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Ice over troubled waters: navigating the Northwest Passage using Inuit knowledge and scientific information

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ABSTRACT: Sea ice throughout the Arctic is undergoing profound and rapid change. While ice conditions in the Canadian Arctic Archipelago have historically been more stable than conditions in the open ocean, a growing body of evidence indicates that the major thoroughfares in much of the western and central Canadian Arctic, including the Northwest Passage, are increasingly vulnerable to climatic forcing events. This is confirmed by the observations of Inuit elders and experienced hunters in the communities of Cambridge Bay, a hamlet along Dease Strait, and Kugluktuk, a hamlet situated at the mouth of the Coppermine River where it meets Coronation Gulf. People in these hamlets now face new navigational challenges due to sea-ice change. Navigation practices described by elders and hunters reflect an intimate knowledge of the land and ice topography, currents, and weather conditions for hundreds of kilometers around their communities, although people reported increasing unpredictable weather and ice conditions, making travel more treacherous. Many emphasized the importance of traditional knowledge and survival skills as necessary to adapt to ongoing and impending changes. They expressed particular concern that younger generations are untrained in traditional navigation practices, landscape- and weather-reading abilities, and survival practices. However, elders and hunters also stressed the need for more localized weather information derived from weather stations to help with navigation, as current weather and ice conditions are unprecedented in their lifetimes.

KEY WORDS: Northwest Passage · Navigation · Inuit knowledge · Sea ice · climate change

1. INTRODUCTION

Around the Arctic, stable sea ice serves as a platform for life. Sea ice regulates the timing and magnitude of algal and phytoplankton blooms — nearly half of all marine primary productivity — and influences the timing of the migration of higher predators (Post et al. 2013). The structure of cracks and flaw leads in the ice provides habitat for marine mammals such as ringed seals and the polar bears that hunt them (Barber et al. 2012a). By creating a near-continuous solid surface across marine areas for several months of the year, sea ice functions as a route for, or barrier to, transportation for both people and wildlife. Sea ice in the Canadian Arctic Archipelago (CAA) serves as an important land bridge and habitat for migrating terrestrial wildlife such as caribou and muskox traveling between the Canadian mainland and summer feeding grounds (Poole et al. 2010, Post et al. 2013).

Sea ice is a critical component of the territories that Inuit use and occupy (Boas 1964, Milton Freeman Research Ltd. and Canada Department of Indian Affairs and Northern Development 1976, Riewe 1991, Aporta 2004, 2011, Laidler et al. 2009, Krupnik et al. 2010). For Inuit people who have lived in the

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Canadian Arctic for thousands of years, navigating over sea ice — and learning to read the ice for vital clues on thickness, stability, and other properties essential for safe travel — allows access to the region's abundant resources and connections to neighboring communities. Long-distance navigation over ice to hunting grounds in the CAA typically occurs from November to June, depending on ice conditions (Berkes & Jolly 2002, Ford et al. 2006a,b, Pearce et al. 2011, Prno et al. 2011). December through March are the coldest months of the year in much of the CAA (Government of Canada 2018) and are regarded by experienced hunters in Ulukhaktok (Northwest Territories, Canada) to be the safest for traveling on sea ice (Ford et al. 2008a). Inuit knowledge of the ice and surrounding lands enables this travel (Berkes & Jolly 2002, Ford et al 2006a,b, Pearce et al. 2011, Prno et al. 2011), which today is also complimented by use of navigational technologies such as GPS, satellite imagery (Aporta & Higgs 2005), and, when feasible, near-real-time weather information.

However, across the Arctic, ice conditions are changing dramatically. Empirical measurement and satellite data suggest ice extent in the CAA is indeed declining, although not in the same manner as the Arctic overall. While summer sea-ice extent in the Arctic Ocean has decreased by 10% per decade since 1979 (NSIDC 2011), and up to 13.3% per decade in recent years (Perovich et al. 2016), estimated ice-extent loss in the CAA is less severe, ranging from 2.9% per decade (Tivy et al. 2011) to 8.7% per decade (Howell et al. 2009). But considering ice extent alone belies the significance of changing ice conditions in the region. Several studies have shown that the CAA is experiencing a longer melting season (Howell et al. 2009, Galley et al. 2012), leading to a lengthier period of open water and later fall freeze-up. The ice pack in the CAA is showing greater vulnerability to atmospheric forcing events, demonstrated in recent years as poor recovery of ice thickness, especially following the extreme melt years of 2012 (lowest), 2007 and 2016 (second lowest), and 2011 (third lowest) (Howell et al. 2013, NSIDC 2017a). High-resolution RADARSAT data indicate early melt onset in record-low ice years and increasingly variable melt times since the extreme low-ice year of 2007 (Mahmud et al. 2016). In that same year, the Northwest Passage (NWP) was completely ice free for the first time in recorded history (Cressey 2007, Perovich & Richter-Menge 2009); a phenomenon repeated in 2016 (Di Liberto 2016). The ice retreat was the most pronounced (40–70%) in 2017 in the western Beaufort Sea (NSIDC 2017b). The combination of longer melt seasons and more open water, however, appears to allow greater import of multi-year ice into the CAA from the north (Howell et al. 2013), which partly explains the relatively small change in ice extent in the region. This thick, strong multi-year ice presents a significant navigational hazard, and sets up an interesting problem as vessel transits through the NWP increase in response to the longer open-water season (Pizzolato et al. 2016, NSIDC 2017b).

