Sustain Sci (2017) 12:15–29
DOI 10.1007/s11625-016-0401-5

ORIGINAL ARTICLE

Longitudinal assessment of climate vulnerability: a case study from the Canadian Arctic

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Received: 29 April 2016 / Accepted: 14 September 2016 / Published online: 23 September 2016

Abstract The Arctic is a global hotspot of climate change, which is impacting the livelihoods of remote Inuit communities. We conduct a longitudinal assessment of climate change vulnerability drawing upon fieldwork conducted in 2004 and 2015 in *Ikpiarjuk* (Arctic Bay), Nunavut, and focusing on risks associated with subsistence harvesting activities. Specifically, we employ the same conceptual and methodological approach to identify and characterize who is vulnerable, to what stresses, and why, assessing how this has changed over time, including re-interviewing individuals involved in the original study. We find similarities between the two periods, with many of the observed environmental changes documented in 2004 having accelerated over the last decade, exacerbating risks of land use: changing sea ice regimes and wind patterns are the most widely documented at both times, with new observations reporting more frequent sighting of polar bear and orca. Socio-economic and technological changes have altered the context in climate change impacts are being experienced and responded to, both exacerbating and moderating vulnerabilities compared to 2004. The adoption of new technology, including GPS and widespread use of the internet, has helped land users manage changing conditions while sharing networks remain strong, despite concern noted in the 2004 study that they were weakening. Challenges around access to financial resources and concern over the incomplete transmission of some environmental knowledge and land skills to younger generations continue to increase sensitivity and limit adaptive capacity to changing climatic conditions.

Keywords Climate change · Inuit · Vulnerability · Adaptive capacity · Nunavut · Subsistence · Adaptation · Resilience

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Introduction

The Canadian Arctic is widely acknowledged as a global hotspot of climate change impacts (Larsen and Anisimov 2014). The implications of this are particularly pronounced for indigenous populations, including Inuit, whose close association with the natural environment for livelihoods and culture creates unique sensitivities to the rapidly changing climate (Ford et al. 2015b). Changing ice conditions, for example, are already inhibiting travel and constraining Inuit subsistence harvesting activities, with implications for food security, death or injury while travelling on the ice, as well as mental wellbeing (Cunsolo-Willox et al. 2015; Ford et al. 2012, 2014; Durkalec et al. 2015). More frequent and extreme weather events including flooding, landslides and erosion have affected fresh water resources and damaged built infrastructure (e.g., houses, roads, and community facilities) (Ford et al. 2015a; Hatcher and Forbes 2015; Martin et al. 2007). Despite these and other ongoing impacts and sensitivities to climate change, Inuit has also demonstrated significant adaptive capacity to manage changing climatic conditions (Berkes and Jolly 2002; Pearce et al. 2011a, b; Ford et al. 2015a; Pearce et al. 2015).

The last decade has witnessed a rapid expansion of studies examining climate change impacts, adaptation and vulnerability (IAV) in the Arctic, with much of this research focusing on Canada in general and Inuit communities in particular (Downing and Cuerrier 2011; Ford et al. 2012, 2013), along with work from Alaska (Alessa et al. 2008a, b; Kofinas et al. 2010; Sakakibara 2010). Early work in this area focused on documenting observations of climate change (Krupnik and Jolly 2002; Nickels et al. 2005; Riewe and Oakes 2006), with studies increasingly investigating what makes certain regions, communities, households, and individuals more or less susceptible to harm and documenting how human systems are adapting (Ford et al. 2015b). This work emphasizes that vulnerability and adaptive capacity are not just a function of how the climate is changing, but how these changes interact with non-climatic conditions and stresses operating at various spatial and temporal scales (Berkes and Jolly 2002; Gearheard et al. 2006; Ford et al. 2015b, 2006; Laidler et al. 2009; Pennesi et al. 2012; Wolf et al. 2013; Pearce et al. 2015). Studies have focused primarily on the risks posed by climate change to subsistence-based livelihoods and land-based activities, reflecting community concerns with hunting, fishing, and trapping; all of which continue to have significant social, cultural and economic importance to Inuit. Key findings have illustrated the importance of traditional knowledge, social networks, access to financial resources, and resource use flexibly as underpinning adaptability, demonstrating that emerging vulnerabilities are driven by social-economic–political–demographic changes (Ford et al. 2015b).

Existing IAV research has made notable contributions to our understanding of how climate change interacts with society in an arctic context, yet our knowledge remains incomplete (Ford and Pearce 2012). In particular, we lack a dynamic understanding of how Inuit are experiencing and responding to climate change over time. Our current understanding of Inuit vulnerability to climate change is limited to place-based case studies over relatively short temporal periods (i.e., a few months), whereas vulnerability is dynamic and adaptation is a process that unfolds over time. This knowledge deficit stems from conceptual and methodological limitations of contemporary climate change IAV research (Ford and Pearce 2012). New approaches and methodologies are needed if we are to develop a more dynamic understanding of Inuit vulnerability and adaptive capacity to climate change. In this paper, we employ a longitudinal approach to examine vulnerability to climate change through a re-study of a vulnerability assessment (Ford et al. 2006) conducted in *Ikpiarjuk* (Arctic Bay), Nunavut, over a decade ago. In this study we draw upon interviews with the original cohort and examine of instrumental data on changing biophysical conditions (e.g., sea ice) to document current exposure sensitivities and adaptive responses, which are then compared with the findings from the original study.

