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Article:

Archer, L, Ford, JD orcid.org/0000-0002-2066-3456, Pearce, T et al. (3 more authors) (2017) Longitudinal assessment of climate vulnerability: a case study from the Canadian Arctic. Sustainability Science, 12 (1). pp. 15-29. ISSN 1862-4065

https://doi.org/10.1007/s11625-016-0401-5

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

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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 killer whales. Socio-economic-technological changes have altered the context within which 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 in the 2004 work 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.

1. Introduction

The Canadian Arctic is widely acknowledged as a global hotspot of climate change impacts (Larsen & 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 well-being (Cunsolo Willox et al., 2015; Ford et al., 2014, 2012;(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 have also demonstrated significant adaptive capacity to manage changing climatic conditions (Ford et al., 2015,(Berkes and Jolly, 2002; Pearce et al., 2015; Pearce et al., 2011).

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; Ford et al., 2014), along with work from Alaska (Alessa et al., 2008a, 2008b; 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., 2006; 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; Ford et al., 2006; Ford et al., 2015b; Gearheard et al., 2006; Laidler et al., 2009; Pearce et al., 2015; Pennesi et al., 2012; Wolf et al., 2013). Studies have focused primarily on risks posed by climate change to subsistence-based livelihoods and land-based activities, reflecting community concerns, with hunting, fishing, and trapping continuing 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 (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 later. We draw upon interviews with the original cohort and an examination 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.

2. Methodology

2.1. 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 which 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 (community) to harm relative to a climate stimuli, and relates to both to sensitivity to climate exposures and capacity to adapt (Smit and Wandel, 2006). Exposure-sensitivity refers to the susceptibility of human systems (individual, 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 & Smit, 2004; Smit & 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 which seek to identify and quantify vulnerability specifically attributable to climate impacts (O'Brien et al., 2007)(Rasanen et al., in press). In the original study, the vulnerability approach was used to identify and characterize current vulnerabilities to climate related risks and change in Ikpiarjuk; here we use the 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’ IAV research, which it has been argued focuses on the negative, overlooks 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 socio-economic-political conditions and change. Vulnerability assessments often emphasize adaptive capacity and resilience, and we further note the long history of political activism in vulnerability work which seeks to account for and challenge what makes people vulnerable (Blaikie et al., 1994; Bohle et al., 1994; Hewitt, 1983; Liverman, 1990; O'Brien et al., 2007; Ribot, 2011; Ribot, 2014; Smit and Wandel, 2006). 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).

2.2. Case study location

Ikpiarjuk (also called 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) (Figure 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 sixty 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 subsistence-wage economy (Damas, 2002; Ford et al., 2006).

Subsistence-based activities, including hunting, fishing, and trapping are important in Ikpiarjuk, as they are for Inuit communities across the Canadian Arctic, with country foods derived from harvesting underpinning local food systems, culture and well-being. Key species locally harvested include narwhal, ringed seals, caribou, and 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 the sea, river and lake ice, open ocean, and terrestrial environments.

2.3.Data collection

2.3.1. 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 3 formats of research design: i) continuous research in the same geography over a number of years; ii) periodic re-studies at regular or irregular intervals; and iii) returning after a lengthy interval of time has elapsed since the original research. 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.

2.3.2. 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 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 2). 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 replace the kind of individuals originally interviewed according to age, gender, and livelihood characteristics. This was done in collaboration with the same local research assistant who was involved in the 2004 work, 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 2). Interviews were complemented with overt participant observation, experiential trips with people 'on the land', with the purpose of these trips made explicit to the participants and consent was obtained. Finally, 7 informal meetings were held with key informants

Instrumental data were also used to inform the analysis of biophysical change in and around Ikpiarjuk 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). This data is 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 9 sampling points surrounding the community (Figure 2), and were chosen on the basis importance for trail usage of community harvesters: 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 break-up 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 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 in such a fashion that for each year (from 1968 to 2014) there are 9 breakup and 9 separate freeze-up dates pertaining to each of the 9 superimposed sampling points (See figure 2) (Gagnon and Gough, 2005; Kowal et al., 2015). One derived metric is included, the ice free season duration, which is the difference between freeze-up date and breakup date and as a result there are 9 separate ice-free dates (Kowal et al., 2015).

2.3.3. Analysis

The data were analyzed in a two-part process: first, analysis of data pertaining to the current nature of climate change vulnerability in Ikpiarjuk in 2015; 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 that 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 ten-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 break-up/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 at each point. Linear regression was used to detect trends in freeze-up and break-up timing according to date, with a t-statistic calculated on the slope to determine statistical difference from zero (see Laidler et al., 2009). We also analyze trends in ice coverage by decade: 1970-81, 1982-92, 1993-03, 2004-14.

3. 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.

3.1. 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.

3.1.1. 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 is 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 break up. Changing thickness of sea ice featured also 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 instrumental data, which indicates that from 2004-2014 there has been a 25% increase in the length of the ice-free open water period by 18 days. This finding is also consistent with longer-term warming trends since 1968 (Figure 3). Very late freeze-up dates are becoming more frequent, with recordings of November freeze-ups (norm is early October) in the most recent decade (2012, 2007 and 2006); there is only one other recording of a November freeze-up from 1968-2003, documented in 1993. While break-up dates are occurring progressively later in the year, there is one recorded anomaly of an early break-up of July 7th in 2014, ten 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). Other than 1998, there are no other recordings of such extended ice-free seasons, with an average of approximately 60 ice-free days per year from 1968-1998.

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. Participants noted that these changes have worsened over the last decade. Changes at data points 2,3 and 4 (Figure 2) 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 & Hall, 2014; Vihma, 2014).