First-hand accounts from Inuit elders and experienced hunters of changes in sea ice, weather, and climate in the Canadian Arctic demonstrate significant impacts on Inuit activities and livelihoods. Many report that weather and sea-ice conditions are increasingly unpredictable (Ford & Smit 2004, Ford et al. 2006a, 2008a). Interviewees in Igloolik (Nunavut), Ulukhaktok (Northwest Territories), and Churchill (Manitoba) report later freeze-up, earlier break-up, thinner ice, stronger wind, changes in wind direction, and unpredictable weather (Ford et al. 2008a). Community members from Paulatuk, Sachs Harbour, and Ulukhaktok (Northwest Territories) report less sea ice and more open water, changes in the formation of land-fast ice, a 1-month advance in fall freeze-up, and changes in ice cracks, pressure ridges, and flaw leads (Barber et al. 2012b). Similarly, interviewees in Umiujaq, Kangiqsualujjuaq, and Kangiqsujuaq in Nunavik, northern Quebec, report increases in shrub growth and abundance, increased mammal abundance, and lower water levels, while reported changes in other factors such as sea-ice thickness and storm frequency varied by community (Cuerrier et al. 2015). These changes are seriously impacting daily life in many communities. Precarious conditions such as rough ice, open water leads, thin or unstable ice, and storm events pose significant challenges to navigation and hunting activities (Nichols et al. 2004, Ford et al. 2008b). Hunters in Igloolik, Ulukhaktok, and Churchill report increased risks and hazards when utilizing sea ice for traveling and hunting; they also note that changing weather conditions have disrupted the timing and dependability of travel and wildlife migrations (Ford et al. 2008a).

Increased commercial activity in the NWP can also compound environmental stressors by breaking-up sea ice and delaying animal migrations (Dumond et al. 2012). While more development may mean an increase in local economic opportunities, many Inuit are concerned that these activities might disrupt wildlife migration routes, distributions, and overall viability (Taylor 2005). These concerns are underscored by the fact that most of the caribou herds in

the Canadian Arctic are already in serious decline (NOAA 2009, Festa-Bianchet et al. 2011, Government of Canada 2016), destabilizing subsistence practices and food security within these communities (Ford 2009, Statham et al. 2015). Only the Dolphin and Union caribou herd, which migrates seasonally over sea ice connecting Victoria Island to wintering grounds on the Canadian mainland, has remained stable in recent years (Dumond & Lee 2013), but increased development combined with sea-ice changes may compromise this stability.

Inuit have shown tremendous coping skills and adaptability to changing climate, both in the past and the present (Krupnik 1993, Freeman 1996, Pearce et al. 2015). These result from extensive knowledge of the land (land skill) and from profound knowledge of the Arctic ecosystems and environment, which together are sometimes referred to as traditional ecological knowledge (TEK) (Pearce et al. 2015) or more commonly now, Inuit knowledge (IK). Canadian Inuit face many social, political, economic, and environmental challenges, all of which can impact the transmission of navigation and subsistence hunting knowledge from older to younger generations (Laidler et al. 2009). There is ongoing discussion about the extent to which the disruption of knowledge transmission may impact climate adaptability among the Inuit, who are the youngest and fastest-growing population in Canada (Pearce et al. 2015).

In a time of rapid melting of sea ice and unprecedented weather conditions in the Arctic, understanding the unique challenges and needs of people in coastal Canadian Arctic communities is increasingly urgent to ensure their wellbeing and survival (Parlee & Furgal 2012). Identifying community use of technology and needs for localized weather information may help support emergent strategies where IK and technology are used together for navigating an unpredictable and unprecedented climate. In this paper, we report observations from community members in 2 predominantly Inuit communities in the Canadian Arctic, Cambridge Bay and Kugluktuk, Nunavut, on sea-ice change, emerging navigational challenges, and the use of traditional and scientific information in navigation. This research was conducted in partnership with the Kugluktuk Angoniatit Association Hunters and Trappers Association (HTA) and Ekaluktutiak Hunters and Trappers Organization (HTO) in Cambridge Bay, Nunavut, and focused on the use of Dease Strait and Coronation Gulf in the NWP by community members, specifically their navigational techniques and current challenges to safe travel. (While there are in fact several passages through the Canadian Arctic known as the 'Northwest Passage', 3 main routes exist, and in this paper we use NWP to refer to the route known as the 'southern route'. The main difference between the southern route and the other routes is that it passes south of Victoria Island via Queen Maud Gulf, Dease Strait, and Coronation Gulf and Amundsen Gulf; northern routes pass north of Victoria Island.)

In addition, local needs for weather information to improve local navigation were identified to inform instrumentation of meteorological stations in Dease Strait and Coronation Gulf. The meteorological stations implemented as a result provide real-time weather observations to community members along common travel routes and at sites where subsistence activities take place (Else et al. 2015, Else 2016). The stations also collect data on the sea-ice energy balance to inform understanding of current conditions of climate change in the NWP.

1.1 Study area: political, cultural and geographic context

The Canadian Arctic is divided politically into 3 territories: Nunavut, the Northwest Territories, and Yukon. Nunavut includes most of the CAA, a group of over 36 000 islands occupying an area the size of Greenland (Arctic Council 2009). Nunavut is the largest and least populous Canadian territory, with 31 906 people in 1 877 787 km^2 — a total of only 0.1% of the Canadian population in 21% of Canada's land area (Government of Canada 2011). The population of Nunavut is predominantly Inuit (83%) (Government of Canada 2011).

