Ice over troubled waters: Navigating the Northwest Passage using Inuit Knowledge and scientific information

Bindu Panikkar^{1*}¶, Benjamin Lemmond¹¶, Brent Else²¶, Maribeth Murray³¶

¹ Rubenstein School of Environment and Natural Resources, University of Vermont, Vermont, United States of America, 05405

² Department of Geography, University of Calgary, Alberta, Canada, T2N 1N4

³ Arctic Institute of North America, University of Calgary, Alberta, Canada, T2N 1N4

* Corresponding Author:

E-mail: bindu.panikkar@uvm.edu

¶ These authors contributed equally to this work.

25 **Abstract**

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

43 Key Words: Northwest Passage; navigation; Inuit Knowledge; sea ice; climate change

44 **Introduction**

As sea ice and weather conditions become more unpredictable, understanding the challenges facing people in coastal Canadian Arctic communities is increasingly urgent, as do community needs for dependable weather information. In this paper, we report observations from two Inuit communities in the Canadian Arctic, Cambridge Bay and Kugluktuk, Nunavut (Fig 1). 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 Northwest Passage (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,” three 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.)

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 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://iht.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. Basemap provided by the Government of Canada (<http://atlas.gc.ca/>).

Local needs for weather information to improve 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. The stations also collect data on the sea ice energy balance to inform understanding of current conditions of climate change in the NWP.

Environmental background

Around the Arctic, sea ice serves as a platform for life; it connects people to the marine environment and communities to each other through regional networks. Sea ice functions as a route for or barrier to transportation for both people and wildlife. For example, in addition to providing habitat for marine mammals, and enhancing marine primary production, sea ice is also an important land bridge and habitat for migrating terrestrial wildlife such as caribou and muskox traveling between the Canadian mainland and summer feeding grounds further north (Poole et al., 2010; Post et al., 2013).

Sea ice conditions, in isolation or in combination with other environmental variables, especially weather, regulate the abundance of and access to a many marine resources. In the Canadian Arctic, sea ice supports transportation routes for Inuit people who depend upon it for travel to visit neighboring communities and to hunting locations; it is a critical component of the territories that Inuit use and occupy (Aporta, 2011, 2004; Boas, 1964; Freeman, 1976; Krupnik et al., 2010; Laidler et al., 2009; Riewe, 1991).

The coldest months, when the sea ice is stable and when the daylight returns between March-June, are the safest for travel on sea ice. Long-distance navigation over ice to hunting grounds and other areas is common during this time (Berkes and Jolly, 2002; Ford et al., 2006a, 2006b; Tristan Pearce et al., 2010; Prno et al., 2011). Inuit knowledge of the ice and surrounding lands enables this travel (Berkes and Jolly, 2002; Ford et al., 2006a, 2006b; Tristan Pearce et al.,

2010; Prno et al., 2011), which today is also complimented by use of navigational technologies such as GPS, and satellite imagery (Aporta and Higgs, 2005) and when feasible, near-real-time weather information.

Empirical measurement and satellite data suggest ice conditions in the CAA have changed significantly, 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 (Galley et al., 2012; Howell et al., 2009), 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 2007 (second lowest), 2011, 2012 (lowest) and 2016 (second lowest) (Howell et al., 2013; NSIDC, 2016). High-resolution RADARSAT data, indicates 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 NWP was completely ice-free for the first time in recorded history (Cressey, 2007; Perovich and Richter-Menge, 2009); a phenomenon repeated in 2016 (Di Liberto, 2016). 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).

Downscale, first-hand accounts from Inuit elders and experienced hunters of rapid and profound 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 et al., 2008a, 2006a; Ford and Smit, 2004). Interviewees in Igloolik (Nunavut), Ulukhaktok (Northwest Territories [NWT]) 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 (NWT), report less sea ice and more open water, changes in the formation of land fast ice, a one-month advance in fall freeze-up, and changes in ice cracks, pressure ridges, and flaw leads (Barber et al., 2012). Similarly, interviewees in Umiujaq, Kangiqsualujjuaq, and Kangiqsujaq in Nunavik, northern Quebec, also report thinner sea ice, later fall freeze-up, and earlier ice break-up as well as changes in animal and plant abundance (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 (Ford et al., 2008b; Nichols et al., 2004). 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). While commercial activities such as shipping, tourism, and resource development are changing sea ice regime, and while these ventures may provide some local economic opportunities, many Inuit are concerned that these activities might disrupt wildlife migration routes, population

viability and distributions – compounding the problem of environmental stressors. Leaving aside the uncertain impacts of increased marine traffic and associated noise on seals, whales, and walrus, these concerns are already underscored by the fact that most of the caribou herds in the Canadian Arctic are in serious decline (Festa-Bianchet et al., 2011; Government of Canada, 2016; NOAA, 2009). 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 and Lee, 2013) and 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 (Freeman, 1996; Krupnik, 1993; 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 or may not impact climate adaptability among the Inuit, who are the youngest and fastest-growing population in Canada (Pearce et al., 2015).

