · Human dimensions

INTRODUCTION

Climate change research focusing on impacts, adaptation and vulnerability has expanded exponentially over the last decade (Aspinall 2010; Ford et al. in press). Keeping track of publishing trends has therefore become increasingly important but has not been matched by comparative attempts to collate, synthesize, and track current knowledge. This perhaps reflects the myth that reviews are not research (Petticrew and McCartney 2011) and is particularly apparent in the Arctic, which has become a hotspot for climate change research due to amplification of impacts, presence of vulnerable populations, and emergence of the region as an early warning opportunity to understand how climate change impacts might play out elsewhere (ACIA 2005; IPCC 2007; Lemmen et al. 2008; Crowley 2010; Ford et al. in press). In Canada, for instance, major, multi-year research programs focusing on Arctic climate change have been initiated. Yet as these programs have progressed, concerns have been noted by policy makers, Inuit communities, and scientists that research is being duplicated and policy applications overlooked due to the proliferation of studies. In this context, examining what we know, don't know, and need to know has become an important research question (Ford and Pearce 2010; Pearce et al. 2010; Ford 2012).

In this paper, we characterize trends in the study of the human dimensions of climate change (HDCC) in the eastern and central Canadian Arctic to identify current understanding and identify research gaps. We begin by evaluating recent developments in knowledge synthesis techniques in climate change scholarship, which informs the development of a systematic literature review methodology. The methodology is applied to map research trends and evolution of knowledge domains over the last

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decade. We finish by identifying future research needs and examine the application of the methodology in a broader context.

KNOWLEDGE SYNTHESIS IN CLIMATE CHANGE RESEARCH

The task of assessing and synthesizing current understanding of multiple aspects of climate change has traditionally been performed by major (inter)governmental initiatives. Examples include the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) and national climate change assessments which engage hundreds of experts in the review process, extensively evaluate scientific scholarship, seek consensus in key findings, and involve external evaluation. This kind of assessment is consistent with what Petticrew (2001) terms a ‘narrative review,’ the strengths of which in a climate change context are widely noted (Ravindranath 2010). Nevertheless, critiques in recent years have highlighted the lack of transparency in methods of searching, selecting, and synthesizing relevant scholarship with implications for replicability and validation; disciplinary bias towards the physical sciences; dominance of a western scientific worldview; limitations of consensus seeking; and the time required to complete such comprehensive assessments (Hulme 2010; van der Sluijs et al. 2010; Bjurström and Polk 2011; Ford et al. 2011a, 2012).

Literature reviews documenting and reviewing current understanding of climate change in Arctic regions are more recent and have largely followed the ‘narrative review’ procedures of the IPCC. Thus the Arctic Climate Impact Assessment (2005) provides an in-depth characterization of climate change in the circumpolar region. The Canadian national assessment has a specific chapter for northern regions that examines mostly peer reviewed scholarship on multiple aspects of climate change (Furgal and Prowse 2008; Prowse and Furgal 2009; Prowse et al. 2009c), and is complemented by regionally focused projects that have created databases of references relevant to climate change (Ford and Pearce 2010; Pearce et al. 2010), and reviews that focus on specific sub-sectors or risks (Furgal and Seguin 2006; Prowse and Furgal 2009; Prowse et al. 2009b, c; Forbes et al. 2011). These are important and comprehensive contributions, and some have involved indigenous organizations in the review process. However, if we are to characterize, compare, and monitor trends in publishing and understanding, alternative approaches to literature review also need to be developed (Petticrew 2001; Petticrew and McCartney 2011).

New models for literature review in a climate/environmental change context have emerged in recent years and

offer opportunity for assessments to complement narrative style reviews. These include the mobilization of small research teams to ask specific questions of the literature (Tompkins et al. 2010; Berrang-Ford et al. 2011; Ford et al. 2011a; Keskitalo et al. 2011), the use of national-level reporting on climate change actions to the UNFCCC to characterize knowledge and action on climate change (Gagnon-Lebrun and Agrawala 2007; Lesnikowski et al. 2011), the analysis of publications in select journals as a proxy for developments in the field (Arnell 2010), and the use of systematic review approaches common in the health sciences (Berrang-Ford et al. 2011; Ford et al. 2011a). These studies provide important insights for review methodology. Firstly, it is important that reviews target specific sectors and/or components of the HDCC, and be conducted in a timely manner to maximize relevance to policy makers (Ford et al. 2011a). Secondly, there is a need for transparency in the review process with full specification of search terms, inclusion and exclusion criteria, and databases searched, to allow for study replicability and validation (Petticrew and McCartney 2011). Thirdly, broad engagement of scientists and knowledge users is essential if the review is to address needs of users, and address concerns noted by some that scientific reviews generally include personal biases and are aimed at defining the research agenda for individual benefit (Leemans 2008). Fourthly, the use of multiple analytical techniques is important for examining the knowledge base. Quantitative analysis, for example, allows for standardized assessment of articles and enables the use of statistics to identify and examine key trends and associations, and is particularly important for tracking the evolution of understanding and characterization of knowledge domains over time (Hofmann et al. 2011). Finally, involving knowledge users is important for ensuring comprehensiveness and linking the review to policy processes.