Kugluktuk (or *Qurluktuk*, 'place of moving water') is the westernmost community in Nunavut, north of the Arctic Circle, located on the Canadian mainland. It is a small hamlet at the mouth of the Coppermine River, which flows into Coronation Gulf. Known as Coppermine until 1996, Kugluktuk became a major settlement for the people in the region often known as 'Copper Inuit' for their skills in shaping arrowheads, harpoons, and *ulu* knives from the copper sourced from the shores of Coppermine River (Jenness 1946, Condon & Ogina 1996). Since 1927, the hamlet has served as an outpost for the Hudson Bay Company, leading to a gradual accumulation of services, including the Royal Canadian Mounted Police, a weather station, radio facilities, a nursing station, and a day school. In more recent years, commercial resource exploration has been on the rise (Kitikmeot Heritage Society and Polar Knowledge Canada

2016). As of the 2011 census (the latest census data with complete demographic information), the population of Kugluktuk was 1450 people, 90% Inuit (Statistics Canada 2012a). The 2016 census reports a slightly higher population figure (1491), but figures on Inuit and non-Inuit identity have not yet been released (Statistics Canada 2017). The people of Kugluktuk still rely heavily on their traditional economy of hunting and fishing for cultural, economic, and nutritional wellbeing. The area is primarily tundra close to the tree line. The region is projected to see significant development of transit shipping, fishing, tourism, and mining.

Cambridge Bay (or *Iqaluktuuttiaq*, 'place with plenty of fish') is located on the southeast coast of Victoria Island, Dease Strait. It is an important commercial fishing area and the transportation and administrative center for the Kitikmeot region, one of the three regions in Nunavut. It is the largest stop for passenger and research vessels traversing the NWP. Cambridge Bay is home to the newly established Canadian High Arctic Research Station (CHARS) and consequently will soon see an influx of new research activities and wage labor positions. Cambridge Bay, like Kugluktuk, is settled by Copper Inuit who moved to the region after the establishment of a trading post there in the 1920s (The Hamlet of Cambridge Bay undated). The establishment of a long-range navigational beacon (LORAN) and distant early warning (DEW) military base, one of the largest manned stations in the North Warning System, in the 1950s, increased the population and job opportunities in the hamlet (The Hamlet of Cambridge Bay undated). As of 2011, Cambridge Bay has a population of 1610, 77% of whom are Inuit (Statistics Canada 2012b). The 2016 census reports a slightly higher population figure, 1766 (Statistics Canada 2017), but lacks data on Inuit vs. non-Inuit identity.

2. METHODS

In partnership with the Kugluktuk HTA and the Ekaluktutiak HTO, semi-structured open-ended interviews were conducted in November 2015 using the snowball sampling method (Noy 2008). Cambridge Bay and Kugluktuk were selected because both communities are located along the NWP and, because of the history of land use and occupancy, people there were well positioned to discuss navigational practices and provide insight on how sea-ice change is impacting travel and wildlife harvesting. Ethics approval to conduct interviews in Cambridge Bay and Kugluktuk was obtained from the University of Vermont Institutional Review Board (CHRBSS 16-113). A research license (05 014 16N-M) was issued from the Nunavummi Qaujisaqtulirijikkut (Nunavut Research Institute) to conduct interviews in the study locations. An additional research license (04 018 15R-M) from the Nunavut Research Institute was issued for work related to weather stations in the study region. Participants provided both written and oral informed consent. The interviews were conducted in English and Innuinaqtun, with local partners providing translation and guidance. The participants were remunerated according to local guidelines. Transcribed interviews were coded with HyperResearch (ver. 3.7.3) software using an iterative coding process (Maxwell 2005) based on research questions and previous research on sea-ice change and navigational hazards, Inuit ways of navigation, and use of scientific information. Major themes such as environmental change, adaptation, food security, family, traditional knowledge, hazards, etc. were identified and then coded by specific sub-categories (e.g. change, ice conditions, summer melt). Responses were then grouped by code and compared by location. Observations of environmental changes are displayed in Fig. 2.

We interviewed 25 participants in total from both communities (21 men and 4 women), 10 from Cambridge Bay and 15 from Kugluktuk. All were over 18 years of age and the majority were elders and experienced hunters. Hunting is predominantly a male activity in these communities, and thus the interviews potentially reflect a gender bias toward male experiences. The few women represented in this study were HTO or HTA members or managers, and some also accompanied their partners to harvesting expeditions. The bias towards male experiences remains one of the limitations in this study. However, as men are the primary harvesters in these communities, their observations and reflections are therefore central to our understanding of changing navigation practices.

3. RESULTS

3.1 Traveling the NWP

People in the hamlets of Cambridge Bay and Kugluktuk travel far and wide to the neighboring settlements for hunting and fishing, and to visit past settlements. Cambridge Bay residents report regularly traveling throughout the year to the Canadian mainland, including Kent Peninsula, Ellice River in

Fig. 1. Selected land use and navigational destinations of elders and hunters. Map depicts location of study sites, Cambridge Bay and Kugluktuk, as well as some land use and navigational destinations frequented by participants. These destinations do not represent an exhaustive list of all navigation destinations or depict full land use. Place names were identified in interviews by their official names, but traditional place names are also provided here where available from Inuit Heritage Trust (http://ihti.ca) and used with permission; the reader is encouraged to view additional maps of common travel routes provided by the Inuit Heritage Trust (Inuit Heritage Trust 2015) to more fully understand the extent of Inuit travel in this region. Base map provided by the Government of Canada (http://atlas.gc.ca/)

the Queen Maud Gulf Wildlife Sanctuary, Bathurst Inlet, and a couple of small islands in the Queen Maud Gulf such as Jenny Lind Island, Perry Island, and Flagstaff Island; they also report traveling to the neighboring communities of Gjoa Haven and Kugluktuk (Fig. 1). In Kugluktuk, interviewees describe year-round use of ice and water to travel to Victoria Island and other hunting grounds. People talked about annual trips to Victoria Island both in the winter and summer. Other destinations mentioned include Lady Franklin Point, Ulukhaktok, Locker Point, Lady Franklin, Read Island, Rymer Point, and Tree River (Fig. 1).