Study area: political, cultural and geographic context

The Canadian Arctic is divided politically into three 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 km² – 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 (Condon and Ogina, 1996; Jenness et al., 1946). 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 (Dredge 2001, Nunavut tourism). As of the 2011 census (the latest census data with complete demographic information), the population of Kugluktuk was 1450 people and 90% Inuit (Nunavut Bureau of Statistics, 2013). The 2016 census reports a slightly higher population figure –1,491– 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, but one that is rapidly changing with many recent extreme weather events. 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 Northwest Passage. 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. The landscape includes rolling tundra and innumerable lakes and ponds. The abundant wildlife made Cambridge Bay a popular meeting place for hunting, fishing, and trade prior to 1940s and it has a history similar to Kugluktuk in that it was settled by Copper Inuit who started moving to the region after the Hudson's Bay Company set up a trading post there in the 1920s (The Hamlet of Cambridge Bay, n.d.). 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, n.d.). As of 2011, Cambridge Bay has a population of 1610, 77% of whom are Inuit (Statistics Canada, 2012) (The 2016 census reports a slightly higher population figure, 1,766 (Statistics Canada, 2017), but lacks data on Inuit vs. non-Inuit identity).

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 using *HyperResearch* (ver. 3.7.3) software.

We interviewed 25 participants in total from both the communities (21 men and 4 women). 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 women interviewed represent the HTO/HTAs and some also accompanied their partners to harvesting expeditions. Thus the experiences represented here are varied.

Results

Traveling the NWP

People in the hamlets of Cambridge Bay and Kugluktuk travel far and wide to the neighboring settlements for hunting, fishing, and to visit past settlements. Most of the participants interviewed in Cambridge Bay originally came from other areas or settlements, including Perry Island, Perry River, Peary River, Prince Albert Sound, and Bathurst Inlet. Many

226 moved to Cambridge Bay because it was the location of the nearest trading outpost, but one
227 person moved to Cambridge Bay from Peary River in 1961 because his father was sick with
228 tuberculosis and needed to be close to a nursing station. Another moved from Prince Albert
229 Sound (between Cambridge Bay and Holman), but had lived on Read Island and at Bernard
230 Harbor before moving to Cambridge Bay with his wife and children. Initially this participant
231 worked as a trapper, until he found a job at the DEW line site in the 1960s. He has also worked
232 briefly in mining, which he found more lucrative. He still misses living out in the land, noting:
233 “Some are used to this way of life and [we] feel are stuck here, we’re stuck here, having to be in
234 one place.”

235 Most of the participants interviewed in Kugluktuk came from elsewhere; only two were
236 born and raised there. The rest came from Read Island, Rymer Point, and Ulukhaktok. One
237 participant moved to the coast from inland in the Lake Pellet region close to the Nunavut border
238 where his family was working on and off at the Lupine Mine. He emphasized the nomadic nature
239 of his existence growing up.

240 We traveled from camp to camp as the seasons changed. Like right now in the
241 winter, we’d be here in Kugluktuk doing fishing in the river here, coming in from
242 the ocean after summer and fall camp, hunting for caribou. And here in the mouth
243 of Coppermine River we’d have fish through the ice in the river, catching arctic
244 char, whitefish. And as the ice froze over, like over the ocean, we’d move out
245 onto the ocean around Bernard Harbor.

Another participant talked about growing up in Read Island, Lady Franklin, and Kugluktuk, the communities with which he still maintains close contact. A third participant lived on and off at a cabin in Klengenberg Bay.