METHODOLOGY

This paper develops a systematic review methodology to search, select, and survey the peer reviewed literature. Systematic reviews involve reviewing documents according to clearly formulated questions and using systematic and explicit methods to select and critically appraise relevant research (Table 1). Because they make their methods and search criteria explicit, they are reproducible and are thus considered a rigorous tool for evaluating current knowledge (Berrang-Ford et al. 2011; Ford et al. 2011a). This transparency is particularly important given the politicized nature of the climate change debate and is one of the primary driving forces behind the recent development and application of systematic reviews in the

Table 1 Systematic reviews versus traditional reviews (after Petticrew 2001)

Key characteristics	Systematic review	Traditional ‘narrative’ review
Review question	Clear question to be answered or hypothesis	Typically general discussion of a subject without clear question
Search for relevant studies	Aim to locate all relevant publications, use of consistent search terms in multiple databases	Do not usually attempt to locate all relevant literature; search terms often unclear
Deciding which studies to include and exclude	Explicit description of studies to be included; specification of inclusion and exclusion criteria	Limited information on how studies were included and excluded
Analysis	Standardized quantitative analysis & qualitative analysis	Typically just qualitative
Disclosure of review information	Full reporting of review process, identification and categorization of included and excluded studies. Independent replication possible.	Limited disclosure of review procedures, excluded articles not identified, search engines not specified

environmental change field. For instance, ‘climate skeptics’ have used small mistakes in specific chapters of previous IPCC assessments (e.g., ‘Himalaya-gate’) to broadly critique the rigor of the IPCC process, where the rationale for including and excluding articles is only broadly defined, and publications omitted from the review not identified or explained. More openness in review procedures herein—as embodied in systematic review methodology—would limit the potential for such critique.

This review was initiated by, and was closely developed in collaboration with, knowledge users at the federal-level knowledge (Aboriginal Affairs and Northern Development), northern science bodies (Nunavut Research Institute), and the national Inuit organization Inuit Tapiriit Kanatami (ITK), reflecting their concerns over the rapid expansion of research and consequent lack of understanding on research gaps, concerns over research duplication, and need for strategic planning for policy and research programming on climate change. Working with researchers at universities based in southern Canada, collaboration involved regular meetings and discussion at all stages of the review process from project scoping, methodology development, to interpretation, analysis, and identification of research gaps. Community members were not formally engaged in the review process but were represented by two organizations actively involved on-the-ground at the science-community interface in identifying local priorities: ITK and the NRI.

INCLUSION AND EXCLUSION CRITERIA

The review focuses on identifying and characterizing publishing trends and current knowledge on the HDCC in the eastern and central Canadian Arctic. The regional focus reflects needs identified by knowledge user partners. The area selected covers the territory of Nunavut, and Inuit regions of Nunavik and Nunatsiavut (Fig. 1), and has a

population of ~43 000 covering an area of ~2.5m km², and capturing roughly 90 % of the Canadian Inuit population. Socio-economic–demographic indicators are provided in Table 2. The eastern and central Arctic is predominantly inhabited by Inuit, and is undergoing some of the most rapid and pronounced changes in climate globally (Lemmen et al. 2008; Prowse et al. 2009a).

Articles were selected based on a focus on the HDCC. Herein, *climate change* is defined consistent with the IPCC (2007) as any change in climate over time, whether due to natural variability or as a result of human activity. The HDCC covers scholarship that examines how human systems (households, communities, businesses, regions, etc.) will be/are affected by and/or respond to climate change, including impacts, adaptation, and vulnerability studies. Given the limited population (and hence emissions) in the study region and focus in the review on how climate change impacts interact with and are experienced by communities, mitigation studies were not included. The review focused on peer reviewed publications in English or French published after 1st January 2000 and before 30th July 2010, with included studies having to have a substantial focus on Nunavut, Nunavik, or Nunatsiavut.