While most travel is to contemporary hunting grounds, it is not uncommon for people to also frequent former harvesting sites used by family members. 'I know people still remember, maybe the people you interview, they're familiar with their trap line from their parents. I still know where they are, even in Peary,' said a participant from Cambridge Bay. Many of these visits occur during longer harvesting trips with some serving as stopover points providing shelter from inclement weather, and as storage locations. Some locations have cabins, which are maintained and repaired, mostly in the winter when it's easier to transport materials by snowmobile. In addition to hunting and trapping, travel for visiting and recreation, some interviewees traveled the NWP for work, including maintenance of DEW line sites, for search and rescue operations, and as guides for sport hunter and tourist expeditions.

3.2 Use of IK in navigation

In most places today travelling from point A to point B is about navigating extensive road and highway systems using paper or digital maps, road signs,

and highway markers. But in places where such travel infrastructure does not exist, navigation often requires excellent place-based locational knowledge and proficiency in reading the local elements whether on land or water. In the Arctic, where snow and ice dominate the landscape for most of the year, interspersed with seasonal melting, navigational skills and ability to read the weather patterns are quintessential to subsistence living and survival.

Navigational skills used by Arctic Inuit are learned from previous generations as well as from an individual's own direct observation and experience on the land, sea, and ice. The relationships with the land, competency in hunting, and navigating difficult terrains, including in inclement weather, are an integral part of IK (Pearce et al. 2015). Navigation itself or 'traveling the land' is a way of connecting with terrains, learning the skills of reading the land, water, ice, and weather, and honing one's knowledge. IK, in this sense, is dynamic, and continually updated and revised to meet the needs of the changing weather conditions and times (Ingold & Kurttila 2000). This refined awareness and emphasis on experiential knowledge allows people to be flexible and adaptive (Krupnik 1993). Navigation presents the opportunity to continually update the information base of IK (Krupnik 1993).

Participants in this study described learning navigational skills in early childhood, including navigating difficult terrains and in inclement weather. They talked about learning to read the land and the experiential knowledge of 'learning by seeing and doing' as a skill, as well as a crucial part of building one's relationship with the land. Participants from both communities recalled childhood experiences hunting with their families, and many talked about learning from their parents and grandparents to read the land, water, wind, clouds, and ice and to navigate. Some talked about embarking alone on small hunting or trapping excursions with their dog teams as early as 5–12 years old. Some participants reported interruptions in learning traditional navigation methods and other land skills as a result of being sent to residential schools away from their families and communities.

Interviewees in both communities mentioned how IK is an essential tool for emergency preparedness and survival. One participant (Kugluktuk) offered several examples — including an instance where a forest fire prevented restocking of the Northern Store; IK was essential as a 'fallback'. Others echoed the view that even in the modern world, IK could be essential for survival; almost all talked about the importance of knowing shelter-making and other survival skills when navigating during inclement weather. 'We use our traditional life if we need to fall back, or something's not quite right, we'll go back to our traditional way of living just to survive. That's why we have cabins out on the land. Just in case if there's something happen in Cambridge Bay, we could go to our cabins, bring our families down there for warm, or hunting.'

People from both communities describe a breakdown in transfer of IK to the current generation, though interviewees in Kugluktuk expressed greater concern and went into more detail about this. Four Kugluktuk participants mentioned that young people were not as interested in learning traditional practices. Five participants mentioned that fewer elders are getting out on the land, and that this has had an impact on children learning the traditional ways. Talking to elders is a process by which knowledge is acquired and imparted (Berkes 2008). One participant suggested that the younger people need to talk to the elderly more often, because the elders experienced travel on the land under different circumstances and they can teach the newer generations when the best times for hunting are and survival techniques. A participant from Kugluktuk cites the involvement of parents in traditional hunting practices as the single most important factor in whether or not children will take up hunting. A respected elder (in her late 80s) shared that things had changed drastically since her childhood, and that the children today do not share the same experiences that she had as a child. She commented that '[e]lders can't even tell them to do anything … some of them can't listen now. Can't go anywhere and can't go hunting.'

3.3 Use of land, sea, and weather observations for navigation

Navigation and successful harvest in the past were tied to the teamwork of Inuit and their dog teams. According to the participants we interviewed, dog teams are not currently used for hunting or travel in either Cambridge Bay or Kugluktuk. Most participants talked about navigating using landmarks and landscape features, such as the orientation of snowdrifts and the nature of pressure ridges. The brightness of stars, wind patterns, and cloud formations are used to predict weather and travel conditions and to avoid unnecessary risk. One participant from Cambridge Bay said he travels a lot to Kugluktuk by snowmobile or by boat and that he finds that as long as it is bright, he can see the landscape quite a long way off and inspect the terrain for open water and

dark spots on ice, which indicates thin ice and other areas to avoid. Other participants also talked about using color as an indication of ice thickness and safety for travel. Some people check the ice with a chisel for thickness, especially early in the season after initial freeze-up. One participant noted: 'We know that it's dangerous, and when we snowmobile on it and the ice is waving behind you, then we just turn around and go back to solid ice. Basically we have to test it out.' Most people test ice conditions this way, using only a snowmobile, and often one will follow another while doing these tests.

The same participant from Cambridge Bay stated that it is easy for him to get from there to the mainland, even though conditions vary each year: 'Ice formation every year, it's different. Some years it might be smooth to go across, some years it will be really rough. So it will take a lot longer to get to the mainland. And we have to find routes on the ocean, where we can get through the really rough ice.' He can manage to get to the mainland and back without refueling on a regular run, but not when testing ice conditions. Most hunters know where the danger areas are located, and try to avoid them, traveling only when they know the sea surface is frozen solid. Interviewees displayed extensive knowledge of ice conditions, including a rich and nuanced vocabulary for ice formations and characteristics; 22 distinct types of ice formation were described during 2 interviews in Kugluktuk. A participant talked about this with respect to location. For example, 'Cambridge Bay and Peary River — they got different type of ice. You have to know the ice.' Most navigation depends on knowledge of landmarks. Some are able to follow these even in stormy conditions. 'You have to know the land, but you could do it. You have to travel quite a bit, use landmarks. Even shallow water between here and Peary River. I have to know shallow part, otherwise you're gonna get into trouble. You can't see sometimes.'

