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What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review

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Abstract
This letter systematically reviews and synthesizes scientific and gray literature publications ($n = 420$) to identify and characterize the nature of climate change vulnerability in the Inuvialuit Settlement Region of the western Canadian Arctic and identify gaps in understanding. The literature documents widespread evidence of climate change, with implications for human and biophysical systems. Adaptations are being employed to manage changing conditions and are indicative of a high adaptive capacity. However, barriers to adaptation are evident and are expected to constrain adaptive capacity to future climate change. Continued climate change is predicted for the region, with differential exposure sensitivity for communities, groups and sectors: a function of social–economic–biophysical characteristics and projected future climatic conditions. Existing climate risks are expected to increase in magnitude and frequency, although the interaction between projected changes and socio-economic–demographic trends has not been assessed. The capacity for adapting to future climate change has also not been studied. The review identifies the importance of targeted vulnerability research that works closely with community members and other stakeholders to address research needs. Importantly, the fully categorized list of reviewed references accompanying this letter will be a valuable resource for those working or planning to work in the region, capturing climate change research published since 1990. At a broader level, the systematic review methodology offers a promising tool for climate/environmental change studies in general where there is a large and emerging body of research but limited understanding of research gaps and needs.

Keywords: climate change, vulnerability, adaptation, Arctic, Inuvialuit Settlement Region, Canada, systematic literature review, indigenous peoples, aboriginal peoples

S Supplementary data are available from stacks.iop.org/ERL/5/014008/mmedia

1. Introduction

Canada's Arctic is at the forefront of our changing climate with temperature increases in excess of 2 °C documented in some regions over the last 50 years (Furgal and Prowse 2008, IPCC 2007a, 2007b). These changes are having implications for people living in the Inuvialuit Settlement Region (ISR) in the Northwest Territories, the majority of who live in small, remote, settlements. Communities in the ISR continue to depend on the harvesting of fish and wildlife for their livelihoods, which has made them particularly susceptible to climate change (Furgal and Prowse 2008, 2009).

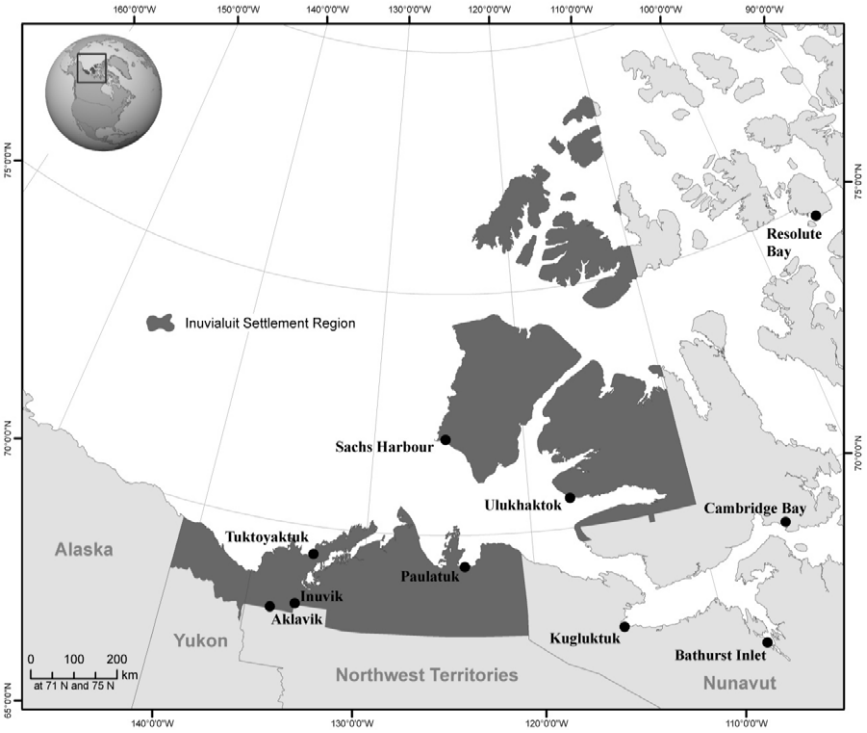

Figure 1. The Inuvialuit Settlement Region.

Communities, governments, and Inuit organizations have expressed concern about the rapidly changing climate, with models indicating accelerated climate change in the future even with greenhouse gas stabilization (Barber *et al* 2008, Furgal and Prowse 2008). In this context, adaptation as a response to climate change is particularly important, as stressed by scientific publications (Ford 2009, Ford *et al* 2007, IPCC 2007b, Newton *et al* 2005, Pearce *et al* 2010) and local and regional government (Government of Northwest Territories (GNWT) Bureau of Statistics 2008).