THE SEARCH STRATEGY

Three databases were used to search for peer reviewed research: ISI Web of Knowledge (WOK), PubMed, and GeoBase. These search engines were selected at the recommendation of a librarian team member, and capture the most powerful, current, comprehensive, and widely used search engines available for analysis of interdisciplinary, peer-reviewed literature (Berrang-Ford et al. 2011). A search phrase (in English and French) consisting of geographic place names, ranging from community names to geographical features within the area of interest was used to select relevant literature, and is available in Electronic

Region	Province/territory	Inuit Population (% of total)	Average community size	Population 15+ ^a	Average individual total income ^a	Unemployment rate ^a
Territory of Nunavut	Nunavut	24 635 (84)	1063	16 650	\$26 924	17.4
Nunavik	Quebec	9565 (90)	688	5830	\$23 215	14.5
Nunatsiavut	Newfoundland & Labrador	2169 (89)	1767	1785	\$17 945	40.3

A two-stage process was used to screen articles (Fig. 2). In the first stage, the title and abstract of each document was read and assessed according to the inclusion criteria by the primary researcher. Abstracts are widely used in

systematic reviews for screening as they provide a summary of the paper's findings. Of 2082 non-duplicate articles identified in the database searches, 1863 documents were excluded at this stage as they did not match the search criteria. Excluded articles typically examined the biophysical aspects of climate change without reference to human dimensions explored, did not have a climate change

Fig. 2 Flowchart of search procedures

focus, or did not focus on the region of interest. To validate the screening process, a second researcher independently screened the same list of documents, and, in contrast to the primary researcher, was female, from a humanities background, with no prior Arctic experience. These different characteristics were sought to minimize bias in the validation of article coding. Selection between the two researchers showed agreement on included articles to a degree greater than what would be randomly expected (measured using the Kappa Statistic, $K = 0.41$). Of the remaining 219 documents, another 115 did not match the inclusion criteria and were excluded after a full read-through, leaving 104 included articles.

In the second stage, a citation ‘snowball’ search of included journal articles ($n = 104$) was performed, identifying a further 13 additional documents not originally identified, bringing the total literature review sample to 117. Snowballing involved examining all cited references in selected articles to identify additional publications which might have been missed by the search and which are then screened for inclusion. The inventory of included articles is

provided in Electronic Supplementary Material along with excluded articles (Tables S2, S3).

DOCUMENT REVIEW AND ANALYSIS

Full-text review of all (117) articles was performed. Firstly, selected articles were coded to document and characterize publishing trends, enabling standardized analysis using descriptive statistics. The coding scheme is available in Electronic Supplementary Material (Table S4) and sought to facilitate bibliometric analysis capturing general characteristics of the publications in terms of year published, journal, and authorship, and more detailed information including geographic location of the study, scale at which the study focused on, engagement of knowledge user partners, disciplinary background of scientists involved, sectoral focus, and integration of traditional knowledge. These questions are important for examining the nature of research being conducted, evaluating research approaches with respect to best practice, and identifying knowledge

gaps. Coding development involved collaboration between university-based researchers and knowledge user partners to reflect scientific, policy, and community needs. Secondly, an in-depth review of each article was conducted to further characterize the nature of publishing trends and topics being examined.

PUBLISHING TRENDS

There Has Been a Rapid Growth in HDCC Research Over the Last Decade

Published research on the HDCC in the eastern and central Arctic has increased significantly over the last decade (Fig. 3; Table 3), with 2 articles meeting the inclusion criteria in 2000 and 25 in 2009. At the July 30th cut-off for 2010, 13 articles had been published suggesting a similar publication rate as 2009. This trend is observable across the three regions. The increase in publishing effort is particularly pronounced between 2004–2005 and 2007–2010.

Research Conducted by the Social and Biophysical Sciences is Well Represented

Research where the lead author is from the social sciences ($n = 48$, 41 %) (Table 3) has become increasingly important over the observation period, particularly studies employing concepts from vulnerability science and utilizing community-based research methodologies (Ford et al. 2006a, b, 2008a), identifying broad level opportunities at a regional level for policy intervention to reduce the negative effects of climate change and take advantage of new opportunities (i.e., adaptation) (e.g., Newton et al. 2005; Budreau and McBean 2007; Ford et al. 2007, 2010), and examining specific developments needed to enhance adaptive capacity/resilience. A major focus of the latter

Fig. 3 Frequency count of included articles by year (2010 is omitted due to review cut-off date in July 2010)

Table 3 Breakdown of publications according to disciplinary specialization of lead author ($n = 117$)

Years	Broad discipline of first author			Total
	Health (% of the annual total)	Biophysical (%)	Social (%)	
2000	0 (0)	2 (100)	0 (0)	2
2001	0 (0)	1 (100)	0 (0)	1
2002	0 (0)	2 (67)	1 (33)	3
2003	0 (0)	1 (25)	3 (75)	4
2004	0 (0)	2 (50)	2 (50)	4
2005	3 (21)	8 (57)	3 (23)	14
2006	2 (14)	5 (36)	7 (50)	14
2007	2 (12)	9 (53)	6 (35)	17
2008	2 (10)	10 (50)	8 (40)	20
2009	1 (4)	11 (44)	13 (52)	25
2010 ^a	3 (24)	5 (38)	5 (38)	13
Total	13 (11)	56 (48)	48 (41)	117

^a Note cut-off date for articles included on 31st July 2010

includes the development of community-monitoring networks for tracking environmental conditions including sea ice thickness, trail safety, and permafrost (Gearheard et al. 2006; Meier et al. 2006; NTK 2008; Tremblay et al. 2008; Gauthier et al. 2010; Hanesiak et al. 2010), and the investigation of governance and resource management bodies and their capacity to manage changing wildlife access and availability (e.g., Armitage 2005b; Clark et al. 2008; Dowsley and Wenzel 2008). Despite this trend, of the studies reviewed here, only two had first authors from a political science department, and none from law, economics, or psychology, with the majority of scholars from geography or anthropology background.