Today in the study area the waterways and sea ice of the NWP are widely used as a transportation corridor between the mainland and the islands of the CAA to access hunting, fishing, and trapping grounds. Key subsistence and furbearing species are caribou, muskox, wolf and wolverine. Cambridge Bay residents report regularly traveling throughout the year to the mainland including Kent Peninsula, Ellice River in 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 as well as to Bay Chimo, and 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 for caribou, muskox, seal, and for fishing. People talked about annual trips to Victoria Island both in the winter and summer. One mentioned traveling to Lady Franklin point, northeast from Kugluktuk across Coronation Gulf, 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,” says 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

268 maintained and repaired, mostly in the winter when it's easier to transport materials by
269 snowmobile. One participant describes his cabin as such:

270 My cabin is the blue one. 16 x 16 It's all plywood, two-by-fours, all the wooden
271 material... It's at Cape Alexander. There are a number of cabins there and HTO
272 has a cabin up there too. Anyone can use it as long as they keep it clean and they
273 do not damage anything...

274 In addition to hunting and trapping, travel for visiting and recreation, some interviewees
275 traveled the NWP for work, including maintenance of DEW line sites, for search and rescue
276 operations, and as guides for sport hunter and tourist expeditions. One participant used to be a
277 guide for polar bear hunting.

278 **Use of IK in navigation**

279 In most places today travelling from point A to B is about navigating extensive road and
280 highway systems using paper or digital maps, road signs and highway markers. But in some
281 places where such travel infrastructure does not exist, navigation is about possessing excellent
282 place-based locational knowledge and proficiency in reading the local elements whether on land
283 or water. In the Arctic, this includes snow and icescapes. One individual from Cambridge Bay
284 explains his ethic:

285 I use the land, I was taught to learn the land. I walk this land. You travel to see the
286 land that's gonna help you survive. And hopefully one day your kids will see—
287 live to tell again stuff like that. Because that's where [the] freedom is, on the land.
288 You challenge yourself to be strong inside. You want to be, you want to make

289 sure you're okay to look after your land and whatever's surrounding. You have
290 responsibilities. To respect everything. You have to keep it clean too. Just take
291 whatever you need. And we don't need very much. It's just short-time thing. We
292 have to make sure there's enough for everybody. And it goes around. So, I see
293 that it's good. It's nice to see people do that, share their food.

294 The ethic expressed articulates a spiritual and sustainable approach to use of the environs.
295 Navigational skills are learned from previous generations as well as from an individual's direct
296 observation and experience on the land, sea and ice. The relationships among terrain,
297 competency in hunting, and navigational skills are an integral part of IK (Pearce et al., 2015).
298 Knowledge, in this sense, is dynamic, continually updated and revised to meet the needs of the
299 changing conditions and times. This refined awareness and emphasis on experiential knowledge
300 allows people to be flexible, and to adaptive (Krupnik, 1993). Navigation itself or "traveling the
301 land" is a way of connecting with terrains, learning the skills of reading the land/water/ice and
302 honing one's knowledge. Navigation presents the opportunity to continually update the
303 information base of IK (Krupnik, 1993).

304 Participants described learning navigational skills gradually, starting in childhood. They
305 talked about learning to read the land and the experiential knowledge of "learning by seeing and
306 doing" as a skill as well as a crucial part of building one's relationship with the land, a process
307 that starts at a young age. Participants from both communities recalled childhood experiences
308 hunting with their families, and many talked about learning from their parents and grandparents
309 to read the land/water/ice and to navigate. Some talked about embarking alone on small hunting
310 or trapping excursions with their dog teams as early as 5-12 years old. Without exception, those

311 skilled at traditional practices started at an early age, although some reported interruptions in
312 learning as a result of being sent to residential schools away from their families and communities.

313 **Use of dogs in navigation**

314 Navigation and successful harvest in the past was tied to the teamwork of Inuit and their
315 dog teams. Many elders learned first, as children, to travel with dog teams, initially with two
316 dogs and then, adding more dogs to the team as they grew older. The dogs were not pets. One
317 participant recollects:

318 We were raised with a dog team, that's all we had. The dogs know which way to
319 go, and they know because [we] trained the dogs to, let them go home. Even when
320 it's stormy out, the dogs would know which way to go when it's stormy. ...I'm
321 also thinking, the dogs also learn from other dogs. So the dogs start doing these
322 trips when they're young too, and they learn. Yes. Because of the people that are
323 using them for trapping, they would get to know the area where they're going all
324 the time. And maybe the dog team, that kind of a trip, you can take so much more
325 than what you take on a Skidoo.... [but] you have better preparation for the trip, if
326 you have dog, food en route.