Methodology

Conceptual approach

This research utilizes a consistent ‘vulnerability approach’ to the original study described by Ford and Smit (2004), which in turn builds upon a long history of research in the climate change and natural hazards field that seeks to understand human–environment interactions in light of environmental changes and stresses (Bohle et al. 1994; Cutter 1996; Liverman 1990; Smit and Pilifosova 2003). In this work, vulnerability refers to the susceptibility of a system (i.e., community) to harm relative to climate stimuli and relates to both to exposure sensitivity and capacity to adapt to climatic changes (Smit and Wandel 2006). Exposure sensitivity refers to the susceptibility of human systems (i.e., individuals, households, communities) to climatic risks and is dependent on both the nature of the climatic conditions experienced and the characteristics of the system experiencing them. The nature of climate-related risks may include the magnitude, frequency, temporal spacing, rapidity of onset, and spatial distribution of biophysical risks. Adaptive capacity refers to the potential or ability of human systems to address, plan for, or adapt to these risks, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007). Adaptive capacity is influenced by various interacting factors operating at multiple scales, including livelihoods, financial resources, social networks, infrastructure, social institutions, experience with risk, the range of technological adaptation available, as well as the equity of access to resources (Ford and Smit 2004; Smit and Wandel 2006; Keskitalo 2008).

The vulnerability approach that we use does not predetermine a focus on climate change, but rather characterizes climate change in the context of socioeconomic drivers, particularly focusing on issuing such as marginalisation, inequality, exploitation, and exclusion (Ribot 2011, 2014; Ford et al. 2013; Wang et al. 2014). As such, the work is consistent with what has been termed ‘contextual’ or ‘starting point’ approaches to vulnerability assessment, and contrasts to ‘end point’ assessments that seek to identify and quantify vulnerability specifically attributable to climate impacts (O’Brien et al. 2007;

Räsänen et al. 2016). In the original study, the vulnerability approach was used to identify and characterize current vulnerabilities to climate-related risks and change in *Ikpiarjuk*. Likewise, here we use the same model to characterize vulnerability in 2015, from which we compare and contrast to findings from the original study.

Since the publication of the original work, the vulnerability field has rapidly expanded (McDowell et al. 2016; Wang et al. 2014). Some have also critiqued the use of 'vulnerability' in IAV research. The term has been argued to focus on the negative, overlooking socio-historical drivers of change and community resilience, downplays local agency, and represents a techno-bureaucratic approach (Cameron 2012; Hall and Sanders 2015). These critiques hold insights for strengthening our understanding, but we also note the long tradition in vulnerability research of focusing on how societies experience and respond to climate change in the context of multiple stressors. Vulnerability assessments often emphasize adaptive capacity and resilience. We further note the long history of political activism in vulnerability work that seeks to account for and challenge what makes people vulnerable (Hewitt 1983; Liverman 1990; Blaikie et al. 1994; Bohle et al. 1994; Smit and Wandel 2006; O'Brien et al. 2007; Ribot 2011, 2014). We, thus, view vulnerability approaches as an essential starting point for understanding how climate interacts with society, alongside approaches from different intellectual traditions (e.g., resilience, sustainable livelihoods).

Case study location

Ikpiarjuk (Arctic Bay) is a coastal community on northern Baffin Island in the territory of Nunavut, Canada, approximately 700 miles north of the Arctic Circle (73° 02′N, 85° 10′W) (Fig. 1). The settlement (population: 823) is representative of many communities throughout Nunavut, most of which are small, remote, coastal and predominantly Inuit. Over the last 60 years, the economy of *Ikpiarjuk* has shifted from one based on subsistence activities to a mixed economy in which both the informal and formal economic sectors assume an important role (Damas 2002) (Table 1). The building of a lead, zinc, and silver mine 20 miles away in the community of Nanisivik began in 1976 and, until its closure in 2006, provided employment for the community and also exaggerated the transition to a mixed economy (Damas 2002; Ford et al. 2006).

In *Ikpiarjuk*, as they are for Inuit communities across the Canadian Arctic, subsistence-based activities including the harvesting of local plants and animals (known as 'country food') are of significant cultural and economic importance. 'Country foods' underpin local food systems, culture and wellbeing. Key species locally harvested include: narwhal, ringed seals, caribou, arctic char, and, to a lesser extent, ptarmigan, snow goose, beluga whale and arctic fox. Subsistence activities require time spent on 'the land' and the use of semi-permanent trail networks to access harvesting locations on sea, river and lake ice, open-ocean, and terrestrial environments.

Finally, the selected community had to be representative of communities throughout Nunavut (small, largely Inuit, and dependent upon the harvesting of renewable resources).

Data collection

Longitudinal study design

Repeated observation of human–environment interactions over extended periods of time is essential for understanding the dynamics of vulnerability, recognizing that exposure-sensitivity and adaptive capacity are continually evolving, shaping and re-shaping how climate risks are experienced and responded to. To capture this dynamism, this study employs a longitudinal approach, facilitating the analysis of continuity and change over an 11-year period. Herein, Epstein (2002) and Young et al. (1991) classify longitudinal studies into three formats of research design: (1) continuous research in the same geography over a number of years; (2) periodic re-studies at regular or irregular intervals; and, (3) returning after a lengthy interval of time has elapsed. This research project sits within the third classification, as the research involves returning to *Ikpiarjuk* to examine the same themes over a decade after the original study.

Mixed methods

We employ the same methods used in the original study, the fieldwork for which was conducted in 2004, noting that, while the 2015 fieldwork was undertaken by a different researcher, those engaged in the original study helped to direct the work and examine the findings. Semi-structured interviews ($n = 40$) were conducted with research participants using the same interview guide as the 2004 study, and during the same months (February and March) (Table 3). We sought to interview the same participants involved in the 2004 study ($n = 50$), of whom 24 were available for a repeat interview in 2015. The remaining original participants had either passed away ($n = 8$), relocated to other communities ($n = 11$), or either declined or were unavailable for inclusion in the restudy ($n = 7$). This represents an attrition rate of 52 %. To account for this, new participants ($n = 16$) were recruited, with sampling seeking to recruit participants with similar demographic characteristics (i.e., age, gender and livelihoods) to those interviewed in the original study (Table 2). This was

Fig. 1 The Canadian territory of Nunavut with *Ikpiarjuk* and sea ice data points highlighted

