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Original Contribution

Caribou (*Rangifer tarandus*) and Inuit Nutrition Security in Canada

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Abstract: Caribou (*Rangifer tarandus*) has been fundamental to the diet and culture of Arctic Indigenous Peoples for thousands of years. Although caribou populations observe natural cycles of abundance and scarcity, several caribou herds across the Circumpolar North have experienced dramatic declines in recent decades due to a range of interrelated factors. Broadly, the objectives of this study are to examine food and nutrition security in relation to wildlife population and management status across Inuit Nunangat (the Inuit homeland, consisting of four regions across the Canadian Arctic). Specifically, we: (1) characterize the contribution of caribou to Inuit nutrition across northern Canada and (2) evaluate the population and management status of caribou herds/populations harvested by Inuit. Dietary data were derived from the 2007–2008 Inuit Health Survey, which included dietary information for Inuit adults (n = 2097) residing in thirty-six communities, spanning three regions (the Inuvialuit Settlement Region, Nunavut, and Nunatsiavut) of the Canadian North. Published information regarding the range, abundance, status, and management status of caribou herds/populations was collected through document analysis and was validated through consultation with northern wildlife experts (territorial governments, co-management, and/or Inuit organizations). While caribou contributed modestly to total diet energy (3–11% of intake) across the regions, it was the primary source of iron (14–37%), zinc (18–41%), copper (12–39%), riboflavin (15–39%), and vitamin B12 (27–52%), as well as a top source of protein (13–35%). Restrictions on Inuit subsistence harvest (harvest quotas or bans) are currently enacted on at least six northern caribou herds/populations with potential consequences for country food access for over twenty-five Inuit communities across Canada. A holistic multi-sectorial approach is needed to ensure the sustainability of wildlife populations, while supporting Inuit food and nutrition security in the interim.

Keywords: Inuit, Arctic, Indigenous, Food security, Traditional food, Country food, Caribou, Rangifer tarandus, Wildlife harvest

Introduction

Wild foods obtained from hunting, fishing, and gathering provide important economic, cultural, psychosocial, spiri-

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tual, and nutritional benefits to over one billion people globally, including Indigenous Peoples and many of the world's most vulnerable and marginalized peoples (Burlingame 2000; Nasi et al. 2008; Kuhnlein et al. 2009; Bharucha and Pretty 2010; Golden et al. 2011; Sarti et al. 2015; Hickey et al. 2016). An estimated 23–36% of species used by humans for food and medicine are threatened with extinction (Butchart et al. 2010). Wildlife species are impacted by a range of pressures, including climate change, habitat degradation, and harvest for human consumption (Wilkie et al. 1998; Bowen-Jones et al. 2003; Heinsohn et al. 2004; Brashares et al. 2004; Fa and Brown 2009), and the cumulative impact of multiple threats can lead to species declines and extinctions (Thomas et al. 2004; Heller and Zavaleta 2009). While millions of people around the world depend on wildlife for food security, human nutrition remains one of the most often overlooked ecosystem services within research and food security policy (Declerck et al. 2011; Hickey et al. 2016).

Literature at the intersection of wildlife conservation, subsistence harvesting, and food security (i.e., the state of continued and sufficient access to safe/nutritious and culturally preferred foods) has largely favored the "bushmeat" (i.e., forest animals) context in the humid tropics of the Americas, Asia, and Africa (Fa et al. 2003; Davies and Brown 2008; Nasi et al. 2008; Golden et al. 2011; Nasi et al. 2011; Cawthorn and Hoffman 2015). At the same time, Arctic Indigenous Peoples, such as the Inuit, maintain strong connections to the environment through subsistence food procurement (i.e., hunting, fishing, and gathering) (Nuttall et al. 2005) and face similar challenges in supporting the sustainable harvest of wildlife in the context of global environmental change. Global warming is occurring more rapidly in the Arctic than elsewhere on the planet (IPCC 2014), with profound impacts on northern ecosystems, wildlife species (Post et al. 2009), and systems of subsistence harvest and wildlife management (Armitage 2005).

Harvesting, sharing, and consuming country (wild-harvested) foods remain a critical facet of life and identity for Inuit (Wenzel 1991; Borré 1991; Condon et al. 1995), embedded within cultural, psychosocial, and spiritual dimensions of health and wellness (Pufall et al. 2011) and integral to dietary quality (Kuhnlein and Receveur 2007; Kenny et al. 2018), food security (Power 2008; Huet et al. 2012), and the "right to food" for Inuit (Inuit Tapiriit Kanatami and Inuit Circumpolar Council 2012). While Inuit have been sustained by harvesting northern wildlife for thousands of years (Nuttall et al. 2005; Bonesteel and Anderson 2008)—in an environment historically perceived to be "susceptible to dramatic fluctuations in food availability" (Harder and Wenzel 2012)—they are now experiencing significant climate change-related impacts on local food systems, with repercussions for country food availability/access (e.g., changes in health, abundance, distribution, and migration of wildlife populations), and harvestability (e.g., changes in landscape and unpredictable weather conditions) (Chan 2006; Lambden et al. 2007; Ford 2009; Meakin and Kurvits 2009; Nancarrow and Chan 2010; Wesche and Chan 2010). Declining abundance of key culturally important species in the Arctic represents a critical challenge to the sustainability of subsistence harvests and to the food and nutrition security of the Inuit (Theriault et al. 2005; Nancarrow et al. 2008; Wesche and Chan 2010; Brinkman et al. 2016; Rosol et al. 2017).