327 Most of the participants shared similar thoughts and experiences. A man from Cambridge
328 Bay explained additional benefits to using dogs:

329 With the dog team it's also good because the dog won't jump into something.
330 You don't break down. Right now Skidoo break. Run out of gas. Can go wrong
331 [laughs]. Dog, overnight, still going. ...Sometime nice, sometime it's stormy—

332 that's when the people freeze. [On] Skidoo. [It is a] long way to walk, [and easy
333 to] get lost because you can go fast and go long ways. But with dogs...the dogs
334 know where to go. It's way better. Can take a lot even if you don't use it. Never
335 know. And [with] Skidoo you don't take anything. But with a dog team you take
336 everything.

337 According to the participants we interviewed, dog teams are not presently used for
338 hunting or travel in either Cambridge Bay or Kugluktuk.

339 **Use of land, sea and weather observations for navigation**

340 Most participants talked about navigating using landmarks and landscape features such as
341 the orientation of snowdrifts and the nature of pressure ridges. The brightness of stars, wind
342 patterns, cloud formations are used to predict weather and travel conditions and to avoid
343 unnecessary risk. One participant from Cambridge Bay says he travels a lot to Kugluktuk by
344 snowmobile or by boat and that he finds that as long as it is bright, he can see the seascape quite
345 a long way off and inspect the terrain for open water, dark spots on ice, which indicates thin ice
346 and other areas to avoid. Other participants also talked about using color as an indication of ice
347 thickness and safety for travel. Some people check the ice with a chisel for thickness, especially
348 early in the season after initial freeze up. One participant notes: "We know that it's dangerous,
349 and when we snowmobile on it and the ice is waving behind you, then we just turn around and
350 go back to solid ice. Basically we have to test it out." Most people test ice conditions this way,
351 using only a snowmobile, and often one will follow another while doing these tests.

352 The same participant from Cambridge Bay states that it is easy for him to get from there
353 to the mainland, even though conditions each year vary: "Ice formation every year, it's different.

354 Some years it might be smooth to go across, some years it will be really rough. So it will take a
355 lot longer to get to the mainland. And we have to find routes on the ocean, where we can get
356 through the really rough ice.” He can manage to get to the mainland and back without refueling
357 on a regular run, but not when testing ice conditions. Most hunters know where the danger areas
358 are located, and try to avoid them, traveling only when they know the sea surface is frozen solid.
359 Interviewees displayed extensive knowledge of ice conditions, including a rich and nuanced
360 vocabulary for ice formations and characteristics; 22 distinct types of ice formation were
361 described during two interviews in Kugluktuk. A participant talked about this with respect to
362 location. For example “Cambridge Bay and Peary River—they got different type of ice. You
363 have to know the ice.” Most navigation depends upon knowledge of landmarks. Some are able to
364 follow these even in stormy conditions. “You have to know the land, but you could do it. You
365 have to travel quite a bit, use landmarks. Even shallow water between here and Peary River. I
366 have to know shallow part, otherwise you’re gonna get into trouble. You can’t see sometimes.”

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

377 travel when I can't see at least 200 yards or something. I have to be able to see quite a distance
378 when I travel."

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

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

Interviewees in both communities mentioned how IK is an essential tool for emergency preparedness and survival. One participant (Kugluktuk) offered several – 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 are the best times for hunting 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 comments that “[e]lders

420 can't even tell them to do anything... some of them can't listen now. Can't go anywhere and
421 can't go hunting."

422 **Changing practices in navigation: use of new technology and**
423 **scientific information in navigation**

424 The practices of navigation have changed over the years as a result of technology (Fig 2).
425 People travel on skidoos (snowmobiles) instead of using dog teams and some use GPS to
426 navigate. They check the weather reports online before they travel in addition to utilizing their
427 traditional skills of observing the land. Participants also reported checking a Norwegian site to
428 get their weather data (www.yr.no). Hunters in Kugluktuk talked about closely following the
429 wintytv.com, which provides a comprehensive forecast of daily wind patterns, cloud cover, rain
430 and snow, temperature and air pressure. Though many combine traditional and new ways of
431 navigating people are not entirely dependent on the new ways; some, especially elders, do not
432 use GPS. One participant notes that "... navigation's changed, we have lots of technologies. I
433 think some of us older ones who still don't use that, but these younger generation people, they
434 use the instruments or GPS. Most people combine both the traditional ways with the new ways
435 of navigating to some extent but when it's time to use our old traditional ways, I think we could
436 use it again."

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

Fig 2: Impacts of technology on navigation and travel. Positive and negative impacts of technology on navigation and travel described by participants in both communities.

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 says, “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

451 weather. If I know where the person is, where he might be, then I'll use my GPS
452 to get there. If that's the only way, then I'll use the GPS. Like I said, I have three
453 of them. I take them all with me when I go hunting. I forgot to look for the right
454 one so I can show you all my tracks.