Table 1 Demographic change in *Ikpiarjuk* over a 10-year period

Characteristics	2001	2006	2011
Population (total)	645	690	823
Aged 0–14 years	240 (37 %)	235 (44 %)	300 (36 %)
Aged 15–64 years	400 (62 %)	445 (64 %)	485 (58 %)
Aged 65 and over	10 (1.5 %)	15 (2 %)	35 (4 %)
Inuit population	610 (94 %)	640 (92 %)	795 (96 %)
Employment rate %	49.4 %	42.0 %	39.8 %
Unemployment rate %	21.6 %	26.0 %	25.9 %
Average individual income	$21,270	No data	$28,813
Sources: StatsCanada	(2001)	(2006)	(2011)

done in collaboration with the same local research assistant involved in the 2004 work (Mishak Alluraut, who is a co-author here. Consistent with the original study, a fixed list of questions was avoided in favour of an interview guide, which identified key themes to be covered in the interview. The interview guide was consistent with the one used in the original study, with elements of change explored as the participants led discussions (Table 3). Interviews were complemented with overt participant observation, experiential trips with people on 'the land', with the purpose of these trips made explicit and consent formally obtained. Finally, seven informal meetings were held with key informants.

Instrumental data were also used to inform the analysis of biophysical change experienced between the original study and the present day and also to provide longer-term context on the nature of the changes occurring in the *Ikpiarjuk* region (such data was not used in the original study).

Sea ice data were obtained in chart form from the Canadian Ice Service (CIS), which has issued sea ice concentration data for Hudson Bay on a weekly basis since 1971 (Gagnon and Gough 2005). These data are derived from both surface observation and satellite imagery, with ice concentration information expressed in tenths (from 0 to 10/10) which refers to the fractional surface area of the ocean that is covered with sea ice, or essentially, the percentage of surface ice cover (Gagnon and Gough 2005). Sea ice concentration data were obtained for nine sampling points surrounding the community (Fig. 1), and were chosen on the basis importance for trail usage of community harvesters. Specifically, point 1 is an area in which spring-time seal hunting takes place; points 2, 3 and 4 along well-used hunting trails; while points 6 and 7 represent the floe-edge from which narwhal hunting takes place.

The ice charts were also used to estimate sea ice breakup and freeze-up dates and conditions from 1968 to 2014. The sea ice breakup date is defined as the first date when the ice concentration was 5/10 or less during the summer months, while the ice freeze-up date was determined to be the earliest date when the ice concentration reached 5/10 or more between October and December (Gough et al. 2004; Gagnon and Gough 2005). These thresholds are in accordance with the terminology utilized by both the Canadian Sea Ice Service and the World Meteorological Organization (WMO) (Gagnon and Gough 2005). Dates were expressed numerically as the ordinal day of the year, where January 1st was the 1st day and December 31st was the

Table 2 Interview guide

Section	**Questions**
Introduction and context Background information Hunting patterns	Where were you born? How long have you lived in Arctic Bay? Do you have family? Do you work? Do you hunt? What do you hunt, and when/where?
Current climate change exposures Climate related Social, economic and cultural	What problems do you face when hunting? What affects your ability to hunt? Have you experienced any difficulties in hunting? How do environmental conditions affect your hunting and community? Describe the demand for the animals you hunt.
Management strategies Strategies Constraints Opportunities	How do you manage risks in hunting? Has this changed since you were younger? Why? What constrains your ability to manage risk? Are things more difficult today than when you were younger?
Change over time Climatic change Economic change Change in skills, behaviours or strategies	Have climatic conditions changed in recent years? Has this affected your ability to hunt? Has the local economy changed in recent years, what does this mean for your trade? Have you developed new strategies, behaviours or skills in recent years?

Table 3 Cohort demographics

COHORT 1 (2004)		COHORT 2 (2015)	
$n = 50$		$n = 40$	
Descriptor	Sample (%)	Descriptor	Sample (%)
Sex		Sex	
Male	63	Male	55
Female	37	Female	45
Age group		Age group	
20–30	14	20–30	3
31–40	12	31–40	20
41–50	12	41–50	15
51–60	8	51–60	15
61–70	20	61–70	5
70–80	29	70–80	30
81+	4	81+	13
Employment		Employment	
Unemployed	39	Unemployed	40
Part time	4	Part time	5
Full time	35	Full time	33
Retired	22	Retired	23
Hunting frequency		Hunting frequency	
Never	18	Never	13
Rarely	18	Rarely	18
Spring time only	20	Spring-time only	8
Weekends only	20	Weekends only	28
All year round	22	All year round	35

365th day, unless there was a leap year in which case December 31st would be the 366th day of the year (Gagnon and Gough 2005; Kowal et al. 2015). As a result, the data is structured that for each year (from 1968 to 2014) there are nine breakup and nine separate freeze-up dates pertaining to each of the nine superimposed sampling points (See Fig. 1) (Gagnon and Gough 2005; Kowal et al. 2015).

Analysis

The data were analyzed in a two-part process. First, data pertaining to the current nature of climate change vulnerability in 2015 were analysed; and second, data from both studies were compared and contrasted to extract information regarding the nature and drivers of change. Longitudinal analysis was specifically incorporated through the comparison of interview data between the 2015 cohort and that of the 2004 cohort. For those individuals who were interviewed in both studies, the two transcripts were examined simultaneously, identifying and characterizing the similarities, differences, and changes in exposure sensitivity and adaptive capacity over the 10-year period. Changes in exposure sensitivity and harvesting-related behaviors were coded, as were contextual changes such as changes in the employment, retirement, and health of the individual. This allowed for the chronological assembly of data, organizing or re-storying to develop an understanding of what happened first, next and then what is currently taking place (Ollerenshaw and Creswell 2002). Coding was an iterative process. Initially, a descriptive analysis was performed using a coding scheme consistent with the one used in the initial study, identifying key exposure sensitivities, adaptive strategies and determinants of adaptive capacity. Throughout this process, particular attention was given to how these themes have or have not changed over time.