Caribou (*Rangifer tarandus*) and Inuit

The contemporary Inuit diet comprises over one hundred wildlife and plant species (Kuhnlein and Turner 1991; Kuhnlein and Soueida 1992; Kuhnlein and Receveur 2007), with caribou (*Rangifer tarandus*), which was reported to be consumed by over 90% of Inuit adults who participated in the 2007–2008 Inuit Health Survey (Kenny and Chan 2017), a "cultural keystone species" (i.e., a species integral a people's diet, cuisine, and society) (Garibaldi and Turner 2004) in many communities. Caribou and human histories have converged in the North for thousands of years (Stewart et al. 2004; Gordon 2005). As such, caribou has been socially, spiritually, culturally, and materially (for clothing, shelter and tools, in addition to food) embedded in the livelihoods, knowledge systems, worldviews, and identities of the Inuit and other Indigenous Peoples of the North for generations (Wilson et al. 2014; UPCART 2017).

While caribou populations exhibit natural cycles of abundance and scarcity (Gunn 2003)—that are well known to Inuit, who possess extensive multi-generational knowledge on the species (Ferguson et al. 1998; Wilson et al. 2014; UPCART 2017)—dramatic declines have been documented across the Circumpolar North in recent decades (Vors and Boyce 2009; Gunn et al. 2011). Barren-ground caribou populations, for example, have declines by over 70% in northern Canada over the last two decades (Parlee et al. 2018).

Elucidating the causes of these declines is complicated by the lack of comprehensive temporal data for many herds

and populations, the cyclical nature of caribou abundance, and interactions between density-independent abiotic conditions, and density-dependent population dynamics (Tyler 2010; Gunn et al. 2011). Overall, northern caribou declines are believed to represent the cumulative effect of many interrelated factors, including habitat degradation, climate change, increasing predator populations, and anthropogenic pressures (Vors and Boyce 2009; Gunn et al. 2011; Wilson et al. 2014). Local anthropogenic pressures, such as infrastructure and industrial development, can also influence caribou behavior and disrupt migratory patterns (Dyer et al. 2001; Reimers and Colman 2006), which can impact their availability for subsistence hunters. While hunting by humans can exacerbate caribou declines, it is not believed to represent a definitive cause of shifting demographic trajectories. Narratives and hypotheses of overharvesting by Indigenous Peoples, constructed in the early twentieth century, were predicated upon cultural biases and limited empirical evidence (Usher 2003; Payette et al. 2004). Nevertheless, management has traditionally focused on restricting Indigenous harvesting (Parlee et al. 2018).

Various strategies, initiatives, and frameworks exist for the management of caribou herds across the North (PCMB 2016; UPCART 2017). These include short-term actions aimed to reduce caribou mortality (e.g., attenuating predation and hunting pressure) as well as long-term initiatives to maintain the integrity of caribou habitats and their supporting resources (e.g., land-use management procedures) (Festa-Bianchet et al. 2011). Ultimately, caribou declines across the North have prompted the implementation of institutional conservation measures, including quota restrictions and harvest moratoria (Government of Newfoundland and Labrador 2013; Government of Nunavut 2014).

While harvest restrictions have been reported as barriers to country food access (Chan et al. 2006), the relationship between wildlife status, country food harvest/consumption, and food security is multifaceted and complex (Power 2008). For example, the dichotomized approach of dealing separately with wildlife conservation and food security may be incongruous with traditional Inuit notions of harvest, which recognize the mutually interdependent relationships between humans, animals (non-human), and the environment (Wenzel 1991; Borré 1991). Furthermore, the ability to reliably access country food over time [i.e., the "stability" dimension of food security (FAO 1996)] necessitates sustainable wildlife populations over the long term. Indeed, taking into consideration the needs of future generations is a top priority within Indigenous management strategies for caribou (UPCART 2017). Nevertheless, restricted access to caribou in the interim may have food and nutrition security repercussions on individuals, households, and communities. Importantly, the dynamics (i.e., changes over time and/or in relation to changing circumstances) between wildlife status, conservation measures, subsistence hunting, and food and nutrition security have received limited examination through empirical research and dedicated case studies.

Broadly, this study aims to examine food and nutrition security in relation to wildlife population and management status across Inuit Nunangat (the Inuit homeland, consisting of four regions across the Canadian Arctic). Specifically, we: (1) describe the importance of caribou to the nutrition security of contemporary Inuit, by relating caribou consumption to nutrient intakes and (2) examine the management status of northern caribou herds by compiling population status trends and identifying restrictions to caribou harvest (i.e., harvest quotas or moratoria). We stress that the value of caribou to Inuit, and indeed to other Indigenous Peoples across the Circumpolar North, far exceeds dietary nutrients. Accordingly, the potential health and wellness impacts of restricted caribou access (whether through caribou abundance declines, harvest restrictions, or shifting herd ranges) necessarily include impacts on cultural, psychosocial, and spiritual aspects of health and wellness. The following study serves therefore as an initial attempt to use available information to bridge these often disparate fields of inquiry and practice and may serve to complement community-oriented research involving Inuit knowledge and perspectives regarding caribou and human health. Given the fundamental importance of caribou to Inuit culture and food and nutrition security, coupled with the amplified responses of Arctic species and ecosystems to climate change, this research may serve as a case study for changes in other global regions.