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

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

463 **An overview of navigational challenges**

464 **Climate Change**

465 There was no doubt among participants from both communities that climate change is
466 affecting the environment. All remarked on some significant change in recent times (Fig 3). In
467 the winter months the sea ice is used between December and June, when the NWP is completely
468 frozen. However, one participant reported that in 2014 it was not safe to travel from Cambridge
469 Bay across the NWP until after Christmas. Another participant remembers going caribou hunting
470 on snowmobile in July but now travel on ice in July is uncertain. The NWP normally was used
471 for boating between the months of July and September but now the boating season extends into

October. Travel between September and November is often unsafe as the ice is still forming between the mainland and the islands. People noted that five- to six-inch ice can be safe for sea ice but not river ice, because sea ice is stronger than fresh water ice. Storms can still crack open ice that is a few inches thicker. Even after solid ice has formed, new patterns in pressure ridges and flaw leads have made it difficult to rely on the same route.

Fig 3 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 six from Kugluktuk reflected on how change is a constant in their communities. While tradition and change may seem at odds with one another, IK enables building expertise to deal with both. 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.”

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. Many commented on earlier 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 in both communities described break up as more variable from year-to-year, whereas freeze up seemed to be consistently later from year-to-year. 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. Some mentioned an increase in storminess and unusual weather patterns.

Participants from Kugluktuk remarked on several other changes (Fig 3), 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) on 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; two mentioned taller shrubs/plants, while in Cambridge Bay one 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.

506 **Traveling Farther**

507 Participants in both communities note that most people are taking one-day or weekend
508 trips but traveling longer distances, which increases hazard exposure. People from both
509 communities described how they are traveling farther to find food. One person mentioned that
510 the new generation of hunters, equipped with snowmobiles and GPS technology, take more risks
511 and travel farther without the proper preparation. Some commented that safe use of the NWP is
512 dependent on a good machine that will not breakdown; a breakdown without knowledge skills
513 for survival can be deadly and the provides the speed to cover long distances also can be
514 dangerous if one is not good at navigating leads and pressure ridges.

515 Overall, those in Kugluktuk conveyed a stronger concern about increased hazards due to
516 changing ice and weather conditions and use of snowmobiles, which are considered less safe
517 than dog teams. Four people commented on how the decrease in snowpack was making travel by
518 snowmobile more dangerous, as the machines can crash on rocks or rough patches.

519 **Unreliable routes**

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

524 I have to know shallow part, otherwise you're gonna get into trouble. You can't
525 see sometimes. I think they need to know where the water is shallow, even ice.

526 The risk when you're navigating, you got to know where you're going first.

527 Because sometimes, wintertime, the pressure ridges, ice and everything, is really
528 rough. You have to go around, all over the place. But you got to know how far
529 you're going, which way you're going. If you want to [go] Flagstaff Island or
530 Gjoa Haven, you have to move around quite a bit. It's pretty hard, because I think,
531 another part, if you have a pressure ridge, there's always open water. There's a
532 risk, you got to watch, wintertime, especially when you're traveling in nighttime...
533 best to do is just to stay away from pressure ridges, because it's like a big rock or
534 something like that. I think nowadays, we worry about more people not coming
535 home from hunting.

536 In a group interview, some participants reflected on how animals also modify their routes
537 in order to adapt to changes.

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

544 **Hazards and accidents**

545 One participant described an increase in accidents (as opposed to merely an increase in
546 risk) and attributed it to “more access to getting out onto the land, and to travel.” He also
547 described rougher ice conditions traveling across the NWP from Kugluktuk to Lady Franklin
548 Point at the western end of Coronation Gulf, and said that finding the smooth patches of ice was

549 more difficult and wasted expensive gas. In Cambridge Bay, two people said that some people
550 are sinking or losing their snowmobiles and they recollected such an incident that happened not
551 long ago. One said that his main worry is not being able to go to the mainland in the winter.

552 Five interviewees from Cambridge Bay commented on hazards. Two concluded that there
553 was no change in the frequency of accidents. Several interviewees described how the change
554 from dog teams to snowmobiles for the primary mode of travel inherently increased risk. Dog
555 teams were able to navigate with an injured driver and/or in hazardous conditions (whiteout,
556 pressure ridges, unfamiliar landscape) but machines can and do break down or run out of gas,
557 stranding the driver. One man who has been with the search and rescue operation for 45 years,
558 noted that this year, a few hunters went missing in September-October, when they were hunting
559 caribou coming from the north. He found that in most cases, they had broken down or run out of
560 gas, or were lost and had no communication. He did not attribute these events to climate or sea
561 ice change. Another participant gave an account of hitting a rock on his snowmobile because of
562 shallow snow; his windshield was damaged and he was injured. People talked about occasional
563 freezing and drowning; one man attributed these incidents as follows: “some guys don’t know
564 which way to go, and they end up sinking their four-wheeler.”