To initiate adaptation actions, decision makers need to know the nature of vulnerability in terms of who and what are vulnerable, to what stresses, and in what way, and also what is the capacity of human systems to adapt to changing conditions (Ford and Smit 2004, Smit and Wandel 2006). Considerable research on climate and climate change has already been conducted in the ISR, with studies typically focusing on the biophysical environment in terms of experienced and projected climate change impacts. There is also an emerging literature on the human dimensions of climate change with research largely focusing on documenting climate impacts and sensitivities for specific communities and/or economic sectors (Furgal and Prowse 2008, Prowse and Furgal 2009, Prowse *et al* 2009). Limited research, however, has *explicitly* assessed vulnerability and its determinants (Duerden 2004, Pearce *et al* 2009). Nevertheless, despite the lack of formal vulnerability assessments, the literature provides important insights on the social, economic, political, cultural, and biophysical conditions that determine how human systems experience climate change and their ability to adapt (Duerden 2004). In this letter we systematically review and critically assess this literature to identify and characterize the nature of climate change vulnerability in the ISR and locate gaps in understanding. We begin, however, by describing the ISR before explaining the methodology. Using a well established vulnerability framework to guide the review, we then characterize our current understanding of vulnerability and conclude by identifying future research needs.

2. The Inuvialuit Settlement Region

The ISR was established as a result of the 1984 Inuvialuit Final Agreement creating limited self-government for the Inuvialuit population of the Northwest Territories. Encompassing 906 430 km^2 of land (figure 1) the ISR contains a range of physical environments including the Mackenzie Delta, the mainland coast of the Beaufort Sea, and Banks and Victoria Islands. In the south along the Mackenzie River and in the vicinity of the tree line, ecosystems are relatively rich and diverse becoming thinner along the Arctic coast and on the islands. The region's population is dispersed over six communities (figure 2): Aklavik (pop. 630) and Inuvik (pop. 3590) located in the Mackenzie Delta; Tuktoyaktuk (pop. 1010) and Paulatuk (pop. 312) on the mainland coast of the Beaufort Sea; and Ulukhaktok (pop. 420) and Sachs Harbour (pop. 120) on Victoria and Banks Islands respectively. Populations are predominantly Inuvialuit: Inuit inhabiting the western Canadian Arctic. Life is strongly oriented towards the marine and terrestrial resources of the Beaufort Sea, and dependency on the region's traditional wildlife resources, such as seal, whale, caribou and musk-ox for food, clothing, and culture remains strong (Snow and Carpenter 2001, Usher

Figure 2. The six ISR communities: A = Tuktoyaktuk, B = Inuvik, C = Aklavik, D = Paulatuk, E = Sachs Harbour, F = Ulukhaktok. Sources: www.assembly.gov.nt.ca/_live/pages/wpPages/maptuktoyaktuk.aspx; www.colorado.edu/geography/blanken/GEOG%206181%20Fall%202003/noble/images/inuvikaerial3.jpg; www.stats.gov.nt.ca/.../Pics/Aklavik%20Angle.jpg; www.dot.gov.nt.ca/_live/pages/airports/airportProfile.aspx?AirportId=19; www.dot.gov.nt.ca/_live/images/airports/SachsHar.jpg; www.stats.gov.nt.ca/Infrastructure/Comm%20Sheets/Holman.html.

2002). With the exception of Inuvik and Tuktoyaktuk, with their commercial and industrial functions, the economies of ISR communities largely depend on public administration, subsistence hunting, and tourism. By any formal measurement they are economically challenged and transfer payments and government payrolls make a substantive contribution to local economies.

3. Methodology

3.1. A vulnerability approach

We use the vulnerability approach of Ford and Smit (2004) and Smit and Wandel (2006) to structure the literature review and guide the synthesis of published work to develop an understanding of climate change vulnerability (figure 3). This approach conceptualizes vulnerability as a function of exposure sensitivity to climate-related risks and the adaptive capacity to deal with those risks. Exposure sensitivity refers to susceptibility of a system to climatic conditions that represent risks. Adaptive capacity refers to the ability of individuals, households, communities, institutions etc to address, plan for, or adapt to these risks. In this conceptualization, vulnerability at a local level is viewed as being determined by human and biophysical conditions and processes operating at multiple scales (figure 3). Therefore when assessing the literature for what we know about vulnerability, attention was given to studies which concern human–environment interactions in general and not just limited to climate change. Empirical application of this conceptual model to assess what we know about vulnerability followed a two step framework. Firstly we characterized what we know about current vulnerability to climate-related risks (current exposure sensitivity and adaptive capacity). This provided a baseline understanding of vulnerability, its determinants, and the functioning of social–ecological systems in the ISR which grounded assessment of what we know future vulnerability to climate change (future exposure sensitivity and adaptive capacity) (Ford and Smit 2004, Ford *et al* 2008, 2009) (figure 4). Similar versions of this approach are widely used in the literature (Adger 2006, Burton *et al* 2002, Eakin and Luers 2006, Smit and Wandel 2006).