Methods

We employed a mixed-methods approach, drawing on qualitative and quantitative research methods. Dietary data were derived from a cross-sectional health survey of Inuit adults (Saudny et al. 2012), conducted across three regions of Inuit Nunangat. Information regarding the range,

abundance, population, and management status of northern caribou herds was obtained through document analysis (Bowen 2009) and verified through consultation with northern wildlife experts from Inuit organizations, wildlife co-management bodies, and/or territorial governments in each region. We distinguish between Inuit rights to subsistence harvests, and resident, sport, and commercial harvest privileges, as they are subject to distinct management regimes and policies.

Contribution of Caribou to Nutrition Security

The cross-sectional Inuit Health Survey (IHS) collected detailed health information from Inuit adults between late summer 2007 and fall 2008. Detailed survey methodology and design, including the participatory research process, has been reported elsewhere (Saudny et al. 2012). Households (n = 2796) in 36 communities (latitudes between 54°10'N and 76°25'N), spanning the Inuvialuit Settlement Region (ISR), Nunavut (NU; including the Qikiqtaaluk, Kivalliq, and Kitikmeot subregions, respectively) and Nunatsiavut, were randomly selected to participate. Dietary information for Nunavik (northern Quebec), the fourth Inuit region, was assessed during the separate Qanuippitaa Health Survey in 2004 (Rochette and Blanchet 2007) and 2017 and was therefore beyond the scope of the present study (although information regarding caribou status in Nunavik is presented below). From each household, Inuit men and non-pregnant Inuit women (18 years and older) were eligible. Informed consent was obtained from each participant. Ethical approval for the IHS was granted by McGill University (Faculty of Medicine Institutional Review Board), and the University of Ottawa (Health Sciences and Science Research Ethics Board, file number H05-15-16) provided ethical approval for data analysis. Scientific Research Licenses for the IHS were obtained from the Aurora Research Institute (Northwest Territories (NT)) and Qaujisaqtulirijikkut (Nunavut (NU)).

Dietary Assessments (2007–2008 Inuit Health Survey)

Dietary assessments were conducted in-person by trained interviewers in English and Inuit languages. This involved a single 24-h recall, based on an adapted form of the USDA multi-pass approach (Blanton et al. 2006). Participants were asked to recall all foods (both country (wild) food and market food) consumed on the day preceding the interview (beginning and ending at midnight) and estimate portion sizes with the help of three-dimensional graduated food model kits (Direction de Santé Québec, Institut de la Statistique du Québec 2013). The Canadian Nutrient File (Health Canada 2015) was used to calculate energy and nutrient intakes. Nutrient composition information for foods not included in the CNF was drawn from an in-house food file (McGill School of Dietetics and Human Nutrition) (Egeland et al. 2011). Missing nutrient values were imputed following the methodology outlined by Schakel et al. (1997).

Analyses

Data management and nutrient calculations were performed with SAS statistical software (version 9.4; SAS Institute, Cary, NC). The population proportion method (Krebs-Smith et al. 1989) was used to calculate the contribution of caribou to nutrient intakes by region.

Northern Caribou (*Rangifer tarandus*) Population and Management Status

Document analysis (Bowen 2009) was used to identify published information regarding the most recent abundance estimates, population status, and harvest/management status of northern caribou herd, as well as confirm use of specific herds by Inuit communities. Our intent was to systematically summarize published information (from both the academic and gray literatures) about the population and management status of caribou across Inuit Nunangat, so as to identify where access barriers for a key country food species (caribou) may exist. Accordingly, we neither collected new data, nor drew novel conclusions about caribou population or management status. Furthermore, Inuit possess extensive multi-generational knowledge regarding wildlife dynamics (Ferguson et al. 1998; Kendrick and Manseau 2008), which is increasingly documented using culturally appropriate methods and included in wildlife co-management systems. At the time of writing, however, a comprehensive and systematic compilation of this (generally, locally focused) information does not exist for the North. Based on information access and availability, we have therefore synthesized results from scientific assessments (largely reported by government organizations) for caribou recognizing that the fundamental definitions (e.g., conceptions of caribou populations, herd designations and delineations, caribou behavior/tendencies,

and the relationships between caribou and people), and results (e.g., population abundance estimates, range distributions) derived from scientific assessments and local and traditional knowledge may differ. We recognize, furthermore, that disagreement may exist between the conclusions drawn by institutions involved in wildlife management (i.e., territorial governments, wildlife co-management boards, and Inuit and other Indigenous organizations) (Dowsley and Wenzel 2009). The equitable inclusion of traditional knowledge within wildlife co-management systems can be a source of management solutions that explicitly considers the unique concerns of rights-holders and other stakeholders (Kendrick and Manseau 2008; Parlee et al. 2010).