Next, data were analyzed with the intent of explaining and characterizing the processes shaping vulnerability. Analysis of CIS data involved the calculation of the average date of breakup/freeze-up across each of the nine data points for the year. From here, these figures were input into graphs for the identification of trends. Graphs were further drawn up for individual data from each point to identify trends and anomalies. Linear regression was used to detect trends in freeze-up and breakup timing according to date, with a t-statistic calculated on the slope to determine statistical difference from zero (Laidler et al. 2009). We also analysed trends in ice coverage by decade: 1970–81, 1982–92, 1993–03, 2004–14.

Results

Consistent with the 2004 study, the vulnerability approach is used to structure the presentation of results, focusing on identifying and characterizing the nature and determinants of exposure sensitivity and adaptive capacity. Within this structure, we compare results from 2004 with 2015, documenting and examining the nature of vulnerability, its drivers, determinants, and influencing factors, and seeking to tease out change over the observation period. In presenting results, we use quotes from interviews to give depth to the description and, consistent with the first study, include the names of the research participants quoted in this paper where permission was given.

Exposure sensitivities

Changes in sea ice dynamics, wind strength and direction, and the health and availability of some species of wildlife important for subsistence have exacerbated risks associated with hunting and travel in *Ikpiarjuk*. Changes in the socio-economic context of the community further entrench these risks.

Sea ice dynamics

The sea ice surrounding *Ikpiarjuk* is the platform for the community's wildlife harvesting activities. Except for a period of open water from mid-July to early October, travel and harvesting are largely performed on the sea ice. Changes in sea ice dynamics were identified by all participants in the 2015 study ($n = 40$), most commonly later ice freeze-up and earlier breakup. Changing thickness of sea ice also featured prominently in interviewee responses. The *Ikpiarjuk* region was described to be experiencing thinner ice year-round, with most notable changes in ice thickness in the spring and fall, when the ice becomes too thin and dangerous for travel. Similar observations were made in 2004, although only by the more experienced and regular land users; whereas, in 2015 almost all research participants stressed that the rate at which the sea ice is changing has accelerated over the last decade.

> "I have noticed that the ice is very thin today. In all seasons, it is much thinner than it once was"—Qaumayuq Oyukuluk, 2015.

> "The ice seems to be thinning all the time, I think. But every year it changes, I mean it's different"—Jobie Attitaq, 2004.

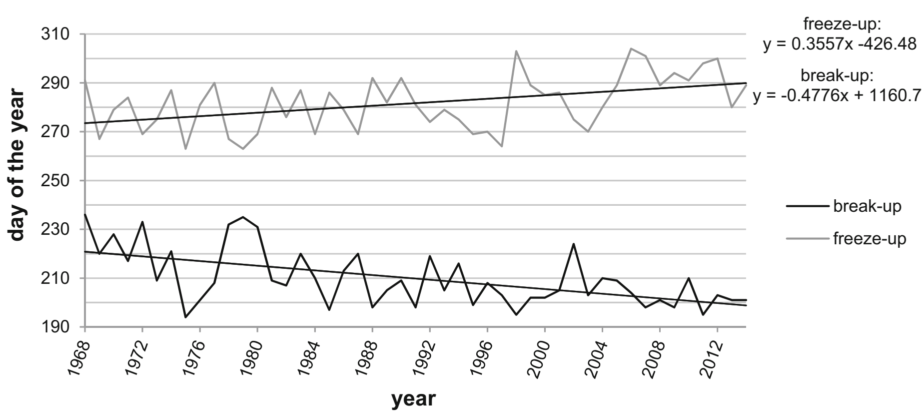
These observations are consistent with the instrumental data, which indicates that from 2004 to 2014 there has been a 25 % increase (18 days) in the length of the ice-free open water period. This finding is also consistent with longer-term warming trends since 1968 (Fig. 2). Very late freeze-up dates are becoming more frequent, with recordings of November freeze-ups (typically October) in the most recent decade (2012, 2007 and 2006); there is only one other recording of a November freeze-up from 1968 to 2003, documented in 1993. While breakup dates are occurring progressively later in the year, there is one recorded anomaly of an early breakup: July 7th 2014, 10 days earlier than the earliest recording in the previous decade. Data also show an increase in the number of extremely long summers of completely ice-free water. In the most recent decade (2004-2014), there are two recordings of more than 100 days of ice-free water per year (2007 and 2011). Besides 1998, there are no other recordings of such extended ice-free seasons, with an average of approximately 60 ice-free days per year from 1968 to 1998.

All research participants reported reduced access to hunting areas in the late spring and fall months as a result of these changes, with negative implications for food and income security. This signifies a shift from the 2004 study, in which fewer participants reported experiencing environmental change. This change could, in part, be due to a prolonged experience with climate change and the increased media attention on these changes, discussed in "Experience with change". Participants noted that these changes have worsened over the last decade. Changes at data points 2, 3, and 4 (Fig. 1) were reported to be particularly problematic for the community as they represent important access routes to hunting areas, delaying access to harvesting opportunities. Similarly, changes at points 6 and 7 at the floe-edge create unstable ice conditions for narwhal hunters, increasing both the risk and cost of hunting at this time. These findings are consistent with regionally observed trends across the Canadian Arctic (Perovich et al. 2013; Comiso and Hall 2014; Vihma 2014).