Studies led by an author from the biophysical sciences represent a majority of articles ($n = 56$, 48 %). This research generally does not directly focus on the HDCC per se, but nevertheless integrate a human component into analysis of changes in and vulnerability of biophysical systems that are of relevance to communities. Research on polar bears is prominent (Stirling and Parkinson 2006; Regehr et al. 2007; Crompton et al. 2008; Durner et al. 2009), along with permafrost (Gough and Leung 2002; Smith et al. 2005), caribou populations (Tews et al. 2007; Sharma et al. 2009), contaminants (Constant et al. 2007; Hare et al. 2008; Kuzyk et al. 2010), and storms (Roberts et al. 2008; Roberts and Stewart 2008; Hanesiak et al. 2010). Fewer studies have been led by researchers from the health sciences ($n = 13$, 11 %) but in recent years scholarship has begun to integrate a climate element into long-standing issues such as mental health, food- and water-borne contaminants, food and water security, community infrastructure vulnerability, and hazard planning (Furgal

and Seguin 2006; Martin et al. 2007; Donaldson et al. 2010; Nancarrow and Chan 2010).

Traditional Knowledge is Widely Recognized as Essential for Documenting and Understanding the HDCC

Inuit traditional knowledge (TK) embodies knowledge and values which have been acquired through experience, observation, from the land or from spiritual teachings, and handed down from one generation to another (Wenzel 1999), and has become a major focus of research in recent years. In particular, aspects of TK that relate to ecosystems and human interactions with the environment have been utilized to document and examine changes in environmental conditions (Laidler and Ikummaq 2008; Laidler and Elee 2008; Gearheard et al. 2010; Weatherhead et al. 2010). Other studies have conducted theoretical examinations of how knowledge systems evolve in light of a changing climate (Laidler 2006; Bravo 2009); and used TK to examine how human–environmental interactions have changed over time and identify opportunities for adaptation intervention (Laidler 2006; Mallory et al. 2006; Meier et al. 2006; Ford 2008, 2009b; Ford et al. 2006a, b, 2008a, b, 2009; Laidler and Elee 2008; Mahoney et al. 2009; Pearce et al. 2009). TK has also been identified as underpinning the adaptive capacity of Inuit communities albeit with concern about transmission to younger generations (Ford et al. 2006a, b; Pearce 2011). Herein, a number of projects incorporating TK into the study design are also seeking to engage youth and elders to stimulate knowledge transfer and preservation.

The ways in which communities are engaged in the research process for the purpose of documenting and utilizing TK also differ considerably (Pearce et al. 2009). In some studies, engagement is limited to meetings in which scientific information and TK is shared. In other studies, community engagement involves the collection of TK with minimal local involvement in other aspects of the research, such as topic selection, interpretation, and application. TK here is treated as one source of data contributing to Western scientific research. This kind of interaction is evident in early studies and today, but projects reviewed here are increasingly involving communities throughout the research process, including research design and application, and interpretation and verification of results, building long-term partnerships (e.g., Ford et al. 2006a, b; Gearheard et al. 2006; Laidler and Ikummaq 2008; Laidler and Elee 2008; Laidler et al. 2009; Weatherhead et al. 2010). In doing so, researchers have acknowledged that if Arctic field science is to be rigorous, cost-effective, meaningful to communities, and conducted in an ethical manner, new models of collaboration are needed that engage local

people as partners not subjects (Pearce et al. 2009; Murphy 2011).

While the incorporation of TK into Arctic research is to be welcomed, and a number of recent projects have made significant progress herein, challenges have been noted. Bates (2007) argues that there is an inherent tension between scientific understandings of ‘adaptation planning’ and Inuit understandings of ‘planning’ which may inhibit the effective collaboration of scientists with community members. Barriers to incorporating TK into resource management have also been identified (Armitage 2005b; Dowsley and Wenzel 2008; Gearheard et al. 2010). Studies critically reflecting on the engagement of Arctic residents in research and the role and value of TK in HDCC research and examining ways to bridge the science-policy-TK divide, however, remain few.