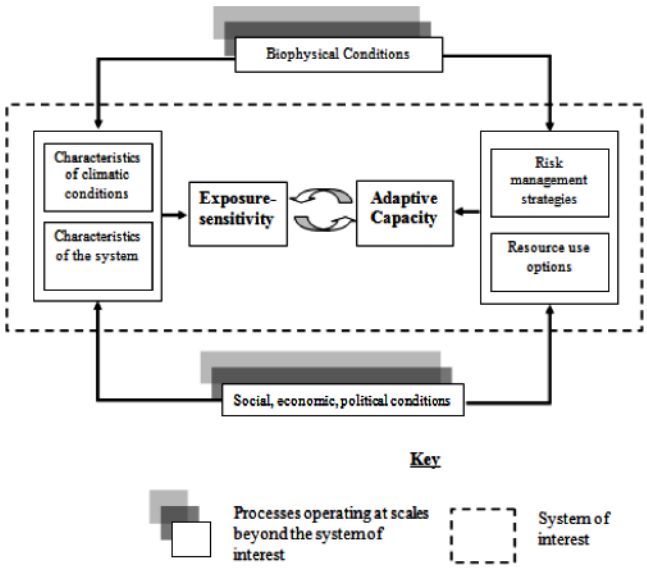

Figure 3. Conceptual model of vulnerability (Ford *et al* 2006).

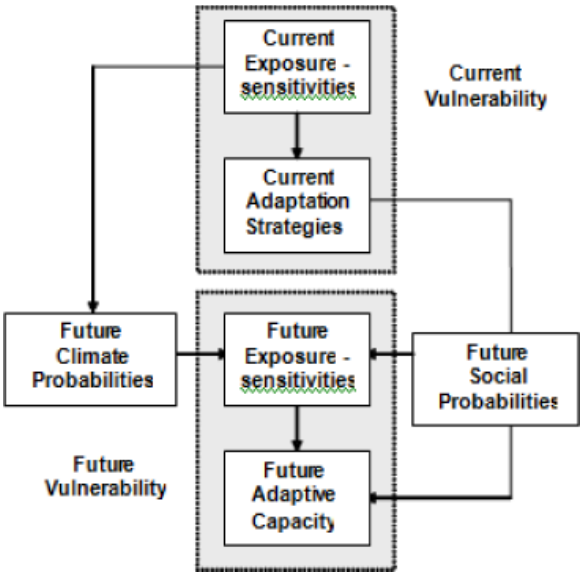

Figure 4. Two step analytical framework use to structure the empirical assessment of what we know and do not know about climate change vulnerability (after Ford and Smit 2004, Smit and Wandel 2006, Ford *et al* 2008).

3.2. Systematic literature review

A systematic literature review is a summary and assessment of the state of knowledge on a given topic area or research question. They are structured to rigorously summarize existing knowledge and evidence while identifying gaps and new directions for future research and differ from generic literature reviews in three main ways: they begin by defining a review strategy, they explicitly identify inclusion and exclusion criteria, and they aim to assess the largest amount of relevant and available literature as possible (Centre for Reviews and Dissemination (CRD) 2001, Petticrew and Roberts 2006, Cochrane Collaboration 2008). The specification of search criteria and full reporting of search results is essential to full disclosure in the review methodology. The review process employed by the Intergovernmental Panel on Climate Change (IPCC), for example, uses many elements of a systematic review including the specification of exclusion criteria and aim to review the literature in its entirety. However, by not fully disclosing search criteria (e.g. search terms used, search databases used, search strategy) and not reporting search results (e.g. number of articles reviewed) the review process has been questioned (Lomborg 2004) and criticized for lack of transparency (Oppenheimer *et al* 2007). While systematic literature reviews are widely utilized in health research (Greenhalgh and Peacock 2005, Heller *et al* 2008), the Cochrane approach being the most common, their use in the social and physical sciences is less common. For example, only eight climate change specific studies in ISI Web of Knowledge report using a systematic literature review methodology (search terms: 'climat* change' and 'systematic review' or 'systematic literature review').

We use a systematic literature review to identify and characterize studies providing insights on the nature of climate change vulnerability in the ISR (i.e. current exposure sensitivity and adaptive capacity, and future exposure sensitivity and adaptive capacity). The review focuses on literature published from January 1990 to March 2009 and is limited to publications in English. To capture the breadth of studies providing potential insights on vulnerability, *all* literature relating to the processes and conditions that determine how climate change risks are manifested and experienced in the ISR and which influence vulnerability was considered eligible, reflected in the use of search terms documented in table 1. Literature concerning climate change mitigation (i.e. reducing greenhouse gas emission) was excluded from the search. The review focused on both the peer reviewed and non-peer reviewed (gray) literature. We expect that this extensive search will have captured the majority of, if not all, scientific and gray literature publications on climate change relevant to the ISR and for understanding vulnerability.