Wind

Changing wind dynamics are also proving problematic for the community. Interviewees identified changes in the direction, strength, and frequency of wind, all of which present risks for land users. The most commonly cited risk reported was sudden and unanticipated changes in wind strength and direction that causes sea ice to unexpectedly disintegrate in July and August, leading to increased

Fig. 2 Changes in sea ice breakup and freeze-up dates over a 46-year period



incidences of individuals being stranded on drifting ice. This has significant implications for the springtime narwhal hunt which takes place at the floe-edge. Here, hunters take up position along the ice edge, waiting for narwhals to surface close enough to shoot them with a rifle and retrieve them with a grappling hook or boat. As a result of detaching the floe-edge from the ice that is anchored to the shore, many hunters in the study have lost equipment and have occasionally been rescued on floating ice. It is noteworthy that narwhal hunting at this time has always entailed risk (Wilkinson 1955; Brody 1976; Kemper 1980), but respondents identified the changing wind and ice conditions as making the activity even more hazardous. This is consistent with the finding of the 2004 study with the modification of wind direction, speed, and predictability creating unique challenges. Both instrumental and interview data indicate the continuation and exacerbation of these risks over the last decade. An increase in frequency of hunters stranded on drifting ice in need of search and rescue missions, as reported by the community Search and Rescue coordinator, may be indicative of the increasing risks:

> "We were floating on the ice for a couple of days, a helicopter was flying around, it managed to rescue us, got RCMP and asked for help. But that is really uncommon"—Levi Barnabas, 2004.

Participants further reported that changing wind dynamics make travel on the land and ice in wintertime more challenging and expensive. These stronger winds mean that canvas tents, typically used on longer hunting trips in the spring and summer time, can no longer be used. As such, while interview data suggest that strong winds are experienced year-round, implications for camping are most acutely felt in the spring as this is when people are most actively engaged in on the land activities. There is a lack of consistent long-term meteorological data from the local weather station in the community to examine instrumental data on these trends, with wind conditions also recognized to differ between out 'on the land' and in the community where the weather station is located. Further, we were unable to obtain granular descriptions of wind changes over the last decade to explore in greater detail changing wind dynamics, which would necessitate real-time monitoring and documentation of wind observations.

Wildlife

Research participants also reported observing changes in the health, abundance, and migration timing of a variety of wildlife species utilized for subsistence harvesting. In turn, this has affected both harvesting-related risks and the subsistence-based livelihoods. The most commonly reported change in wildlife dynamics over the 10-year period was the loss of caribou near *Ikpiarjuk*. In the 2004 study, a notable portion of the active hunters reported frequently harvesting caribou close to the community or within a day's travel. This is no longer the case, evident in interviews with the same individuals.

> "I hunt caribou here when the ice is still not formed (…) people will be traveling by four wheeler and going over there to hunt caribou. In winter and summer we have caribou here, sometimes it's bad now because you can't get caribou in winter here"—Levi Barnabas, 2004.

> "There used to be caribou here in abundance. We got used to caribou meat, when populations depleted, we have suffered as we like it. So we started ordering it in from other communities but it is expensive. I first noticed the caribou moving away 10 years ago, we have to travel to Igloolik now which made it more expensive"—Levi Barnabas, 2015.

The loss of caribou was described by the community as recent, but it is unclear what role, if any, climate change has played in this decline, or whether these alterations are part of natural cycles or other yet undetermined reasons. Other studies have noted the sensitivity of caribou populations to climate change (Gunn et al. 2011; Struzik 2015), noting that caribou populations could be disrupted by future warming in the context of resource development.

Further changes in the local ecosystem were observed including an increase in the sighting of orca and polar bear around *Ikpiarjuk*. Many recent polar bear sightings have occurred in and around the town and a number of hunters ($n = 5$) reported being attacked by polar bear in recent years. Very few references to polar bear or orca activity were noted in the 2004 study. While an increase in fox populations were identified by the community, decreases in ptarmigan and bird populations were also noted. Mallory et al. (2003) noted a trend in decreasing Ivory Gull populations in the *Ikpiarjuk* area prior to the original study. Other ecosystem changes are yet to be fully examined.

Socio-economic changes

Socio-economic conditions affect how community members interact with changing exposure via land use activities and behavior, with the 2004 study identifying changing socio-economic conditions to be increasing sensitivity to climatic risks in many instances. Over the last decade, there have been continuing changes in the local economic context. The most commonly cited include: the rising cost of living, limited employment opportunities with the closure of the Nanisivik mine, the increased financial cost of hunting, and weakened traditional practices around the sharing of resources. Indeed, these socio-economic changes, not biophysical changes, were reported most frequently in both 2004 and 2015 as the main concerns to community members. Yet they are also highly relevant for climate change vulnerability as they affect human–environment interactions.

The 2004 study documented the high financial costs of harvesting to be prohibitive in responding to changing environmental conditions, especially for full-time hunters and youth with limited income opportunities. The high financial costs are more acute given the need to purchase safety equipment in light of enhanced climate-related dangers, replace equipment lost or damaged in climate-related accidents, and the need to travel longer distances to avoid dangerous areas on the sea ice (Ford et al. 2006). At that time, census data marked the participation in employment rate at 56 % (Statistics Canada 2007), by 2011 it was 52 % (Statistics Canada 2013), and today is unofficially reported to be 50 %. This is reflected by 80 % of respondents in the 2015 study remarking that financial challenges continue to affect how harvesters interact with changing climatic conditions. This is particularly pertinent for risks associated with narwhal hunting: narwhal tusks have become more valuable over the last decade and can be sold and then the profits can be used to purchase hunting equipment. During the original study, tusks sold for US$80–$150/foot, while in 2015 a tusk commanded between $250–$400/foot (a tusk is typically between 11 and 18 feet in length). With few income earning opportunities and high costs of harvesting, many hunters travel to harvest narwhal even in conditions that would have historically been considered unsafe given its economic value, with increasing risk taking evident at the same time that changing conditions are making such actions more dangerous. Quotas on narwhal affect the harvest of this species, with the community distributing a quota allocated to them (approximately 200 in 2015) on a 'first come first served' basis. This further exacerbates risks as hunters attempt to maximize their chance of catching narwhal before the quota expires by hunting them as soon as they arrive in the region, often in June–July when the ice is breaking up.

> "Search and Rescue is busier now than in the past. Especially in the spring and summer, it's because people want to catch narwhals. The tusks are so valuable so more and more people, even inexperienced hunters, go out after them and get in trouble"—Valerie Quanaq (Search and Rescue Coordinator), 2015.