Communities and Other Knowledge Users Are Being Engaged in Research but the Majority of Projects are University-Led

For each article the affiliation of the first author was documented. University-based researchers represent 73 % of lead authors ($n = 86$), government 18 % ($n = 21$), and those affiliated with northern institutions or communities 7 % ($n = 8$). Of the latter authorship group, the earliest study in the sample was published in 2005. As a proxy of the extent of knowledge user engagement—an important consideration in HDCC research—the number groups included in each article were tabulated based on authorship and identification in acknowledgements. Seventy-two percent of articles report engaging federal government departments, 55 % community residents, and 35 % Inuit organizations and territorial government, respectively. The first study to be co-authored with a community actor was published in 2006. The participation or consultation of municipal governments (i.e., Hamlets) is much less reported, however (9 % each).

There Are Significant Geographic Disparities in Research

Each article was coded according to the administrative region where the research was conducted and, if relevant, the community(s) and/or geographic region(s) involved. The majority of studies focus exclusively on the territory of Nunavut ($n = 46$, 39 %), reflecting population of the region, 21 % ($n = 25$) focus on the Canadian Arctic as a whole, and 11 % ($n = 13$) the eastern and central Arctic in general. Nine percent ($n = 11$) of studies focus on Nunavik and 4 % Nunatsiavut ($n = 5$). Breaking down studies by geographic region and community, Igloolik (NU) has the most published research ($n = 13$). Smaller more

Table 4 Sectoral focus of studies

Sector	Focus of studies in sector	N (%) ^a
Subsistence hunting and harvesting	Ability to engage in local hunting, trapping and fishing activities, and procure traditional foods	52 (44)
Health and well-being	Health of individuals and communities, including physical and mental well-being	29 (25)
Institutional and resource management	Formal governance structures at multiple levels affecting resource utilization	26 (22)
Infrastructure and transportation	Semi-permanent hunting trails on sea ice, lake ice, and land; permanent and seasonal roads; shipping access; air access; building stability; cultural sites	25 (21)
Culture and education	Formal school system and traditional learning, cultural promotion and preservation	25 (21)
Business and economy	Formal economic sector including resource sector and tourism	13 (11)

^a Non-cumulative

homogenous communities are overrepresented in published research, with few studies from regional Inuit centers with their administrative functions, strong economies, and their more diverse, heterogeneous and rapidly growing populations. There are also a large number of communities where no research has been published in the peer reviewed literature reviewed here, and can viewed in geo-coded map.¹

The Majority of Studies Focus on Subsistence Hunting, Fishing, and Trapping, with Few Studies on Business and Economy

The classification scheme of Ford and Pearce (2010) was used to identify the sectoral focus of studies (see Table 4), allowing each article to be classified in multiple categories where appropriate (non-cumulative). Forty-four percent ($n = 52$) focus on hunting, fishing and trapping, reflecting the importance of these activities for communities and sensitivity to climate change. The majority of these studies are conducted in Nunavut and reflect research effort in a small number of settlements (Igloolik, Arctic Bay, Cape Dorset, Clyde River) and by a cluster of researchers from a geography background. Health and well-being is examined in 25 % ($n = 29$) of studies, mostly examining food systems and safety of land-based activities, with recent publications examining the fate of contaminants in light of climate change (McKinney et al. 2009; Gantner et al. 2010; Kuzyk et al. 2010; Macdonald and Loseto 2010). Mental health and vector- and water-borne diseases have received limited attention. Twenty-two percent of articles ($n = 26$) focus on institutional and resource management, with studies largely examining how resource management regimes can be improved in light of climate change with a focus primarily on Nunavut (e.g., Armitage 2005a;

Budreau and McBean 2007; Clark et al. 2008). Twenty-one percent ($n = 25$) focus on infrastructure and transportation, mostly examining the stability and safety of semi-permanent trails on lake and sea ice (e.g., Tremblay et al. 2006, 2008; Aporta 2009; Laidler et al. 2009; Beaumier and Ford 2010; Ford et al. 2010), with a number of projects examining natural hazards on Baffin Island and in Nunavik (e.g., Manson et al. 2005; Roberts et al. 2008; Roberts and Stewart 2008; Dery et al. 2009; Hanesiak et al. 2010). There has been limited research examining the human dimensions of permafrost thaw or municipal infrastructure impacts in the peer reviewed scholarship. Only 11 % of articles reviewed here ($n = 13$) focus on the business and economy sector, despite the dependence of many economic activities on environmental conditions that are changing rapidly (e.g., tourism, mining, shipping).

The State of Current Understanding

As this review highlights, the study of the HDCC is a well-established foci of research in the eastern and central Canadian Arctic, and with a publication rate of 2.7 articles per thousand people is perhaps one of the most intensively studied regions globally. Examining the focus and content of publications we use the classification scheme of Ford and Pearce (2012) to categorize the scholarship into four domains.