3.1.2. 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 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, they watch and wait for narwhals to surface for air close enough to shoot them with a rifle and retrieve them with a grappling hook, or boat. A strong southerly wind, which is now described as being more frequent and more severe, can detach the floe-edge from the ice that is anchored to the shore thereby stranding hunters. 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 risks (Wilkinson, 1955; Brody, 1976; Kemper, 1980), but respondents identified the changing wind and ice conditions as making the activity even more hazardous.

The 2004 study found that the aforementioned changes in ice conditions, combined with the modification of wind direction, speed, and predictability created unique challenges. Both instrumental and interview data indicates the continuation and exacerbation of these risks over the last decade, as ice conditions have continued to change and a southerly wind has become more frequent. 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:

> "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

> "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. Canvas tents, used on longer hunting trips in the spring and summer time, can no longer stand up to the stronger winds that are being experienced; while interviews 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 from which to examine instrumental data on these trends, with wind conditions also recognized to differ out 'on the land' than 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.

3.1.3. 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 ten-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 (refs needed), with concern that caribou 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 killer whales 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 bears in recent years. Very few references to polar bear or killer whale 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.

3.1.4. Socio-economic changes

Socio-economic conditions affects 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 by interviews including 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 changes, and not changing climatic conditions, were reported most frequently in 2004 and 2015 as the main concerns to community members, yet 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 and in the context of the need to purchase safety equipment in-light of enhanced dangers with climate impacts, replace equipment lost or damaged in climate-related accidents, and the need to travel longer distances to avoid dangerous areas on the sea ice with changing ice conditions (Ford et al., 2006). At that time, census data marked the participation in employment at 56% (StatsCanada, 2007), and today that rate is unofficially reported to be 50%, and, as of 2011, 52% (StatsCanada, 2013). 80% of respondents in the 2015 study noted financial challenges as continuing 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 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.

A key theme emerging from the 2004 study concerned the importance of Inuit traditional ecological knowledge (TEK) for subsistence hunting, fishing and trapping (food production, procurement and sharing), 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, and handed down from generation to generations (Huntington, 1998; Berkes, 1999; Pearce et al. 2011). TEK is dynamic, adaptable and 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 in Inuit society and for adaptation to climate change, there is concern among Inuit in Ikpiarjuk and elsewhere the Arctic that some knowledge, skills and values important for subsistence are not being fully transmitted to younger generations (Takano, 2004; Pearce, 2010; Pearce et al., 2011; 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, and thus 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 but even more so for less inexperienced individuals, especially given the unpredictability of changing conditions. These individuals are also experiencing 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, 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 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. 2011). These teachings prepare younger Inuit to cope with and adapt to forces affecting subsistence—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.

3.2 Adaptive capacity

3.2.1 Technology

One of the most pronounced changes in the determinants of adaptive capacity over the ten years is a noteworthy increase in the use of technology in responding to change. In 2015, hunters reported using a variety of digital tools from accessing Facebook to share equipment, obtain information on hazards, or request help, checking online weather forecasts and sea-ice reports, to 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, with such technologies 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 but also altered risk-taking behavior through instilling a sense of security in the technology, and if GPS were to fail, it was a concern that hunters would not possess the traditional skills required to travel safely. Moreover, GPS units were expensive and available only to those with adequate income. In comparison to 2004, such sentiments while documented in the 2015 interviews, were not widely reported. In 2015, 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 with GPS devices loaned 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 subsequent use of Internet services in Ikpiarjuk. By 2015 Internet use 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 (-40C and below); in the shoulder months users are able to identify and avoid areas with bad ice conditions; and in summer, boating is avoided when winds are forecasted to be strong. For those that were unable to read English or did not have Internet access, they 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 appear 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 ten-year period.

3.2.2 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 suggests that the climate perturbations experienced at the time were perceived as both recent and unusual, and 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. It has been suggested in the literature that experience with risk over a longer time period may facilitate adaptive learning, where repeated and continued exposure and response to changing conditions develops experience of how to manage them, and enables ‘response with learning,’ increasing adaptive capacity (Gearhead et al., 2006; Ford et al., 2009; Tschakert et al., 2010)(Reed et al., 2010).

As such, changes are evident in the community's hunting and risk taking behavior. Though the extent to which the increased use of technology (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 its offering of 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 of 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.

3.2.3 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 a scarce resource (money) and facilitates hunting activities. The inclusion use of money in sharing networks, which participants reported to have only begun in the past five years, was perceived benefit 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.

4 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 what was 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 Arctic Bay in 2004. Sea ice break-up 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. Waged employment for instance, reduces the time available to harvest, but also a lack of access to financial resources is one of the main barriers constraining the ability of harvesters to afford gas and supplies 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 mostly 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, and 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, particularly comprised 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 and Harding, 2012). 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; Ford et al., 2013; Pearce et al. 2010) and elsewhere (Davidson-Hunt & Berkes, 2003; Reed at al., 2010; Fazey, Fazey and Fazey, 2005; Fazey et al., 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 ten 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 occuring. 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. More research is needed however, to substantiate the extent to which such learning is being motiovated by climate change, and examine how fast adaptive learning is taking place and 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 Sequin, 2006; Ford et al., 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 at 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 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 which reduce the opportunities for going on the land and challenge the confidence of younger individuals.

The development of a longitudinal restudy design in this work is novel in the Arctic climate change impacts, adaptation and vulnerability 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 thank you 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. Thank you to Malcolm Araos for helping with the creation of figures 1 and 2. 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 15N-M).

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Figure 1 The Canadian territory of Nunavut with Ikpiarjuk highlighted

Figure 2 Sea-ice data points surrounding Ikpiarjuk

Figure 3 Changes in sea-ice break-up and freeze-up dates over a 46-year period