A participant from Cambridge Bay emphasized the importance of understanding the weather for safe travel: 'We're told that you have to go with the weather. Because we didn't have electronic devices to provide support for us … You have to be [a] good observer to do that.' This participant watches the cloud cover and the types of clouds to assess the chances of precipitation and/or wind event that could seriously impact travel. On stormy days, he waits it out. He commented that the younger generation really rushes into things but one has to be patient: 'That's one of the things too that I was taught, to be patient.' A participant from Cambridge Bay added that he does not have a GPS, so he waits until it is clear enough for him to recognize the landmarks before he navigates: 'I like to travel where I can see probably at least 2 to 3 miles. I can see whatever I'm going after, like caribou, wolf, and whatever. I really don't want to travel when I can't see at least 200 yards or something. I have to be able to see quite a distance when I travel.'

Most agreed that while calm weather is important for safe navigation it is also important for the passage to freeze solid; storms can prevent freeze-up, especially in late fall, and they can open up leads and channels in the ice. The most dangerous times to travel, especially long distances, are during whiteout conditions and freezing rain. Wind direction and the orientation of snowdrifts were described in many interviews as navigational tools, especially useful in the dark and stormy weather. Because snowdrifts align with the prevailing winds, the angle of the snowdrifts can be used to orient a traveler in whiteout conditions. Some people use the wind, although one noted it is unreliable: 'That's no good to use the wind, because the wind changes.' One participant said: '[I]n summertime I think we used the wind for navigation. Even the currents, we used the currents, which way the currents go … that would help us to get to where we [want]. I think we have experiences in the past, when it's time to use it it's there already. It's hard to erase the stuff we already know.'

He also said that often, if the west is nice and clear, then good weather is coming: 'If it's a bad windy day and there's clear sky in the west that means good weather's coming.' Increase in wind intensity makes travel unpredictable and can break thin ice and create open water in early winter. A participant commented on the hazards of storms when the ice is new: 'Like this time right now [end of November] you can't even use the passage because most of it is not frozen. And it's very dangerous for anyone to try to go across right now. Especially after the storm. When it storms, it opens up.'

3.4 Changing practices in navigation: use of new technology and scientific information in navigation

The practices of navigation have changed over the years as a result of technology (Box 1). People travel on snowmobiles (often referred to only by the popular brand name Ski-Doo) instead of using dog teams, and some use GPS to navigate. They check the weather reports online before they travel in addition to utilizing their traditional skills of observing the

Positive impacts of technology for navigation and travel:

+ Can travel further on snowmobiles in less time
+ GPS and weather data improve efficiency in travel planning
+ Snowmobiles, weather data and GPS can minimize the time invested in travelling
+ Technology enables country food harvesting while participating in the wage economy
+ Need not be proficient in IK and land based knowledge to navigate

Negative impacts of dependence on technology for navigation and travel:

– Weather data may be unreliable as well as weather predictions
– Technologies are expensive and can fail
– Technologies cannot not predict hazards (pressure ridges, leads, shallow areas, rocks under ice), nor ensure safety, and may increase risk of accidents
– Dog teams are thought to have been more dependable than snowmobiles
– Can take only limited supplies on snowmobiles
– IK is essential to ensure adaptability, emergency preparedness and survival but may be neglected due to adoption of technologies

Box 1. Impacts of technology on navigation and travel. Positive and negative impacts of technology on navigation and travel described by participants in both communities

land. Participants also reported checking a Norwegian site to get their weather data (www.yr.no). Hunters in Kugluktuk talked about closely following Windytv (www.windy.com), which provides a comprehensive forecast of daily wind patterns, cloud cover, rain and snow, temperature, and air pressure. Though many combine traditional and new ways of navigating, people are not entirely dependent on the new ways; some, especially elders, do not use GPS. One participant notes that 'Navigation's changed, we have lots of technologies. I think some of us older ones who still don't use that, but these younger generation people, they use the instruments or GPS. Most people combine both the traditional ways with the new ways of navigating to some extent but when it's time to use our old traditional ways, I think we could use it again.'

Snowmobiles allow hunters to cover greater distances in less time. While dog team expeditions could take days, weeks, and even months, hunters traveling on snowmobiles go on single day or weekend trips. This allows them to participate more easily in the wage economy. As one person said, 'because with the new technology available you can go faster and farther, right?' People use GPS more regularly, especially when traveling to a place that is new to them or in stormy and whiteout conditions. Trails are programmed into the GPS, which helps a hunter return more quickly than when navigating using landmarks or snowdrifts in stormy conditions. If the place is familiar to them, though, interviewees do not use the electronic devices:

> 'I know a lot of landmarks. But when I start traveling in a whiteout, then I have to take out my GPS, just so that I don't go around in circles ... basically it gets me there maybe in a straight line. I do a lot of search and rescue, and I need good weather. If I know where the person is, where he might be, then I'll use my GPS to get there. If that's the only way, then I'll use the GPS. Like I said, I have 3 of them. I take them all with me when I go hunting. I forgot to look for the right one so I can show you all my tracks.'