The literature review procedure involved three main steps. The first step was to identify keywords for use in the search process (table 1). As noted above, the search terms were broad to capture the diversity of human and biophysical conditions and processes determining vulnerability. Secondly, a systematic review of scientific search engines (GEOBASE, ISI Web of Knowledge, and JSTOR) and specialized databases (The Inuvialuit Settlement Region Database, Northern Climate Exchange Infosources Database, and The Aurora Research Institute Research Compendia) was performed according to the search terms. Finally, once all relevant sources were identified and retrieved, pertinent information relating to current and future climate change vulnerability was extracted and analyzed using the vulnerability framework described above.

4. Results

4.1. Review characteristics

Four hundred and twenty documents were identified and analyzed and provide a basis for characterizing the nature

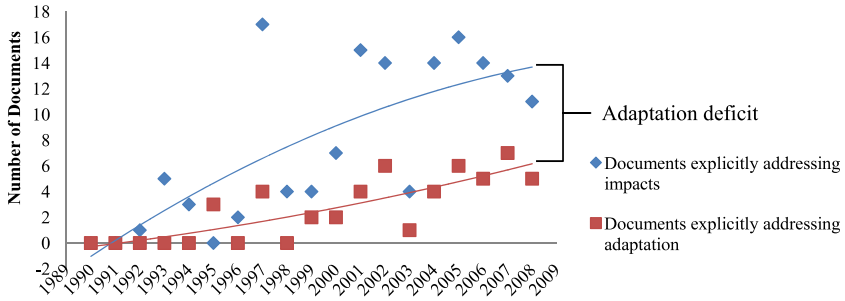

Figure 5. Publications specially addressing climate change impacts and adaptation over time. Note: references from 2009 are not included.

Table 1. Keywords used in guiding the systematic literature review.

	Keyword list				
Place names	Inuvialuit Settlement Region; Mackenzie River Delta; Inuvik; Aklavik; Sachs Harbour; Holman (Ulukhaktok); Paulatuk; Tuktoyaktuk; Banks Island; Beaufort Sea; Northwest Territories; Arctic; Canada				
Generic	Climate; global warming; climate change; climate risks; climate hazards; dangers; risks; hazards; environment, Gwich'in				
Biophysical	Sea ice; sea level; permafrost; precipitation; Ocean; freeze–thaw cycles; temperature; weather; wind; storms; forecasts; snow conditions; erosion; sedimentation; ice freeze-up; ice break-up; forest fires; algae; ice roads; flooding; extreme weather; soil; Pingo; glacier				
Sector	Health and well-being	Economy and Business	Infrastructure and Transportation	Subsistence Hunting and Trapping	Culture and Education
Specific	Socio-economic status; unemployment; livelihood; housing; basic services; drinking water; education; stress; death; injury; accidents; food security; food contamination; disease; community; crime; suicide	Industry; household economy; oil; gas; tourism; sport hunting; tours; public administration; primary resources; exploration; development; mining; technology; government; energy	Transportation networks; buildings; energy; water; sewage; cultural sites; hunting trails; aggregate; construction	Wildlife; wildlife habitat; wildlife migration; youth; technology; country food	Traditional knowledge; land skills; high school; elementary; certificate; degree

of climate change vulnerability and specifying research gaps. The accompanying online data source (available at stacks.iop.org/ERL/5/014008/mmedia) identifies all these documents and is a valuable resource for those working or planning to work in the ISR. Moreover, reflecting the extensive nature of the search, many of the peer reviewed and gray publications listed do not figure in standard searches in academic search engines. The data source therefore makes these publications available for wider dissemination. While in this letter we review this body of knowledge to develop an understanding of climate change vulnerability, there are equally opportunities to review the literature to answer other questions; e.g. what do we know about permafrost thaw in the ISR?

Fifty two per cent of reviewed articles specifically address climate change impacts, vulnerability, and/or adaptations in the ISR and 48% provide insights on vulnerability by discussing aspects of environmental risk and behavior. Out of the publications that explicitly address climate change (n = 217), 74% assess climate change impacts/vulnerability and 26% concern adaptation (figure 5). This is indicative of the adaptation deficit noted for Canada in general (Burton 2005), and the North in particular (Ford 2009, Ford *et al* 2007). The literature focusing specifically on climate change impacts/vulnerability (n = 161) is dominated by studies solely on biophysical systems (42%), followed by general studies of multiple impacts/vulnerabilities (32%). Less work has solely assessed the socio-economic (7%) and health (5%) implications of climate change. The majority (84%) of the documents reviewed can be classified as academic in nature, including articles published in peer reviewed journals, reports, and books. Twenty six per cent of reviewed documents were gray literature and included community, government, NGO, consulting and business reports.