Firstly, studies documenting *observations of climate change* based upon Inuit TK dominated early research (Gearheard et al. 2006; Laidler 2006; Laidler and Ikummaq 2008; Laidler and Elee 2008). This scholarship indicates that the climate of the region is changing rapidly, focusing largely on sea ice and weather conditions (wind speed, direction, storminess), and adding spatial and temporal depth to studies using instrumental datasets to document changing conditions. Now that we have a well-developed understanding of how the climate is changing, studies in this domain have sought to compare indigenous observations and instrumental data

¹ <http://www.google.com/maps/ms?ie=UTF8&hl=en&t=h&msa=0&msid=209189955566604582464.00048b5a9571f3de14339&ll=68.656555,-84.726562&spn=23.162599,74.707031&z=3&source=embed>.

(Gearheard et al. 2006, 2010; Weatherhead et al. 2010), seeking to better understand how communities perceive change and inform impacts assessments.

Secondly, research that has documented observations of change has also examined the *impacts* that climate change is having. Risks associated with changing sea ice conditions and wildlife resources have been widely studied, and to a lesser degree permafrost, landscape hazards, and storm activity (Dumas et al. 2006; Roberts et al. 2008; Roberts and Stewart 2008; Hanesiak et al. 2010; Weatherhead et al. 2010). The majority of these projects have focused on negative effects of changes already experienced, including increased danger of engaging in hunting activities, reduced access and availability of traditional foods, and infrastructure damage. These studies have utilized both Inuit TK and biophysical science methods to characterize the nature of risks posed.

Thirdly, gaining increasing importance over the last 5 years, studies have used concepts from *vulnerability science* to advance understanding on how biophysical changes are experienced and responded to in the context of social, cultural, and economic change. Some studies have also used concepts from resilience scholarship (Armitage 2005a, b), although to a lesser extent than in the western Arctic (Berkes and Jolly 2002; Chapin et al. 2004; Chapin 2006). These studies have highlighted that despite the changes experienced, communities are adapting in a variety of ways, involving both autonomous and anticipatory actions. Harvesters, for example, are altering resource use patterns and transportation routes to maintain hunting activities and safety, the education system is building climate change awareness into classroom programming, adaptation plans have been developed for a number of settlements and the territory of Nunavut, local people are actively engaged in environmental monitoring, and large infrastructural developments are integrating climate projections. Commonly identified determinants of adaptability/resilience include TK, social learning, flexible institutions, strong community social networks, acceptance and experience with uncertainty, and government support (Armitage 2005a, b; Ford et al. 2006a, b, 2009; Gearheard et al. 2006; Armitage et al. 2008; Ford 2009b; Laidler et al. 2009). Notwithstanding, the literature is unequivocal in terms of challenges faced in the future. This stems from the magnitude of projected changes in climate but also underlying social–cultural–economic conditions which currently constrain adaptability and are resulting in emerging vulnerabilities, including poverty, high burden of ill health, erosion of land skills among younger generations, institutional memory, and weakening sharing networks.

The final research domain is the most recent and least studied, focusing on identifying *policy interventions* for adaptation and resilience enhancement. This scholarship

has advanced significantly in recently years, from studies that identified adaptation ‘wish lists’ usually as part of impacts assessments, to studies that utilize knowledge on the determinants of vulnerability and barriers to adaptation to identify and evaluate priorities for policy intervention at a regional to federal level (Ford et al. 2007, 2010; Ford 2009a), and internationally (Ford 2009a). Other studies have identified opportunities for resource management regimes to be strengthened (Armitage 2005a, b; Armitage et al. 2008). These articles highlight the magnitude of the challenge facing communities and governments in adapting to climate change. Nevertheless, they share optimism that many—if not all—of the impacts of climate change can be managed with the right support mechanisms: that is, many of the constraints to adaptation are barriers not limits, and require concerted government action at all levels to address.

RESEARCH GAPS

The review highlights that while current scholarship develops a baseline understanding of the HDCC in the eastern and central Canadian Arctic, key gaps are evident.

Geographic Disparities in Publishing

Research in Nunavut is well represented in the literature, reflective of the size of the territory, long history of research in the region, and output of a cluster of scholars working here. There are few publications from Nunatsiavut by contrast, although we expect this to change as a number of projects in this region are at the reporting stage, initiated after this region was created in 2005. In all regions covered by this review, there is a preference for working in smaller communities. While it is these locations that are likely to have enhanced vulnerability due to their isolation, high dependence on environmental conditions, and indicators of socio-economic well-being (Ford et al. 2010), it is the larger regional centers that are emerging as regional hubs and growing rapidly (Lardeau et al. 2011). Also noteworthy are research hotspots, with highly studied communities and regions mirrored by research deserts characterized by communities where no studies have been reported on in the peer reviewed scholarship. This clustering reflects the nature of research history in specific locations, accessibility, and community leadership in encouraging research (e.g., Clyde River, Igloodik), as much as research need per se. Geographic disparities of this nature matter because research shows significant differences in vulnerability between communities and regions, with implications for policy intervention at a local level (Furgal and Seguin 2006; Furgal and Prowse 2008, 2009; Ford 2009b; Ford et al. 2010).