Some talked about the importance of communication and being able to stay in touch with friends and family members. Satellite radios are another way of learning about the weather conditions nearby. A participant noted:

> 'I have my cabin [in Cape Alexander] and my buddy or my uncle, he has a cabin probably about 7 miles [apart, in the] same area, we communicate by radio. And we talk about weather and I ask him — Oh, its fairly clear and calm [here] … 7 miles away, [we] have a blizzard. That close range, but still such a difference. That's the mainland though.'

3.5 An overview of navigational challenges

3.5.1 Climate change

There was no doubt among participants from both communities that climate change is affecting the environment. All remarked on some significant change in recent times (Fig. 2). The most frequent change noted was a later winter freeze: almost all participants from both communities commented on a later freeze-up, with the general consensus being that freeze-up used to occur in late August–September and is now occurring in October or even November; several participants said it was not safe to travel across sea ice until late December. For safe passage, sea ice must be at least 5 to 6 inches thick. However, storms can still crack open ice that is a few inches thicker; some participants mentioned an increase in storminess, especially in Kugluktuk. In addition, even after solid ice has formed, new patterns in pressure ridges and flaw leads make it difficult to rely on the same route. Many participants commented on earlier ice break-up, but these responses were less consistent between and among communities, and occasionally included accounts of unusually late melt times in recent years. Participants from both communities also describe an

unprecedented shift in the axis of the prevailing wind direction in the fall; prevailing winds used to be from east–west and are now north–south.

Participants from Kugluktuk remarked on several other changes (Fig. 2), including less snow. This is making navigation more difficult and expensive, as new routes have to be scouted around rocky or rough patches. Accounts of less snow were accompanied by observations (5 participants) of increased sediment and grittiness in the snow. One single participant in Cambridge Bay also commented on this. Participants from Kugluktuk also commented on changes in vegetation; 2 mentioned taller shrubs and plants, while in Cambridge Bay, 1 person commented, '[N]othing grows, hardly.' Participants in Kugluktuk also reported stronger currents and unpredictable weather between Kugluktuk and Victoria Island in Coronation Gulf, which made travelling certain stretches of the passage unsafe.

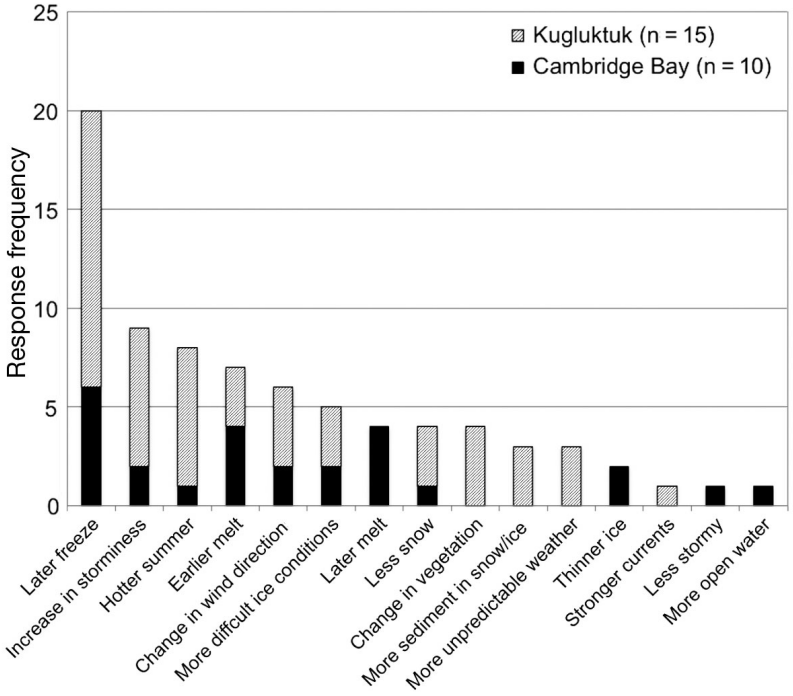

Fig. 2. Environmental changes described by elders and hunters. A summary of environmental changes described in interviews with elders and hunters in Cambridge Bay (n = 10) and Kugluktuk (n = 15)

Two participants from Cambridge Bay and 6 from Kugluktuk reflected on how change is a constant in their communities. While tradition and change may seem at odds with one another, the ability of Inuit to adapt to change was described as a part of the participants' history and identity. The difference today is that environmental change is very rapid and unprecedented in scope and scale. Participants from both communities remarked that the changes they see are occurring quickly. In Kugluktuk, for example, one participant described the changes in the rivers as 'out of balance'.

3.5.2 Traveling farther

Participants in both communities note that most people are traveling longer distances to find animals, which have moved farther away or become scarcer in recent years. This was especially a concern in Kugluktuk, where 10 out of 15 interviewees mentioned caribou becoming scarcer in recent years, while only 2 participants from Cambridge Bay shared this concern. One participant from Kugluktuk describes it this way:

> 'I am finding that more, especially with caribou, we got to go so, so damn far for them. Real far. Not 1 day, 2 day trip, it's mostly 3 or 4 days now. Whereas back then you go take a couple hours, you leave, say I left this morning I'd be back before lunch with 1 or 2 caribous, 3 caribous maybe. But today you got to go so far to get to those points. Everything plays into it. There's hardly any snow, landscape's more rougher, that's why it takes 2, 3, 4 days at a time to get back.'