4.2. The nature of climate change vulnerability: what we know and do not know

4.2.1. Current and future exposure sensitivity. The peer reviewed literature contains considerable information documenting the nature of climate change in the ISR and implications for biophysical systems, mostly focusing on one aspect of the physical or biological environment (e.g. permafrost, hydrology, a specific species of plant or animal, etc). Local observations of environmental changes

are also well documented in each settlement, mostly in the gray literature (e.g. Nickels and co-workers 2005 community perspectives). Changes observed in every community include: more unpredictable weather, changing ice dynamics with thinner ice and earlier ice break-up, decreasing snowfall on land, and accelerated coastal and/or riverine erosion (e.g. Berkes 1999, Carmack and Macdonald 2008, Nickels *et al* (Community of Aklavik) 2005a, Furgal *et al* (Community of Arctic Bay) 2005, Fonger (Community of Holman Island) 2005, Nickels *et al* (Community of Inuvik) 2005b, Fonger and Moss-Davies (Community of Paulatuk) 2005, Nickels *et al* (Community of Tuktoyaktuk) 2005c, Riedlinger and Berkes 2001, Riewe and Oakes 2006). Also frequently noted ($\geqslant$4 communities) are later ice freeze-up, melting permafrost, ground slumping, increased sedimentation, new species of wildlife, decreased health of wildlife, warmer winters, less extreme cold, more freezing rain, and more intense sun. Physical science research has documented similar changes to those observed by communities, although largely at a regional scale and with limited information on wind and weather patterns (Furgal and Prowse 2008).

Changing climatic conditions are having *implications for ISR communities* and the literature documents evidence of compromised food security and health status, constrained transportation access and travel routes to hunting areas, damage to municipal infrastructure, and inability to practice traditional cultural activities in all communities (Berkes and Jolly 2002, Nickels *et al* 2005, Pearce *et al* 2010). Threats are unevenly distributed across the region. The Mackenzie Delta settlements, for example, are particular sensitive to permafrost thaw due their construction on ice rich flood plains (Worsley 1992). Similarly, the sensitivity of subsistence hunting and fishing varies widely between communities, depending on local biophysical conditions and human ecology of hunting, and between community members depending on access to financial resources and traditional knowledge (Betts 2005, Furgal and Prowse 2008). Nevertheless, common across the ISR is the importance of ice conditions as a risk. Sea, lake, and river ice are important transportation routes to hunting grounds and between communities, with changing ice conditions affecting travel routes, increasing the danger of ice use, and restricting access. Benefits have also been noted surrounding more ice free open water in summer, with extended fishing opportunities, improved summer transportation by boat, and the creation of new tourism opportunities (Stewart *et al* 2007, Zimmermann 1997).

The majority of research with relevance for characterizing *future exposure sensitivity* focuses on projecting future climatic conditions and impacts on biophysical systems. This work is largely reported as part of broad climate impact assessments (e.g. ACIA 2005, IPCC 2007a, Lemmen *et al* 2008) although focused studies on permafrost thaw and coastal erosion have been published (e.g. Anisimov *et al* 2002, Manson and Solomon 2007, Zhang *et al* 2008). This work has highlighted that changes documented today will increase in magnitude, frequency and spatial extent in the future including accelerated warming, continued permafrost thaw, declining sea ice extent, enhanced coastal erosion, and changing wildlife health and abundance. However, there are few examples of studies which have extrapolated how projections of climate change and associated impacts will interact with social, economic and demographic trends which determine how climate risks are experienced and responded to.

4.2.2. Current and future adaptive capacity. The literature indicates *significant adaptive capacity* among communities. A number of adaptations are documented as being employed today to manage the risks of current climate change. Examples include the substitution of traditional foods for store foods when hunting areas are not accessible, altered timing, mode and methods of subsistence activities, the establishment of community evacuation and preparedness plans in case of extreme events, the development of new ice-based transportation routes to avoid dangerous areas, the strengthening of municipal infrastructure to cope with altered climatic extremes, the development of youth–elder mentoring programs to transmit traditional knowledge on environmental risks, and increasing use of community freezers to store and make accessible traditional foods (Berkes and Jolly 2002, Borsy 2006, Hayley 2004, Newton 1997, Nickels *et al* 2005, Pearce *et al* 2010, Riedlinger 2001). The majority of documented adaptations are in the subsistence hunting/trapping sector and to a lesser extent infrastructure. Few publications report on adaptations in health, cultural and education, or economy and business sectors.

In most instances, documented adaptations are autonomous and reactive in nature, are largely behavioral in form, are being developed to manage everyday climate-related challenges as opposed to climate change *per se*, and are localized in nature. The literature highlights a diversity of practices as underpinning the ability of communities cope with climatic change, including: livelihood and economic diversity to spread risks, indigenous knowledge allowing exploitation of risky environments and management of dangers, social networks through which risk is shared, and acceptance of risk as part of everyday life and management practice (Bates 2007, Berkes and Jolly 2002, Collings *et al* 1998, Pearce *et al* 2009).