Comprehensive scientific information on the distribution, trends, and population status of northern caribou is summarized in the Canadian Biodiversity: Ecosystem Status and Trends 2010 Technical Thematic Report No. 10 (Gunn et al. 2011). We supplemented this information by systematically searching organizational reports, maps, newspapers, press releases, and various public records for each caribou herd/population to identify: (1) the most recent population estimates (i.e., empirical estimates of caribou abundance based on population censuses, including aerial surveys); (2) herd/population status (based on the interpretation of the population trends, as previously reported in wildlife reports); (3) the extent of the range, including reported community harvest of the herd/population, relevant management entities, and management plans; and (4) management status, including current restrictions on Indigenous harvesting. Locations of Inuit communities and caribou ranges were mapped (Fig. 1) to reveal geographic relationships between caribou herds relevant to Inuit subsistence needs, at different scales (territory, region, and community). ''Relevance'' was defined by community proximity to the herd/population's annual range and/or documented use of the herd by the community. The objective was to infer which communities may currently be impacted by caribou population declines and harvest restrictions. It is important to note that herd status and management will necessarily change over time, as new research and monitoring is conducted, as traditional knowledge is increasingly documented, and, as new management plans are implemented.

We consulted wildlife experts in each Inuit region to confirm the accuracy of results derived from document analysis. Wildlife experts were identified based on their professional association (i.e., professionals from Inuit organizations, wildlife co-management boards, and/or territorial wildlife departments) and experience/involvement in caribou co-management or expertise in northern caribou biology. Experts were consulted in-person, by telephone, or by e-mail, to validate results. Document analysis and validation of results were conducted between August and November 2016.

Results

Contribution of Caribou to Inuit Nutrition

Caribou contributed between 5.6 and 11.2% of the Inuit population's total energy intake (by region) and ranked within the top five dietary sources of energy in the ISR and all three Nunavut subregions (Fig. 2). In Nunatsiavut, caribou contributed less than five percent (3.2%) of total energy intake at the time of the study. It is important to note that reported consumption values reflect species abundance and accessibility at the time of the study (see Study Limitations, below). Caribou was the top dietary source of protein in Nunavut (up to 35% of total intake) and the ISR and the second-most important in Nunatsiavut (Fig. 2). Caribou was the top dietary source of iron in all regions and contributed between 14.3 and 36.5% of total iron intake by region (Fig. 3). Caribou was likewise the most important dietary source of zinc (17.7–41.3%), copper (12.1–38.5%), riboflavin (15.4–39.3%), phosphorous (7.3–22.1%), vitamin B12 (26.6–52%), and vitamin B6 (7.0–22.9%) across all regions (Fig. 3). Caribou ranked within the top three dietary sources of potassium in both Nunavut and the ISR (8.8–17.4%). Nutrients for which caribou contributed less than 10% of total intake across all regions include vitamin C ($< 3\%$), vitamin D ($< 2\%$), selenium ($< 10\%$), vitamin E ($< 10\%$), and MUFA ($< 10\%$) (data not presented).

Caribou Ranges and Inuit Communities

Caribou (Rangifer tarandus) Subspecies, Ecotypes, and Herds

The term ''caribou'' represents the broad, species-level designation of several genetically, morphologically, and/or behaviorally distinct subspecies, ecotypes, and herd/population of *Rangifer tarandus* (Hummel and Ray 2008). Four subspecies of *Rangifer tarandus* occur across Inuit Nunangat: barren-ground (*R. t. groenlandicus*), Porcupine (*R. t. granti*), Peary (*R. t. pearyi*), and woodland (*R.t. caribou*) caribou. Additionally, Dolphin and Union caribou (*R. t. groenlandi-*