Neglect of Non-harvesting Sectors

The majority of scholarship examines harvesting-related vulnerabilities, reflective of the social, cultural, and economic importance of subsistence activities across the north and sensitivity to climate change. While research focusing on other sectors has increased over the last decade, key areas remain understudied. In particular, the implications of climate change for northern economies are not well understood. There is potential for significant economic benefits with climate change as reduced sea ice extent opens up opportunities for enhanced shipping and oil and gas exploration (Stephenson et al. 2011). Mining development is already expanding rapidly and future climatic conditions are projected to be beneficial for future expansion of the industry (Pearce et al. 2011; Ford et al. 2011c), while posing risks for certain mining practices (e.g., use of ice roads for transport and reliance of permafrost for mine tailings). Climate change may also create new opportunities for commercial fishing and cruise tourism (Stewart et al. 2007). There is a paucity of studies examining potential economic opportunities, and how they can be best promoted and managed, consistent with the general climate change scholarship (Berrang-Ford et al. 2011). While it is commonly assumed that the private sector will autonomously take advantage of new opportunities, the Arctic presents industrial activity with logistical, regulatory, and financial barriers, many of which have not been examined. Moreover, resource development also presents challenges as well as opportunities, to communities, potentially enhancing vulnerability. Few studies, however, have examined the ‘double exposure’ (Leichenko and O’Brien 2008) of climate change and globalization in the Arctic. Health is also a neglected area outside of food system/security studies, and there is a strong need for studies to focus on mental health and wellness dimensions of climate change which have been identified as a major concern but little studied.

Preference for the Present

Limited research has examined vulnerability and adaptation to future climate change, with the majority of studies focusing on the past and present. Modeling studies have increased our understanding of how the climate of the Arctic will change and associated impacts but there is a need for studies that examine how projected changes might interact with human systems and assess how socio-economic–demographic trends will affect how communities experience a changing climate. This necessitates place-based research and also a need for downscaling climate impact studies.

Need for Adaptation Research

The importance of adaptation is widely acknowledged in the Arctic, and a number of scholars are working with policy makers and communities to identify opportunities for policy intervention. Nevertheless, the literature remains dominated by impacts and vulnerability studies. While many of these projects have documented adaptations and coping strategies currently being utilized, few examine their effectiveness, durability, socio-economic and ecological implications, and long-term viability and cost in light of multiple stresses and competing policy priorities. Until these gaps are addressed, anticipatory intervention and external support is likely to be constrained (Ford et al. 2010). Community-based adaptation planning is emerging as an important focus to this end and has an important role to play in reducing vulnerability (Pearce et al. 2012). Many drivers of vulnerability at a local level, however, are determined by processes at larger spatial and temporal scales over which the local has limited influence, with need for comparable adaptation focus at a regional, territorial/provincial, and federal level, along with an examination of how these different levels can come together to enable adaptation.

The Needs of Vulnerable Sub-groups

The general scholarship indicates that sub-populations including the elderly, children, and females could have a higher vulnerability to climate change impacts and will have specific adaptation. Except for one study examining gender and food insecurity (Beaumier and Ford 2010), and work focusing on hunters, targeted research on specific sub-populations is not reported on.

Disciplinary Bias

The predominance of authorship from scholars from a geography/environmental science background is important as these disciplines have been identified as well equipped to deal with the inter-disciplinary and integrative nature of climate change research (Aspinall 2010). Notwithstanding, scholarship would benefit from broader engagement of the social sciences and humanities, with perspectives from economists, legal experts, and political scientists largely absent. As Bjurström and Polk (2011) note, the presence or absence of certain disciplinary perspectives has implications for the issues policymaking addresses and how.

DISCUSSION

This paper systematically reviews research on the HDCC conducted in the eastern and central Canadian Arctic. As

with all assessments of this nature, the search procedures will have inevitably overlooked some relevant articles, and to minimize this risk we used multiple search engines, citation tracking, extensive keywords, and double coding. The focus on peer reviewed scholarship will also have omitted the inclusion of relevant gray literature sources of information. This was done for purposes of quality control and to develop a rapid, standardized, and transparent assessment of knowledge that can be regularly updated and tracked, and is consistent with general procedures for systematic review. For these reasons, the review represents a proxy of the current state of knowledge.