A key theme emerging from the 2004 study concerned the importance of Inuit traditional ecological knowledge (TEK) in food production, procurement and sharing (subsistence hunting, fishing and trapping), helping to moderate sensitivity to changing climatic conditions. TEK can be broadly understood as a body of knowledge, practice, and values acquired through experience, observation, and spiritual teachings, handed down from generation-to-generation (Huntington 1998; Berkes 1999; Pearce et al. 2011a, b). TEK is dynamic, adaptable, cumulative, and is constantly being updated with new experiences and technologies (Wenzel 1991; Ford et al. 2009). In the context of climate change, TEK underpins many of the adaptive strategies Inuit hunters are employing to deal with changing conditions and affect sensitivity by affecting decision choices around land use. In some instances, TEK acts as an 'antecedent causal factor' building on other capacities (e.g., enables hunters to travel at different times of year and on new trails) and in other cases TEK acts as an 'effect modifier' influencing the effectiveness of other factors of adaptive capacity (e.g., an experienced hunter may have more success hunting in new locations and new species than one with less experience) (Pearce et al. 2015). Despite the recognized value and importance of TEK for adaptation to climate change, and in Inuit society more broadly, there is concern among Inuit in *Ikpiarjuk* and elsewhere that some knowledge, skills and values are not being fully transmitted to younger generations (Takano 2004; Pearce et al. 2010, 2011a, b; Ford et al. 2013). Unlike their parents and/or grandparents, Inuit youth today are spending less time involved in subsistence activities beyond organized land camps and occasional hunting trips. They, therefore, have fewer opportunities to learn the knowledge, skills, and values necessary for safe and successful hunting under changing climatic conditions. This was a key theme in the original study and reinforced in 2015:

> "Back then, more young people were trained to be hunters and providers. But not anymore. That knowledge isn't passed on. Because there's less incentive. [Young people] can eat store bought food, they also have school. They are preoccupied."—Anonymous, 2015.

Hunting in the Arctic is inherently dangerous and even more so for inexperienced individuals, especially given the unpredictability of changing conditions. These individuals also experience diminishing returns on their hunting trips, which is particularly pertinent given the rising cost of hunting:

> "Young hunters are not paying attention to traditional knowledge. They hunt regardless of moon-cycles and don't listen to elders. As a result they lose equipment

and get stuck at the floe-edge."—Qaumayuq Oyukuluk, 2015.

A number of participants further mentioned how some TEK of the weather and environment is less reliable than it used to be. Changing and unpredictable environmental conditions appear to be lessening the efficacy of TEK in some instances; some elders report being unable to forecast wind or ice conditions based on clouds wind speeds and/or temperatures. This sentiment is consistent in the 2004 and 2015 studies, though it was more frequently cited in 2015.

> "We used to be able to rely on elders to tell us about the weather conditions, but we stopped asking four years ago or so. The cloud formations are now different, they can't predict the weather anymore."—Jobie Attitaq, 2015.

While some elements of the knowledge component of TEK appear to be in the process of adapting to new climatic conditions, respondents stressed that TEK includes much more than a single knowledge base or skillset. TEK encompasses many of the values and teachings that underpin subsistence in modern Inuit society (e.g., sharing 'country foods', patience, forbearance, observation skills, flexibility, the ability to develop strategy and to efficiently execute it) (Pearce et al. 2011a, b). These teachings prepare younger Inuit to cope with and adapt to forces affecting subsistence (i.e., societal, economic, political, environmental, and climate change) and provide them with the opportunity to engage in productive activities that continue to have economic, health, cultural, and social value.

Adaptive capacity

Sharing networks

In 2004, a high level of interdependence within the extended family unit, a sense of collective responsibility and mutual aid, and sharing were documented to be important in managing climate-related risks and adapting to change (Ford et al. 2006). These networks of reciprocity and sharing were found to facilitate the sharing of food, equipment, and knowledge and ensured a quick response when a member of the community was in need. The study concluded that it was unclear whether these networks that facilitated adaptive capacity would remain functional in the context of continuing social and cultural changes, and documented evidence of a weakening of sharing networks, resulting in the emergence of social conflict. The 2015 study suggests that sharing networks have adapted to a new context and remain strong. The changes in the dynamics of the sharing networks in some ways facilitate adaptive capacity for the wider community. For example, the inclusion of money in the sharing economy facilitates the distribution of this scarce resource and facilitates hunting activities. The inclusion use of financial resources in sharing networks, which participants reported to have only begun in the past 5 years, was perceived to be beneficial to the community. As a result, hunters are able to afford to hunt and continue to provide food for family units and the wider community despite the high and rising price of hunting. In turn, this contributes to food security in times of environmental change, changing migration patterns, and changing availability and accessibility of wildlife resources.

Beyond this, building on the themes outlined in "Sharing networks", the proliferation of technology through the community has further modified sharing networks. Both interview and observational data suggest that within the past decade, many hunters have begun sharing both equipment and 'country food' using Facebook. While the sharing of equipment was less common owing to the high cost of inputs and repairs, upon returning from a successful hunting trip many hunters would post on Facebook that fresh 'country food' (usually seal or polar bear) was available for all, leaving the meat outside of their house. Though the dynamics of sharing networks are complex and unexplored in this study, the observation of community-wide sharing through the Internet may signify a move away from sharing exclusively within the family unit documented in the previous work (Ford et al. 2006).

Experience with change

It is widely recognized that adaptive learning and experience with risk influence how climate risks are experienced and responded to, shaping and reshaping how vulnerability evolves over time (Gearheard et al. 2006; Ford et al. 2009). Interview data from the 2004 study suggest that the climate perturbations experienced at the time were perceived as both recent and unusual but were rarely linked to climate change.

> "[these changes were] unusual because the ice doesn't normally start moving until the wind is blowing it away … it was unusual because although it was calm the ice started cracking."—Lisha Levi, 2004.