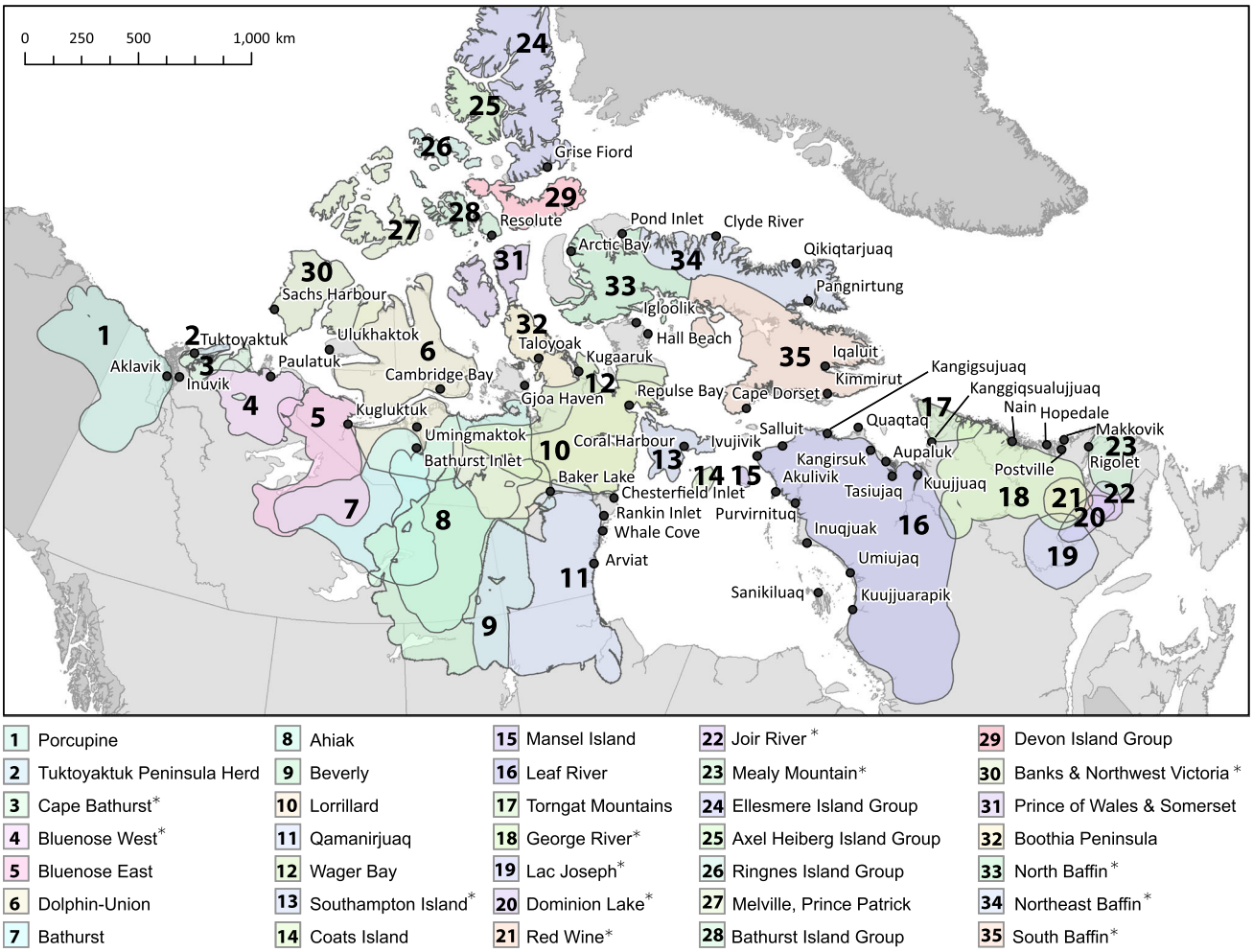

Figure 1. Range and distribution of northern Caribou (*Rangifer tarandus*) herds/populations and Inuit communities across Inuit Nunangat (Canadian Arctic). *Denotes caribou populations where formal restrictions on Inuit subsistence harvest (harvest ban or quota) are currently in effect. See Table 1. Complete information regarding caribou population and management status is provided in supplementary material. Please refer to Gunn et al. (2011) for a complete list of references for the herd range data used to create this map

cus/pearyi) are recognized as a distinct population of the barren-ground caribou subspecies. Caribou are generally designated (and managed) as discrete subpopulations, or herds (for more information regarding caribou designations, see Festa-Bianchet et al. (2011)); however, this classification is complicated by intersecting ranges, with many distinct herds only gaining recognition within the last few decades (Gunn et al. 2011). Distinct caribou populations have also been aggregated as Designable Units for management within the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2011). Although beyond the scope of this paper, we emphasize, once again, that Western science and Inuit perspectives and knowledge regarding caribou population designations may differ (Ferguson et al. 1998).

Seven migratory barren-ground caribou (*R. t. groenlandicus*) herds occur across Inuit Nunangat (Fig. 1, from west to east): Cape Bathurst, Bluenose West, Bluenose East, Bathurst, Ahiak, Beverly, and Qamanirjuaq. Dolphin and Union caribou (*R. t. groenlandicus/pearyi*) are endemic to Victoria Island and the northern mainland of the Kitikmeot region (NU). Porcupine caribou (*R. t. granti*), currently among the largest migratory herds in North America, migrates between Alaska, Yukon, and the western Northwest Territories (NT). Five major populations of sedentary barren-ground caribou (Tuktoyaktuk Peninsula, Wager Bay, Lorillard, Boothia Peninsula, and North Melville Peninsula) occur on the mainland of both Nunavut and the ISR, in addition to three populations on the southern Arctic islands of Hudson Bay (Southampton, Coats, and Mansel Island). Peary caribou (*R. t. pearyi*) inhabit the islands of the Canadian Arctic Archipelago (namely the Queen Elizabeth Islands, Banks Island, northwest Victoria