By focusing only on peer reviewed scholarship there is also the risk that the review overlooked Inuit ways of understanding and information about climate–society interactions embedded in myths, stories, tradition, and observations, potentially contributing towards what Hulme (2010, 2011) and Jasanoff (2010) describe as the civic epistemology of global climate change discourse that prioritizes positivist disciplines at the expense of the interpretative. While this knowledge is increasingly captured in the scientific literature—as evident in this review—it is also widely documented in non-peer reviewed sources including speeches by Inuit political activists (e.g., Noble Prize nominee Sheila Watt-Cloutier), participation at international climate change meetings (e.g., UNFCCC CoPs), northern-led documentary films (e.g., Inuit Knowledge and Climate Change, www.isuma.tv/ikcc), op-ed articles and letters to the editor of northern newspapers, community-led history and climate change initiatives (e.g., the Nanisiniq Arviat History Project, Nauvihaq Oral History Project), and through social-media and web-sites (e.g., Facebook,

Twitter, Blogs). Combined with other gray literature including reports produced by government, NGOs, consultants, and industry, the potential sources of information on various aspects of the HDCC are expanding rapidly. Finding ways to systematically incorporate such knowledge into literature reviews and manage the data available is an emerging frontier in review methodology and will be a focus of future research. Moreover, while the review aimed to capture community priorities and needs in identifying research gaps by working closely with Inuit organizations and northern science bodies, there is a need to solicit direct community input. A number of examples from the general scholarship highlight approaches for working with communities on needs assessment (Tschakert 2007; Berrang-Ford et al. 2012; Sherman et al. in press).

Systematic reviews of this nature have not been widely applied to Arctic climate change scholarship and are essential for informing the development and direction of targeted research programs. Herein, the systematic nature of this review involving explicit inclusion and exclusion criteria, specification of databases searched, disclosure of excluded studies, quantitative analysis of publishing trends, and focus on the eastern and central Arctic differ this review from other northern focused knowledge syntheses. It is also, to our knowledge, the most up-to-date review on climate change in the region. The methodology developed has widespread application in other geographic contexts including other regions of the Canadian North where similar assessments have not been completed, offering a rigorous and transparent means of identifying, appraising, and synthesizing current knowledge that can complement and inform IPCC-style reviews. Additionally, it offers a means

Table 5 Canadian funding specifically for Arctic climate change research

Funding agency/initiative	Date	Focus	\$ Invested
ArcticNet (Networks of Centres of Excellence)	2003–2018	Develop and disseminate knowledge needed to formulate adaptation strategies and national policies to help Canadians face the impacts and opportunities of climate change and globalization in the Arctic	\$113.21m over 15 years
Nasivvik Centre for Inuit Health and Changing Environments (Canadian Institutes of Health Research)	2003–2012	Inuit health and environmental change with a specific focus on engaging communities in multidisciplinary research and local capacity development	\$4.2m
International Polar Year (federal government)	2007–2011	Research on a variety of issues in northern Canada, with a strong focus on climate change and community engagement and outreach	\$156m over 5 years
Northern Ecosystem Initiative (federal government)	1998–2008	Research to increase the understanding of northern ecosystems and to identify and respond to issues at the local and regional levels	\$38m over 10 years
Health Canada's Climate Change and Health Adaptation in Northern First Nations and Inuit Communities program	2008–2011	Supports communities to assess risks posed to their health by climate change	\$7m
Indian and Northern Affairs Canada Climate Change Adaptation program	2008–2011	Supports community planning for impacts and adaptation assessment	\$14m

of mapping of knowledge, providing a characterization of who is studying what, where, and how; analysis that is also long overdue in the general HDCC scholarship.

Over the last decade HDCC research has increased significantly, reflecting multiple factors. Firstly, the Arctic will experience the greatest climate change globally this century and has already experienced significant warming. Concern over the impacts is reflected in the creation of funding programs for Arctic studies (Ford et al. 2011b) (Table 5). Research follows the funding, a trend exacerbated by interest in northern regions as a laboratory for examining how human systems experience and respond to changing conditions. Secondly, a number of funding initiatives documented in Table 5 explicitly target human dimensions research, reflecting broader developments in the literature and among policy makers that recognizes the need and importance of HDCC research to inform climate policy (Ford et al. 2010). These funding initiatives have also played a key role in determining what kind of research takes place, with a number of programs emphasizing the importance of community-based research that engages policy makers. Finally, the last decade in Canada has witnessed a large increase in concern over the North in general, specifically concerning Arctic sovereignty, resource development, Indigenous land claims, and inequalities in socio-economic-health outcomes faced by many northerners.

Despite the increase in research, there remain large gaps in understanding. The review indicates a number of important areas for future research: (i) Geographic disparities indicate that greater attention should be paid to regional centers and communities neglected by climate change research, along with a focus on vulnerable subgroups; (ii) Research should consider the risks and opportunities posed by climate change to economic sectors and Inuit health, alongside the largely harvesting-focused studies conducted to-date; (iii) There is a need for regional analyses alongside local case studies; (iv) The risks posed by projected future climate change need to be examined and factored into decision making; (v) Scholarship would benefit from broader engagement of disciplines; (vi) There is a need for research to address how processes operating on multiple scales affect vulnerability and constrain or enable adaptation; and (vii) Greater focus is needed on identifying and characterizing adaptation interventions at multiple levels that are feasible, durable, equitable, and are sustainable in the long-term.

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