Barriers to adaptation are identified in the literature. Financial resources are an important component of the means to adapt, and are identified as one of the main barriers preventing adaptation from taking place. Many adaptations are costly and exceed the financial ability of households, communities, businesses, regional governments, and regional institutions. Households for example, often do not have access to the capital resources to purchase new hunting equipment to take advantage of new conditions or replace equipment lost or damaged in climate-related hunting accidents, and municipalities often struggle to afford existing maintenance projects and are not able to invest in climate proofing infrastructure (e.g. Borsy 2006). Other adaptation barriers are social–cultural in nature including the erosion of traditional land skills among younger generations, weakening of sharing networks, and the cultural value of hunting and consuming certain traditional foods at certain times of the year (Pearce 2006, Usher 2000). These conditions and processes are eroding adaptive capacity and increasing exposure sensitivity of some

groups within communities, particularly youth and those with limited household income (Nickels *et al* 2005, Pearce *et al* 2010).

The literature *identifies adaptations* that have the potential to reduce future exposure-sensitivities and increase adaptive capacity, including integrated regional planning to anticipate future conflicts and stresses, enhanced harvester support assistance, improved skills training, improved search and rescue capacity, better weather and ice hazard forecasting, protection of cultural sites, infrastructure strengthening, and support for new technology (Nickels *et al* 2005). However, the majority of literature addresses future adaptation options as part of broader climate impact studies, lacking detailed policy analysis and often presenting adaption responses as part of 'wish lists'. No published studies have undertaken cost benefit analysis of adaptation options, examined how adaptations would be developed and implemented, assessed support for various options among stakeholders and community members, or examined the performance of adaptation options under different climate change scenarios.

5. Discussion: what we need to know

While few formal vulnerability assessments have been conducted in the ISR, the literature contains considerable insights on the components of vulnerability and determinants, as synthesized in this letter. We know that the climate of the ISR is changing with widespread implications for human activities. We also know that there is a high level of adaptive capacity, with a number of adaptations currently being utilized and developed. Despite a high level of adaptive capacity, however, the literature documents a number of barriers to adaptation together with social and economic changes which are undermining adaptive capacity. A number of research gaps and priorities regarding current vulnerability are evident. Firstly, while adaptations have been documented across the ISR, their effectiveness, durability, and long term viability in light of multiple stresses and competing policy priorities have not been assessed. Secondly, while there is a well developed understanding on the current vulnerability of subsistence hunting and infrastructure, our understanding of current vulnerability would be improved by further research on health systems, economic sectors, and culture and education.

There has been limited research which has directly assessed future vulnerability to climate change in the ISR and there are few studies from which insights for future vulnerability can be obtained. Modeling studies have increased our understanding of how the climate of the ISR will change but there is a need for studies that examine how projected changes might interact with human systems to affect exposure sensitivity, and assess how socio-economic–demographic trends will affect how communities experience a changing climate. Moreover, location specific assessments of climate change impacts would contribute towards improving understanding of future vulnerability, with the majority of biophysical studies focusing on regional level projections and impacts. While some adaptations have been identified in the literature as having the potential to reduce future vulnerability and determinants of adaptive capacity have been identified, few publications explicitly assess future adaptive capacity. There is need to identify a suite a potential adaptations and examine their effectiveness in reducing climate change vulnerability, specify their costs and benefits, and assess broader non-climatic benefits. Until these gaps are addressed, anticipatory adaptation planning is likely to be limited (Ford 2009).

Of broader significance, the review methodology utilized here is of interest to climate/environmental change research in general. Systematic reviews enable a rigorous characterization of what is known in a given area, enabling existing knowledge to be identified and synthesized, and research gaps determined in an unobtrusive way. They are particularly useful in fields characterized by a large or emerging body of research, offering enhanced transparency compared to standard reviews. With research on climate change impacts, adaptation and vulnerability proliferating, systematic reviews offer a promising tool to assess what we know, do not know, and need to know. Indeed, in light of calls for highly focused specialized reports summarizing knowledge in key areas on climate change, proposed by Oppenheimer *et al* (2007) as a means of overcoming limitations of the current IPCC process, systematic reviews offer significant promise.