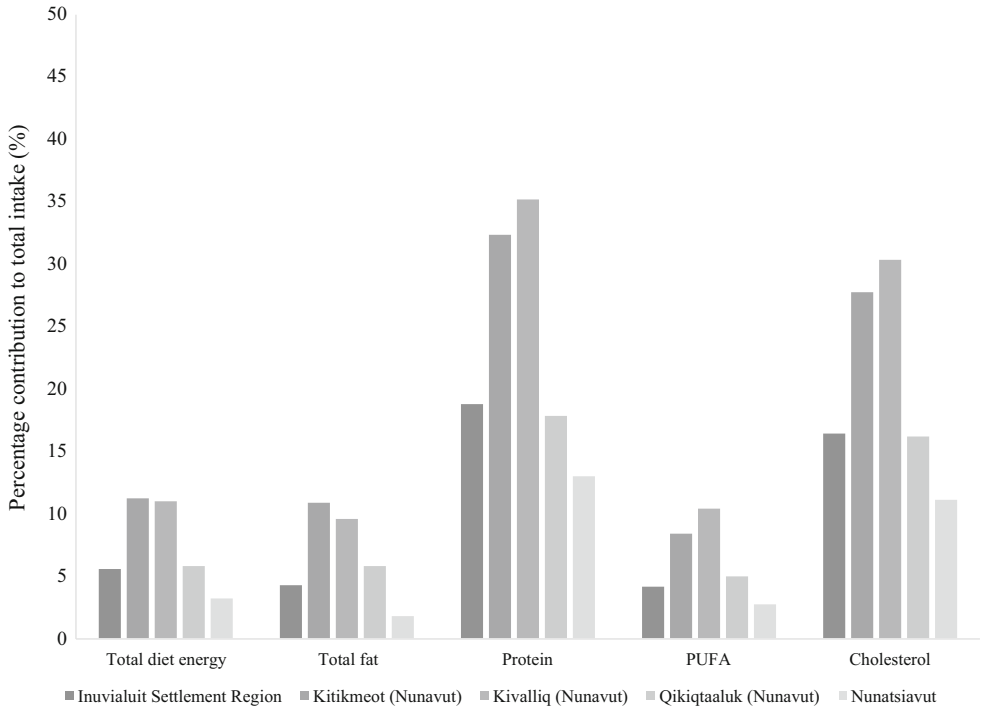

Figure 2. Contribution of caribou (*Rangifer tarandus*) to the intake of dietary energy and selected nutrients among Inuit adults (n 2095) in five regions of Inuit Nunangat (Canadian Arctic)

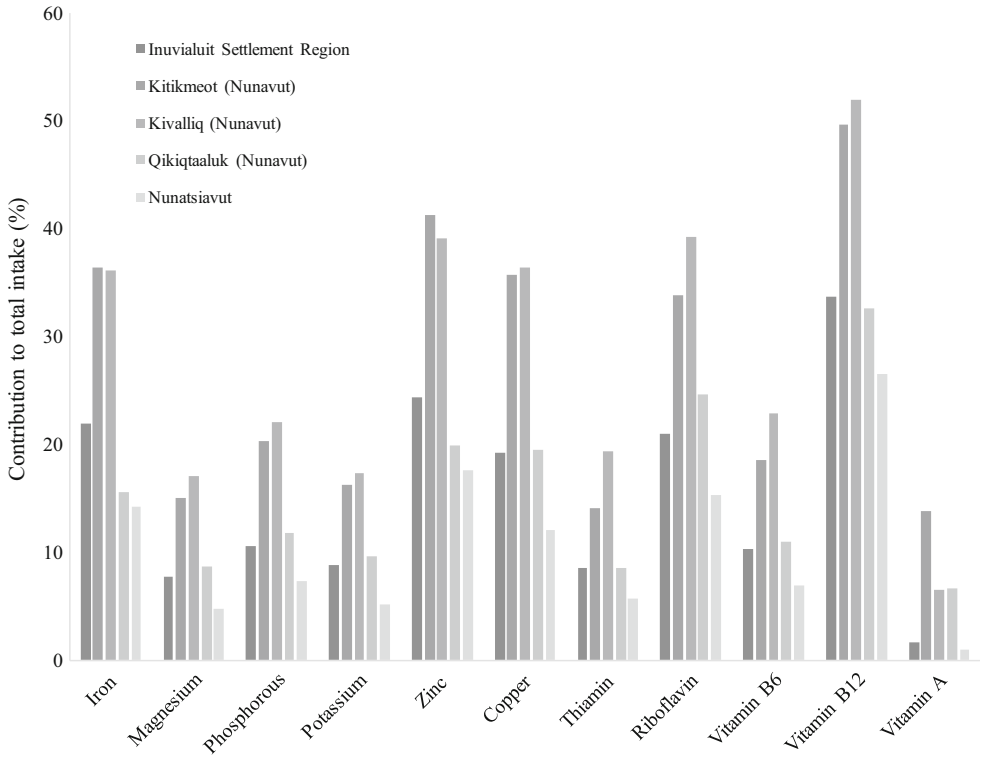

Figure 3. Contribution of caribou (*Rangifer tarandus*) to the intake of micronutrients among Inuit adults (n 2095) in five regions of Inuit Nunangat (Canadian Arctic)

Island, Prince of Wales Island, and Somerset Island), in addition to the Boothia population on the Kitikmeot (NU) mainland. Woodland caribou (*R.t. caribou*) occur in the eastern subarctic regions of Nunavik and Nunatsiavut. Two migratory woodland caribou herds (George River and Leaf River) inhabit the Ungava Peninsula, while a single population of montane woodland caribou inhabits the Torngat Mountains (Torngat population). Three populations of sedentary woodland caribou reside in Labrador (Mealy Mountain—Joir River subpopulation, Red Wine–Dominion Lake subpopulation, and Lac Joseph).