565 Elders are concerned that the younger generations are not taught the skills of living on
566 land at school. One elder says that the younger people are “easy come, easy go. They take off
567 just like riding a horse. You don’t do that up north, you don’t jump on the horse and take off, you
568 know? Nowadays that’s how young people are.”

569 He says that the younger people are not prepared to survive if they get lost, they know
570 how to use snowmobiles, but they don’t know how to survive if they are stuck or in lost in

571 stormy freezing conditions. People believe that it is important learn survival skills to avoid
572 calamities that can be caused by the weather. Two people talked about accidents that have
573 resulted from such incidents:

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

579 **Rising Expenses**

580 Several interviewees commented that avoiding new/increased hazards was both time-
581 consuming and costly. Many interviewees from Kugluktuk commented on how expensive it has
582 become to hunt and travel over the land. One named the expense as a reason that fewer young
583 people are going hunting. Others discussed how they have stopped going to certain hunting
584 grounds because of the expense involved. For the most part, the interviewees from Cambridge
585 Bay did not comment on the expense of hunting in the way that those from Kugluktuk did,
586 although one did lament that “[e]verything, it's all money,” including hunting.

587 Reliance on technologies for subsistence requires engaging in the wage economy to pay
588 for snowmobiles, fuel, GPS, satellite and communication devices – all of which are more
589 expensive in the north. One participant said that the snowmobiles do not last long, only two years
590 or so, and each costs CAD \$15,000-20,000. People find it increasingly difficult to maintain a
591 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; they hunt on foot along the shore and fish and trap.

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 member (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 crossover 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 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 two 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.

614 **Community needs for navigational support**

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

631 Others talked about the general need for better weather forecasts and specific research
632 needs. One participant from Cambridge Bay suggested “[m]aybe put a study here. I’m pretty sure,
633 once your facilities, like your weather stations there. You know, nowadays a lot of the harvesters
634 are depending on the forecasts really.” Others wanted information on flooding, currents, and

635 landscape changes. One of the participants wanted to have a better understanding of caribou
636 migration patterns and how they are changing.

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

643 **Discussion**

644 The NWP is widely used by people in the communities of Cambridge Bay and Kugluktuk
645 and using IK is essential to navigating this landscape. However, knowledge transfer has been
646 impacted by dislocation resulting from the residential school era, and increased participation in
647 the wage economy; the latter limits time available for teaching and learning traditional
648 navigation methods. Climate change, globalization, and modernization all compound the
649 challenges to navigation identified by participants, which include: unpredictable weather
650 conditions, later freeze-up and variable break-up times, unreliable sea ice conditions, less snow,
651 and the cost of equipment and supplies. Snowmobiles, GPS, and satellite radios bring many
652 benefits and are used to compliment some IK-based land skills, but these technologies also bring
653 new risks, especially over-dependence by younger generations not as skilled in hazard mitigation
654 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 (Barber et al., 2012; Cuerrier et al., 2015; Ford et al., 2008a, 2006a). Scientific data on sea ice change in the Northwest Passage is 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. (Galley et al., 2012), who detected a significant advance of ice onset of 0.85 weeks 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 and Jolly, 2002; Ford et al., 2006b; T. Pearce et al., 2010) have also discussed increased risk and hazards associated with travel on land and ice, and compromised trails to hunting grounds 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. IK might be a crucial element of climate change adaptation (Pearce et al., 2015). IK underpins flexibility in adjusting to changing seasonal cycles. 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 adaptation and resilience alone as solution to adaption to the 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.

Conclusion

As Arctic is rapidly changing, there are many benefits to using western science and technology to complement traditional ecological knowledge and to support traditional activities. Weather instrumentation is a good example providing that meets both societal and scientific needs. While navigational technologies compliment IK, traditional skills and experience are still required to ensure safely, avoid hazards, and survive in emergency situations. Maintenance of traditional practices ensures IK evolves with the changing environment times. Investment in IK will protect land-based practices, maintaining a flexible and dynamic knowledge base and enabling innovative solutions to change.

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