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References

ACIA 2005 *Arctic Climate Impacts Assessment* (Cambridge: Cambridge University Press)

Adger W N 2006 Vulnerability *Glob. Environ. Change-Human Policy Dimensions* **16** 268–81

Anisimov O A, Velichko A A, Demchenko P F, Eliseev A V, Mokhov I I and Nechaev V P 2002 Effect of climate change on permafrost in the past, present, and future *Izv.—Atmos. Ocean Phys.* **38** 25–39

Barber D G, Lukovich J V, Keogak J, Baryluk S, Fortier L and Henry G H R 2008 The changing climate of the arctic *Arctic* **61** 7–26

Bates P 2007 Inuit and scientific philosophies about planning, prediction, and uncertainty *Arct. Anthropol.* **44** 87–100

Berkes F 1999 *Sacred Ecology: Traditional Ecological Knowledge and Resource Management* (London: Taylor and Francis)

Berkes F and Jolly D 2002 Adapting to climate change: social–ecological resilience in a Canadian Western Arctic community *Conserv. Ecol.* **5** 1–15 available at www.consecol.org/vol5/iss2/art18/

Betts MW 2005 Seven focal economies for six focal places: the development of economic diversity in the western Canadian Arctic *Arct. Anthropol.* **42** 47–87

Borsy E 2006 *The Impacts of Climate Change on the Availability of Granular Resources in the Inuvialuit Settlement Region, Northwest Territories* (Toronto: Ryerson University)

Burton I 2005 Adapt and thrive: options for reducing the climate change adaptation deficit *Policy Options* **27** (December 2005–January 2006) 33–8

Burton I, Huq S, Lim B, Pilifosova O and Schipper E L 2002 From impacts assessment to adaptation priorities: the shaping of adaptation policy *Clim. Policy* **2** 145–59

Carmack E and Macdonald R 2008 Water and ice-related phenomena in the coastal region of the Beaufort Sea: some parallels between native experience and western science *Arctic* **61** 265–80

Centre for Reviews and Dissemination (CRD) 2001 Undertaking systematic reviews of research on effectiveness (CRD's guidance for those carrying out or commissioning reviews) available at www.york.ac.uk/inst/crd/report4.htm

Cochrane Collaboration (ed) 2008 *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.0.1

Collings P, Wenzel G and Condon R G 1998 Modern food sharing networks and community integration in the Central Canadian Arctic *Arctic* **51** 301–14

Duerden F 2004 Translating climate change impacts at the community level *Arctic* **57** 204–12

Eakin H and Luers A 2006 Assessing the vulnerability of social-environmental systems *Ann. Rev. Environ. Res.* **31** 365–94

Fonger R and Moss-Davies P (Community of Holman Island) 2005 *Unikkaaqatigiit—Putting the Human Face on Climate Change—Perspectives from Holman Island, Inuvialuit Settlement Region* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Fonger R and Moss-Davies P (Community of Paulatuk) 2005 *Unikkaaqatigiit—Putting the Human Face on Climate Change—Perspectives from Paulatuk, Inuvialuit Settlement Region* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Ford J D 2009 Dangerous climate change and the importance of adaptation for the Artic's Inuit population *Environ. Res. Lett.* **4** 024006

Ford J D, Pearce T, Prno J, Duerden F, Berrang-Ford L, Marshall D and Smith T 2009 *Canary in a Coal Mine: Climate Change Impacts, Adaptation, and Vulnerability in the Canadian Mining Sector* David Suzuki Foundation

Ford J D, Pearce T, Smit B, Wandel J, Allurut M, Shappa K, Ittusujurat H and Qrunnut K 2007 Reducing vulnerability to climate change in the Arctic: the case of Nunavut, Canada *Arctic* **60** 150–66

Ford J D and Smit B 2004 A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change *Arctic* **57** 389–400

Ford J D, Smit B and Wandel J 2006 Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada *Global Environ. Change* **16** 145–60

Ford J D, Smit B, Wandel J, Allurut M, Shappa K, Ittusarjuat H and Qrunnut K 2008 Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada *Geogr. J.* **174** 45–62

Furgal C, Akumilik K and Barnes B J (Community of Arctic Bay) 2005 *Unikkaaqatigiit—Putting the Human Face on Climate Change: Perspectives from Arctic Bay, Nunavut* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Furgal C and Prowse T 2008 Northern Canada *From Impacts to Adaptation: Canada in a Changing Climate 2007* ed D Lemmen, F Warren, E Bush and J Lacroix (Ottawa: Natural Resources Canada)

Furgal C and Prowse T 2009 Climate impacts on northern canada: introduction *Ambio* **38** 246–7

Government of Northwest Territories (GNWT) Bureau of Statistics 2008

Greenhalgh T and Peacock R 2005 Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources *Br. Med. J.* **331** 1064–5

Hayley D W 2004 *Climate Change: An Adaptation Challenge for Northern Engineers* (Alberta: Association of Professional Engineers, Geologists and Geophysicists of Alberta)

Heller R F, Verma A, Gemme H I, Harrison R, Hart J and Edwards R 2008 Critical appraisal for public health: a new checklist *Pub. Health* **122** 92–8

IPCC 2007a Climate change 2007: impacts, adaptation and vulnerability *Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report (Geneva)*

IPCC 2007b Climate change 2007: the physical science basis *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Geneva)*