Owing to the unusual nature of conditions experienced, interviewees found the changes disorientating yet it was also widely believed that more 'normal' conditions would return in future years. A decade of continuing environmental change in which many of the changes documented in 2004 have accelerated along with sensitization of the community to climate change via the media have altered perceptions, with the majority of interviewees in 2015 reporting to be observing climate change and believing that these changes will continue. Work elsewhere (Gearheard et al. 2006; Ford et al. 2009; Tschakert et al. 2010; Reed et al. 2010) has suggested that experience with risk over longer time periods may facilitate adaptive learning, with repeated and continued exposure and response to changing conditions, land users develop experience in managing these risks, and enables a 'response with learning,' increasing adaptive capacity.

As such, changes are evident in the community's hunting and risk-taking behavior. Though the extent to which the increased use of technology (e.g., GPS, online weather reports) can be attributed to environmental change is unclear, most hunters now use a form of technology to prepare for, manage risk. While the hamlet office describes offering GPS devices to hunters as a response to environmental change, technologies have also become more accessible in both cost and abundance in the community. It is also evident in comparing the 2004 and 2015 interviews that hunters are generally making additional preparations given the experience with climate impacts. Many participants, for example, cited checking weather conditions online or seeking additional guidance from elders before leaving in response to enhanced risks with climate change; furthermore, participants appear to be packing a greater number of supplies (gas, food, parts, clothes) to ensure their ability to cope with getting stranded, a machine breaking down, or a fall through the ice.

Technology

One of the most pronounced changes in the determinants of adaptive capacity over the 10-year period is a noteworthy increase in the use of technology in responding to change. In 2015, hunters reported using a variety of digital tools, including using Facebook to share equipment, obtain information on hazards, request help, checking online weather forecasts and sea ice reports, and using GPS devices that relay information to websites. In 2004, these technologies were in their infancy. New technology in the original study mostly concerned the use of satellite phones and VHF radios and, for a few early adopters, the use of GPS. These technologies were described as a 'double-edged sword'—while helping to buffer certain risks, new technology was also reported to create new risks, exacerbate others, and generate emerging vulnerabilities. GPS, for example, was described to replace the need for traditional navigational knowledge and understanding of the land. It allowed for safe and easy access to hunting grounds and provided guidance when visibility is poor. It also altered risk-taking behavior through instilling a sense of security in the technology; if GPS were to fail, it was a concern that hunters would not possess the traditional skills required to travel safely. Moreover, in 2004 GPS units were expensive and available only to those with adequate income, while in 2015, interview data show a much more widespread use. Almost all research participants reported using or having used a GPS device. They are most often used on longer hunting trips or when hunting from the floe-edge.

> "I use the GPS now near the floe-edge. I check the coordinates before bed, if they have changed by the time I wake up I know I need to get out of there before I drift away."—Simeone Olayuk, 2015.

GPS and other digital tools were also described to be of use not only in hazard avoidance, but in the navigation of already dangerous situations.

> "I am now able to travel safely. GPS helped me travel safely from Pond Inlet to Arctic Bay in a snowstorm. Another time I was using a GPS but it ran out of power so I used an iPad with a map and coordinates—using that I found my way back."—Simeone Olayuk, 2015.

The local hamlet office has promoted the use of GPS for safe harvesting by providing short-term loans of 15 GPS devices free of charge to residents of *Ikpiarjuk*. The Search and Rescue Officer reported that this program began in 2010, funded by the Department for Emergency Management. It was reported that the program is highly popular with hunters using GPS devices year-round. The Search and Rescue Officer commented that, due to the GPS programme:

> "Hunting is safer now. For example, last year, 7 or 8 people got stuck on the same day, drifting on the ice. They lost their skidoos. With GPS and [satellite] phones we could get a helicopter to them"—Valerie Quanaq, 2015.

The 2004 study documented limited availability and limited use of Internet services in the community. By 2015, the Internet was easily accessed and use was widespread, with almost all active hunters reporting using online weather or sea ice reports as important to their preparations. The use of forecasts was noted as important for hunting in all seasons. In winter months hunters are able to avoid blizzards or very cold days (−40 °C and below); and, in the shoulder months, users are able to identify and avoid areas with bad ice conditions. In summer, boating is avoided when winds are forecasted to be strong. Those who were unable to read English or did not have Internet access reported having a relative check the online forecasts and feed this information back to them. Beyond the use of online weather and ice reports, the use of digital social networks such as Facebook appears to confer adaptive capacity. The active community Facebook group allows for the identification of those in need, for the coordination of unofficial search and rescue trips, and facilitates the sharing of both food and equipment. As an example, during fieldwork several postings were made in the group to confirm the whereabouts of two young hunters who were late returning from a hunting trip. Facebook was used to coordinate a rescue trip and donations of gas, skidoos, and equipment. The use of the Internet by the community of *Ikpiarjuk* signifies perhaps the most salient change in adaptive capacity over the 10-year period.

Discussion and conclusion

There is a well-established body of scholarship examining climate change impacts, adaptation, and vulnerability (IAV) in the Arctic. We contribute to this work by conducting a longitudinal assessment of climate change vulnerability drawing on a case study from *Ikpiarjuk*, Nunavut. Specifically, we conducted a vulnerability assessment in 2015 using the same conceptual framing and methods to those used in a previous study in 2004. The re-study research design allows us to compare and contrast the findings from 2015 with the original study to document changes in the nature, experience, and determinants of exposure sensitivity and adaptive capacity. To our knowledge, no other studies in an arctic IAV context have utilized such a research design.

The work demonstrates, over the course of a decade, the continuities in adaptation and vulnerability to the effects of continuing climatic changes first documented in *Ikpiarjuk* in 2004. Sea ice breakup and freeze-up dates are occurring progressively later and there is a continued pattern in less predictable weather and changes in wildlife dynamics. Similar to the original study, in 2015, we broadly found that the exposure sensitivities and adaptive capacity of present day *Ikpiarjuk* have been modified and challenged by changing socio-economic conditions. The simultaneous rise in the cost of living, limited employment opportunities, and youth disengagement in hunting activities were found to exacerbate vulnerabilities associated with changing climatic conditions. Many community members reported to be unable to purchase the supplies, equipment, or technologies necessary to respond to changing conditions, while others found that wage employment limited time being spent on the land and thus prohibited the acquisition of skills and experience needed to manage risk. However, the community demonstrated significant adaptive capacity through the use of technology, modifying traditional sharing networks, and supporting traditional skills workshops. As such, the longitudinal assessment indicates that, at a broad level, the determinants of vulnerability and adaptive capacity first documented in 2004 are similar today. A number of key additional insights emerged from the longitudinal nature of the study.