3.5.3 Unreliable routes

Commenting on traveling by boat, one participant described how he traveled the same route his whole life, but now, because of increased sedimentation and new sandbars, he has to travel other ways. Another described how the lack of snow in recent years forced travel over unfamiliar routes. Still another from Cambridge Bay commented that:

> 'I have to know shallow part, otherwise you're gonna get into trouble. You can't see sometimes. I think they need to know where the water is shallow, even ice. The risk when you're navigating, you got to know where you're going first. Because sometimes, wintertime, the pressure ridges, ice and everything, is really rough. You have to go around, all over the place. But you got to know how far you're going, which way you're going. If you want to [go to] Flagstaff Island or Gjoa Haven, you have to move around quite a bit. It's pretty hard, because I think, another part, if you have a pressure ridge, there's always open water. There's a risk, you got to watch, wintertime, especially when you're traveling

> in nighttime ... best to do is just to stay away from pressure ridges, because it's like a big rock or something like that. I think nowadays, we worry about more people not coming home from hunting.'

Participants talked about specific parts of Dease Strait by Victoria Island where the currents are strong and unpredictable. Dangerous locations included around Qikiqtarjuaq Island and Trap Point — not far from Qikiqtarjuaq and Unahitok. One person said that these areas are also dangerous because you could find snow with no solid ice beneath it. But most participants had communal knowledge of these locations and they knew how to identify this type of dangerous terrain.

3.5.4 Hazards and accidents

Overall, those in Kugluktuk conveyed a stronger concern about increased hazards due to changing ice and weather conditions and use of snowmobiles, which are considered less safe than dog teams. Four people commented on how the decrease in snowpack was making travel by snowmobile more dangerous, as the machines can crash on rocks or rough patches. One participant described an increase in accidents (as opposed to merely an increase in risk) and attributed it to 'more access to getting out onto the land, and to travel'. He also described rougher ice conditions traveling across the NWP from Kugluktuk to Lady Franklin Point at the western end of Coronation Gulf, and said that finding the smooth patches of ice was more difficult and wasted expensive fuel.

Five interviewees from Cambridge Bay commented on hazards. Two concluded that there was no change in the frequency of accidents. Two people responded that some people are sinking or losing their snowmobiles and they recollected such an incident that happened not long ago. One said that his main worry is not being able to go to the mainland in the winter. Several interviewees described how the change from dog teams to snowmobiles for the primary mode of travel inherently increased risk. Dog teams were able to navigate with an injured driver and/or in hazardous conditions (whiteout, pressure ridges, unfamiliar landscape) but machines can and do breakdown or run out of gas, stranding the driver. One man who has been with the search and rescue operation for 45 years noted that in most cases when hunters get lost or stranded, it was due to a machine breakdown, running out of fuel, or simply becoming lost and having no communication. He did not attribute these events to climate or sea-ice change. Another participant gave an account of hitting a rock on his snowmobile because of shallow snow; his windshield was damaged and he was injured. People talked about occasional freezing and drowning; one man attributed these incidents as follows: 'Some guys don't know which way to go, and they end up sinking their 4-wheeler.'

Many elders are concerned that the younger generations are not taught the skills of living on land, which can be life-saving. One elder said that the younger people are 'easy come, easy go. They take off just like riding a horse. You don't do that up north, you don't jump on the horse and take off, you know? Nowadays that's how young people are.' He said that the younger people know how to use snowmobiles, but they don't know how to survive if they are stuck or lost in stormy freezing conditions. People believe that it is important to learn survival skills to avoid calamities that can be caused by the weather. Two people talked about accidents that have resulted from such incidents:

> 'It could get stormy, right, just suddenly. That's how — there [were these] 2 teenager boys, they were Ski-Dooing and they got lost. It was just in town, down by the bay [Cambridge Bay], they got lost. They took the wrong turn, and got lost because it was stormy and then next day they found them, they were gone. Not too long, a couple years ago. And these boys were young.'

3.5.5 Rising expenses

Several interviewees commented that avoiding new or increased hazards was both time-consuming and costly. Many interviewees from Kugluktuk commented on how expensive it has become to hunt and travel over the land. One participant from Kugluktuk noted that recent years of rougher ice conditions on the NWP from Kugluktuk to Lady Franklin Point were costing him more time and money, since he now had to search longer for smooth patches of ice to travel on. Another named the expense as a reason that fewer young people are going hunting. Others discussed how they have stopped going to certain hunting grounds because of the expense involved. For the most part, the interviewees from Cambridge Bay did not comment on the expense of hunting in the way that those from Kugluktuk did, although one did lament that '[e]verything, it's all money,' including hunting.

Reliance on technologies for subsistence requires engaging in the wage economy to pay for snowmobiles, fuel, and GPS, satellite, and communication

devices — all of which are more expensive in the north. One participant said that the snowmobiles do not last long, only 2 yr or so, and each costs CAD$15 000–20 000. People find it increasingly difficult to maintain a subsistence lifestyle. This is especially an issue in Kugluktuk, where there are fewer employment opportunities than there are in Cambridge Bay. A young couple in Kugluktuk said that they could not afford a snowmobile, so instead they hunt on foot along the shore and fish and trap.

3.6 Development

A few community members in both Cambridge Bay and Kugluktuk expressed concerns with increased development and development potential in the region. The major concern was how this would impact their ability to navigate across to the mainland and back. Community members in Cambridge Bay mentioned that there are more ships going through the NWP in the summer, and at the end of November 2015, an icebreaker passing through caused a great deal of alarm. An email from one of the community members (shared with the interviewer) related an incident in November 2015 where an icebreaker passing through the NWP effectively stranded a Cambridge Bay resident who had traveled across the ice by snowmobile to his hunting cabin on the Kent Peninsula, on the Canadian mainland. There was no passage for him to cross over all along the mainland. The HTO found it frustrating that the Canadian coast guard would allow travel in the NWP after freeze-up, which jeopardizes the safety of residents who travel across the ice at this time of year, as well as the Dolphin–Union caribou that travel across ice to reach their winter grounds on the Canadian mainland.