Lemmen D, Warren F, Lacroix J and Bush E 2008 *From Impacts to Adaptation: Canada in a Changing Climate 2007* (Ottawa: Government of Canada) p 448

Lomborg B 2004 Need for economists to set global priorities *Nature* **431** 17

Manson G K and Solomon S M 2007 Past and future forcing of beaufort sea coastal change *Atmos.-Ocean* **45** 107–22

Newton J 1997 Coping with floods: an analogue for dealing with the transition to a modified climate in the northern sector of the mackenzie basin *Mackenzie Basin Impact Study (MBIS): Final Report* ed S Cohen Environment Canada pp 219–24

Newton J, Paci C D and Ogden A 2005 Climate change and natural hazards in northern Canada: integrating indigenous perspectives with government policy *Mitig. Adapt. Strateg. Glob. Change* **10** 541–71

Nickels S, Furgal C, Castleden J, Armstrong B, Buell M, Dillion D, Fonger R and Moss-Davies P (Community of Aklavik) 2005a *Unikkaaqatigiit—Putting the Human Face on Climate Change—Perspectives from Aklavik, Inuvialuit Settlement Region* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Nickels S, Furgal C, Castleden J, Armstrong B, Binder R, Buell M, Dillion D, Fonger R and Moss-Davies P (Community of Inuvik) 2005b *Unikkaaqatigiit—Putting the Human Face on Climate Change—Perspectives from Inuvik, Inuvialuit Settlement Region* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Nickels S, Furgal C, Castleden J, Armstrong B, Binder R, Buell M, Dillion D, Fonger R and Moss-Davies P (Community of Tuktoyaktuk) 2005c *Unikkaaqatigiit—Putting the Human Face on Climate Change—Perspectives from Tuktoyaktuk, Inuvialuit Settlement Region* Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa

Oppenheimer M, O'Neill B C, Webster M and Agrawala S 2007 Climate change—the limits of consensus *Science* **317** 1505–6

Pearce T 2006 *Vulnerability and Adaptation to Environmental Change in Uluhaktok* University of Guelph, Guelph

Pearce T, Ford J, Duerden F and Smith T R 2009 Climate change vulnerability and adaptation in the ISR: a sytematic literature review and gap analysis *Project Report from the Dept. of Indian and Northern Affairs Climate Change Impacts and Adaptation Program* p 144

Pearce T, Smit B, Duerden D, Ford J, Goose A and Kataoyak F 2010 Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada *Polar Rec.* at press

Pearce T *et al* 2009 Community collaboration and environmental change research in the Canadian Arctic *Polar Res.* **28** 10–27

Petticrew M and Roberts H 2006 *Systematic Reviews in the Social Sciences: A Practical Guide* (Malden, MA and Oxford: Blackwell)

Prowse T D and Furgal C 2009 Northern canada in a changing climate: major findings and conclusions *Ambio* **38** 290–2

Prowse T D, Furgal C, Chouinard R, Melling H, Milburn D and Smith S L 2009 Implications of climate change for economic development in northern canada: energy, resource, and transportation sectors *Ambio* **38** 272–81

Riedlinger D 2001 Responding to climate change in northern communities: impacts and adaptations *Arctic* **54** 96–8

Riedlinger D and Berkes F 2001 Contributions of traditional knowledge to understanding climate change in the Canadian Arctic *Polar Rec.* **37** 315–28

Riewe R and Oakes J (ed) 2006 *Climate Change: Linking Traditional and Scientific Knowledge* (Manitoba: Aboriginal Issues Press)

Smit B and Wandel J 2006 Adaptation, adaptive capacity, and vulnerability *Global Environ. Change* **16** 282–92

Snow N and Carpenter L 2001 *Inuit Observations on Climate Change: Local Action and Global Impact* Paper presented at Climate Change in the Circumpolar North Summit, Whitehorse, Yukon

Stewart E J, Howell S E L, Draper D, Yackel J and Tivy A 2007 Sea ice in Canada's Arctic: implications for cruise tourism *Arctic* **60** 370–80

Usher P J 2000 Traditional ecological knowledge in environmental assessment and management *Arctic* **53** 183–93

Usher P J 2002 Inuvialuit use of the Beaufort Sea and its resources, 1960–2000 *Arctic* **55** 18–28

Worsley P 1992 Problems of permafrost engineering as exemplified by three communities in the north western Canadian Arctic *Quat. Proc.* **2** 67–78

Zhang Y, Chen W J and Riseborough D W 2008 Transient projections of permafrost distribution in Canada during the 21st century under scenarios of climate change *Global Planet. Change* **60** 443–56

Zimmermann D 1997 *Part B: Community Opportunity Listings, Tourism Information and Implementation Plans. Western Arctic Community Tourism: Discussion Paper* Zimmermann Consulting, Inuvik, NWT