Firstly, some barriers to adaptation noted in the original study have become further entrenched while others have become less prominent. Flexibility in resource use, for instance, has been documented to underpin adaptability to variable and unpredictable conditions in a variety of circumpolar indigenous settings—yet, is affected by a variety of factors. Wage employment, for instance, reduces the time available to harvest, but also a lack of access to financial resources is one of the main barriers in accessibility to gas and supplies necessary to make hunting trips and respond to changing climatic conditions. A rise in the costs associated with hunting, combined with reduced employment opportunities, are detrimental primarily to the unemployed and youth. Hunters who have retired from full-time work are particularly at risk as they are often unable to afford the necessary equipment for safe hunting on their limited and fixed pensions.

Cultural changes represent further barriers to adaptation. The 2004 study noted a reduced engagement in traditional practices such as food sharing and hunting. The 2015 interviews indicate the continuation of this trend. Inuit food sharing networks have long contributed to food security in the context of environmental stress, yet the reduced participation of younger Inuit in harvesting is placing strain on sharing networks, exacerbated by limited access to traditional foods with changing climatic conditions.

Second, the last decade has witnessed the widespread adoption of new technologies in the context of harvesting activities, with implications for sensitivity and adaptive capacity to changing conditions. In 2015, participants reported being increasingly prepared for climatic risk as a result of checking online weather reports, while GPS devices and Facebook allow for quick and effective rescue and community mobilization in times of emergency. These facilitators of adaptive capacity were not apparent in the initial study, although their long-term effectiveness in buffering risk needs further investigation in light of potential alteration to risk-taking behavior. The inclusion of monetary resources in sharing networks is also evident over the last decade in *Ikpiarjuk* and elsewhere in the Canadian north (Gombay 2009; Wenzel 2013). The inclusion of money in sharing facilitates adaptive capacity of those for whom access to financial resources is limited, although elder research participants perceive this change as detrimental to Inuit culture with potential negative long-term implications for sharing.

Third, a number of studies, both in the Arctic (Ford et al. 2008, 2013; Pearce et al. 2010) and elsewhere (Davidson-

Hunt and Berkes 2003; Reed et al. 2010; Fazey et al. 2005, 2007) have suggested that continued climatic change may stimulate adaptive learning. These works posit that learning in response to change takes place through observation, iterative experimentation, and practical engagement with the land and oral transmission of knowledge from elders (Ford et al. 2009; Ford et al. 2006; Pearce et al. 2010). There is little indication in the scholarship as to how fast and for whom adaptive learning takes place, or on how climate factors motivate this. In *Ikpiarjuk*, interviewees reported little to no adaptive learning over the 10-year period when directly asked, often citing that hunting patterns and behaviors remain the same today as they always have. However, comparing both interview and observational data from both the 2004/5 and 2015 study indicate that some adaptive learning may well be occurring. Today, for example, many of those interviewed understand the environmental changes experienced as directional, whereas in 2004 interviewees conceptualized environmental change as part of a cycle and commonly noted that they would soon normalize. As such, hunters are preparing for change and not expecting things to go back to normal soon as was the case in 2004. This study has shown that as climate change continues, people are recognizing this and are preparing accordingly, whether taking greater precautions, altering their risk-taking behaviours, or using technology. However, more research is needed to substantiate the extent to which such learning is being motivated by climate change, examine how fast adaptive learning is taking place, and the extent to which such learning can offset future impacts.

Finally, a decade of vulnerability and resilience studies in northern Canada (Pearce et al. 2015; Berkes and Jolly 2002; Furgal and Seguin 2006; Ford and Pearce 2010) has demonstrated the critical role that TEK plays in underpinning adaptive capacity. In several instances, studies have acknowledged that TEK underpins many adaptations—including flexibility with regard to seasonal cycles of hunting and resource use (Pearce et al. 2015). For instance, the ability to use new trails to access harvesting areas or hunt new species depends upon a detailed knowledge of the land and animals. Both the longitudinal nature of this study and growth in TEK scholarship indicate that TEK continues to be important in enabling flexibility in hunting, hazard avoidance, and preparedness—especially in the context of continuing and pervasive climatic and socio-economic changes. Yet, as per other work, this study indicates continued concern over the transmission of TEK between generations, which is being further be challenged by climate change impacts that reduce the opportunities for going on the land and challenge the confidence of younger individuals. The longitudinal restudy design in this work is novel in the Arctic climate change IAV scholarship, allowing a broad characterization of key trends around factors affecting exposure sensitivity and adaptive capacity to changing climatic conditions. The work provides the basis for identifying opportunities for more focused investigation of specific drivers of change. Important foci for future research could involve examining the role of technology such as GPS and social media in affecting climate vulnerability in northern communities of diverse sizes, investigating how sharing networks are continuing to evolve in light of rapid social and climatic changes, and examining the role of adaptive learning.

Acknowledgments A special thanks to the community of *Ikpiarjuk*, particularly the Allurut and Koonoo families. This research would not have been possible without the financial support provided by SSHRC, ArcticNet and CIHR. Thanks to Marie Puddister for helping with the creation of Fig. 1. Thanks also to Dr. George Wenzel at McGill University for his assistance throughout the project, and to Dr. Gita Ljubicic for her considered support. We declare no competing interests. The research had ethics approval from McGill University (REB# 139-1014) and a research license from the Nunavut Research Institute (02 005 15 N-M).

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