One participant also expressed concerns about the 2 mine sites near Cambridge Bay, a gold mine in Hope Bay, and a zinc mine close to Hadley Bay. He did not express any concern regarding navigation, but he worried about the impacts of mining on subsistence hunting and a potential loss of feeding grounds for the caribou and muskox. He said he is concerned about mining because he depends on hunting, and the land takes a long time to get back to normal after mining.

3.7 Community needs for navigational support

More people in Cambridge Bay talked about the need for information than did people in Kugluktuk. Most thought any information that would help with harvesting trips would be useful. They said that while they generally know where dangerous areas are, it would be good to have more weather data. Both communities have a weather station, and some of the unmanned DEW line sites have weather stations (i.e., Cape Peel to the west, and Hat Island to the east of Cambridge Bay). In addition, many rely on a Norwegian site to get their weather data (www.yr.no), and also Windytv (www.windy.com), which provides wind and wave data in addition to temperature and cloud cover information. But weather forecasts for locations farther away from the weather stations can be unreliable and unpredictable. In Cambridge Bay, one participant mentioned that weather stations in more locations would be helpful since current weather information is too generalized. Another commented that a map of rough ice conditions in the winter would be helpful for those hunting in the winter. Some suggested locations for weather stations included Locker Point, Cape Coburn, Thirty Mile River, Ekaluk River, around Back Point, the channel on Melbourne Island and the channel on Brown Point in the mainland. Participants said that there is often a big difference in weather at Melbourne Island, Stuart Point, and Albert Edward Island.

Others talked about the general need for better weather forecasts and specific research needs. One participant from Cambridge Bay suggested putting up a weather station, noting that 'nowadays a lot of the harvesters are depending on the forecasts, really.' Others wanted information on flooding, currents, and landscape changes. One of the participants wanted to have a better understanding of caribou migration patterns and how they are changing.

Almost all interviewees who offered thoughts about the future generation expressed concern about the loss of traditional knowledge and indigenous navigation practices. In both communities, interviewees were concerned by the apparent decline in caribou and muskox populations and the increased difficulty of hunting. One participant from Kugluktuk commented that a government-funded program to train young people in traditional hunting through the HTO office was a success, and hoped for more of that in the future.

4. DISCUSSION AND CONCLUSION

The NWP is widely used by people in the communities of Cambridge Bay and Kugluktuk, and using IK is essential to navigating this landscape. However,

knowledge transfer has been impacted by dislocation resulting from the residential school era, and increased participation in the wage economy; the latter limits time available for teaching and learning traditional navigation methods. Climate change, globalization, and modernization all compound the challenges to navigation identified by participants, which include unpredictable weather conditions, later freeze-up and variable break-up times, unreliable sea-ice conditions, less snow, and the rising cost of equipment and supplies. Snowmobiles, GPS, and satellite radios bring many benefits and are used to compliment some IK-based land skills, but these technologies also bring new risks, especially overdependence by younger generations not as skilled in hazard mitigation or navigating in inclement weather.

Many of the changes in sea ice observed by interviewees are consistent with those reported in other studies in Arctic Canada (Ford et al. 2006a, 2008a, Barber et al. 2012b, Cuerrier et al. 2015). Scientific reports on sea-ice change in the NWP are consistent with some of the key changes noted by interviewees. The advance freeze-up described by nearly every person interviewed is consistent with the observations by Galley et al. (2012), who detected a significant advance of ice onset of 0.85 wk per decade in the Coronation Gulf–Queen Maud Gulf sub-region where both communities are located. The conflicting reports of both earlier and later break-up is consistent with a non-significant trend in ice break-up noted in the same study (Galley et al. 2012) and also with a recent finding of significant increase in the variability of melt onset (Mahmud et al. 2016). Several authors (Berkes & Jolly 2002, Ford et al. 2006b, Pearce et al. 2010) have also discussed increased risk and hazards associated with travel on land and ice similar to those noted here.

People will continue to adapt in the face of changing conditions; traditional methods of navigation and hunting will evolve as in the past. However, IK is a crucial component to be considered in climate change adaptation (Pearce et al. 2015, Peppler 2017). The loss of IK and traditional knowledge could be detrimental to the isolated communities without any transportation infrastructures for safe travel. Most of the Inuit communities in and around the CAA have no direct and easy access to one another by road or rail. Under these circumstances, they are dependent on sea ice as their main course of travel for subsistence hunting and to maintain their regional networks. While there are many benefits to using Western science and technology to support traditional activities, and while navigational technologies may compliment IK, traditional skills and experience are still required to ensure safety, avoid hazards, and survive in emergency situations. Managing uncertainty, unpredictability, and change are foundational aspects of Inuit epistemology and IK, both of which are rooted in paying close attention, making careful observations, and a continued commitment to knowledge. These empirical, relational, situated, and temporal explorations, as well as qualities such as patience, perseverance, and wise adaptation are among the most-valued and -respected skills among Inuit (Cameron et al. 2015). Here the intimate reading of the land, ice, and snow and continual learning, updating, and readjustment itself might offer some solutions to deal with ongoing and future changes.

Still, rapid changes due anthropogenic climate change might be hard to adapt to as environmental vulnerabilities accumulate. It is a huge stretch to suggest local adaptation and resilience alone as solution to dealing with a changing climate (Cameron et al. 2015). Putting the responsibility on the communities affected by climate change to deal with the impacts instead of those countries and entities responsible for climate change undertaking mitigation practices is an act of injustice and a human rights violation. Both climate change and the solutions for it are scientific and technological issues and also political and environmental justice issues. As the Arctic is rapidly changing, maintenance of traditional practices ensures IK evolves with the changing environment times. Investment in IK simultaneously with the introduction to Western scientific practices will protect land-based practices, maintain a flexible and dynamic knowledge base, and enable innovative solutions.

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