Regional and Community Utilization of Caribou Herds

Mainland communities of the ISR (Aklavik, Inuvik, Paulatuk, and Tuktoyaktuk) harvest principally from the Porcupine, Cape Bathurst (suspended since 2007) Bluenose West, and the Tuktoyaktuk Peninsula herds (Fig. 1). Sachs Harbour (Banks Island) and Ulukhaktok (Victoria Island) are situated within the range of both the Peary herd and Dolphin and Union herd; however, harvest restrictions on caribou have been implemented locally through community-based management plans for several decades (Fig. 1; Table 1—Supplemental Material). Communities from the Kivalliq region (Arviat, Whale Cove, Rankin Inlet, Baker Lake, Chesterfield Inlet, Repulse Bay, and Coral Harbour) harvest principally from the Qamanirjuaq, Beverly, Lorillard, Ahiak, Wager, and Southampton herds (Fig. 1; Table 1). Communities on Baffin Island (Qikiqtaaluk Region) harvest principally from the three subpopulations of Baffin caribou (North Baffin, Northeast Baffin, and South Baffin). The George River herd is harvested by several communities in Nunavik (which also harvest from the Leaf River herd) and Nunatsiavut; however, since 2013 an indefinite ban on caribou harvest has been in place in Nunatsiavut.

Many communities are situated at the confluence of overlapping herd ranges and therefore harvest from multiple herds throughout the year (Fig. 1). For instance, Inuvialuit in Tuktoyaktuk (NT) harvest caribou from the Tuktoyaktuk Peninsula, Cape Bathurst, and Bluenose West herds. Likewise, Baker Lake (NU) is situated within the overlapping ranges of five caribou herds (Beverly, Qamanirjuaq, Wager Bay, Lorillard, and Ahiak). Conversely, some communities, such as Arviat (NU), are situated in proximity to the migration route of a single herd (Qamanirjuaq); thus, harvesting may be limited to specific seasons. It is important to note that herd ranges are seasonally and annually variable; as such, actual range-overlap may vary between years.

It is also important to note that many caribou herds occupy transboundary habitats during their lifecycle that cut across political and legislative boundaries. In this capacity, the same herd may be harvested by several Inuit, First Nations, and Métis communities (as well as non-Indigenous people), and be subject to the management decisions of a variety of rights-bearers, stakeholders, and different government harvest and conservation policies/practices.

Caribou Status

Abundance estimates from censuses conducted during recent decades show evidence of dramatic population declines for several caribou herds, including the Cape Bathurst, Bluenose West, and Southampton herds (Campbell 2006; Nagy and Johnson 2006; McFarlane et al. 2016). A notable exception, the Porcupine herd, is currently experiencing a period of increasing population abundance (197,000 animals in 2013) (Table 1—Supplemental Material). Dolphin and Union caribou are stable from historic lows (Dumond and Lee 2013). Peary caribou have been listed under the federal Species at Risk Act (SARA) since 2011 (Species at Risk Committee 2012; Government of Canada 2016). A detailed summary of abundance estimates, population trends, and management status of northern caribou herds across Inuit Nunangat is presented in supplementary material.

Overview of Wildlife Management Structures

Management of wildlife, such as caribou, across the Canadian Arctic is managed/co-managed between public (territorial/provincial and federal, including fulfillment of international treaties) and Indigenous (land claim areas, regions, and communities) governments and originations at various levels, including co-management bodies. While some organizations focus broadly on the management of several species within a defined geographic or legislative boundary (e.g., Nunavut Wildlife Management Board), other organizations focus on a specific population/herd, across multiple boundaries (e.g., Beverly and Qamanirjuaq Caribou Management Board). As such, wildlife management may be fragmented, or shared, among numerous treaty/land claim, legislative, political, geographic, and institutional jurisdictions, with differing roles, formal responsibilities, rights, and power.

Table 1. Summary of Barriers to Caribou (*Rangifer tarandus*) Access from Harvest Restrictions and Population Declines

Barriers to country food access[a]	Caribou herd/population	Inuit regions and communities potentially affected[b]
No access (harvest ban)	Cape Bathurst	ISR (NT) = Aklavik, Inuvik, Tuktoyaktuk
	George River (includes all caribou on provincial land within Nunatsiavut/Labrador[c])	Nunatsiavut (Labrador): Nain, Hopedale, Makkovik, Postville, Rigolet
Restricted access (harvest quota)	Bluenose West	ISR (NT)[d]: Aklavik, Inuvik, Paulatuk, Tuktoyaktuk
	Baffin Island (North, Northeast and South Baffin herds)	Qikiqtaaluk (NU): Arctic Bay, Pond Inlet, Clyde River, Kimmirut, Cape Dorset, Iqaluit, Pangnirtung, Qikiqtarjuaq, Igloolik, Hall Beach
	Peary caribou (Banks & Northwest Victoria Island)	ISR (NT): Sachs Harbour, Ulukhaktok
	Southampton Island	Kivalliq (NU): Coral Harbour, Repulse Bay, Chesterfield Inlet and Rankin Inlet Qikiqtaaluk (NU): Cape Dorset
Declining population (Declining population status or population stable at historic low)	Bathurst[e]	Kitikmeot (NU): Kugluktuk, Bathurst Inlet, Umingmaktok
	Beverly	Kitikmeot (NU): Bathurst Inlet, Umingmaktok Kivalliq (NU): Arviat, Baker Lake, Chesterfield Inlet, Whale Cove, Rankin Inlet
	Bluenose East[f]	Kitikmeot (NU): Kugluktuk
	Dolphin and Union Caribou	ISR (NT): Ulukhaktok, Paulatuk Kitikmeot (NU): Cambridge Bay, Kugluktuk, Bathurst Inlet, Umingmaktok
	Leaf River	Nunavik (all communities)
	Peary caribou	Qikiqtaaluk (NU): Resolute Bay, Grise Fiord, Arctic Bay
	(High Arctic and Low Arctic subpopulations)	Kitikmeot (NU): Kugaaruk, Taloyoak, Gjoa Haven, and Cambridge Bay
	Qamanirjuaq	Kitikmeot (NU): Bathurst Inlet, Umingmaktok Kivalliq (NU): Rankin Inlet, Arviat, Baker Lake, Chesterfield Inlet, Whale Cove
	Tuktoyaktuk Peninsula	ISR (NT): Tuktoyaktuk
Stable or increasing population	Porcupine	ISR (NT): Inuvik, Aklavik
	Lorillard	Kivalliq (NU): Chesterfield Inlet, Baker Lake
	Torngat Mountain	Nunatsiavut (Labrador): Nain Nunavik (Quebec): Kangiqsualujjuaq
	Wager Bay	Kivalliq (NU): Repulse Bay, Baker Lake, Chesterfield Inlet
Unknown	Ahiak	Kitikmeot (NU): Gjoa Haven, Umingmaktok Cambridge Bay Kivalliq (NU): Baker Lake

Acronyms: *ISR* Inuvialuit Settlement Region, *NT* Northwest Territories, *NU* Nunavut

[a]Potential barriers to country food access (caribou), defined by formal management of Inuit subsistence harvests as: harvest ban, quota-based harvest restrictions, declining population status/population stable at historic low, and stable or increasing population. Voluntary harvest restrictions as well as non-quota limitations on Inuit subsistence harvest may also be implemented locally through community-based management plans. Detailed information on caribou abundance and management status is summarized in the supplementary material

[b]Based on community–proximity to herd and/or documented use of the herd by the community

[c]The ban on caribou harvest in Labrador (provincial land) includes the Boreal Population of woodland caribou (Mealy Mountain, Red Wine and Lac Joseph subpopulations)

[d]Sachs Harbour and Ulukhaktok are allocated tags for the Bluenose West herd through the co-management process; however, these tags generally go unused and are redistributed to other ISR communities

[e]Harvest of the Bathurst herd was suspended in the NT in 2014 but is beyond the range of Inuit communities; Harvest of the Bathurst herd in Nunavut is not currently restricted through quota

[f]A harvest quota has since been set for Nunavut (as of 2017). A voluntary restriction has been implemented in the NWT (Sahtu and Wek'eezhi Resources Boards) for several years. The Inuvialuit community of Paulatuk is allocated tags for the herd, however, the herd is typically beyond the community's usual harvest range

The right of Indigenous Peoples to the use and management of their traditional lands, territories, and resources is recognized in the United Nations Declaration of the Rights of Indigenous Peoples (United Nations General Assembly 2007) and entrenched in both the Canadian Constitution (Article 35) and in Inuit land claim agreements across the North (The Inuvialuit Final Agreement, as Amended 2005a; The Nunavut Land Claim Agreement 1993; The Nunavik Inuit Land Claims Agreement 2006; The Labrador Inuit Land Claims Agreement 2005b). Each land claim agreement includes a wildlife article that defines the legal rights of Inuit to harvest wildlife (to meet social and cultural needs; in some regions, this extend to economic needs as well), the role of Inuit in all aspects of wildlife management, the principles of wildlife conservation, and the creation of systems of wildlife management (including the establishment of wildlife management/co-management institutions). It is important to note that provisions outlined in each land claim vary, and distinct sociocultural histories and political contexts between regions have resulted in different wildlife management structures. Although the provisions outlined in each land claim agreement differ, wildlife harvest is generally unrestricted for Inuit, unless a total allowable harvest (TAH) has been set for conservation purposes (Natcher et al. 2012b).

Caribou Management and Harvest Restrictions

Hunting for many caribou herds across Inuit Nunangat is currently closed or restricted for non-Indigenous harvesting, including resident, outfitter/sport, and commercial harvests. At the time of writing restrictions on Inuit subsistence, harvests are implemented for at least six caribou populations, including complete harvest bans on both the Cape Bathurst (since 2007) and, with the exclusion of the Torngat Mountain herd (mostly accessible to people in Nain, Fig. 1, and which is managed under federal jurisdiction), a complete ban on all caribou harvest across Labrador (since 2013). The latter restriction includes the George River herd and three populations of sedentary woodland populations (in Nunatsiavut, only Lake Melville Area residents and the community of Rigolet are located in proximity to these herds) (Table 1).

Harvesting from the Southampton Island herd (since 2012), the three Baffin Island herds (since 2015), and the Bluenose West herd (since 2007) is currently restricted through total TAH designations. Restrictions on Indigenous subsistence harvest are currently implemented for both the Bathurst (since 2014) and Bluenose East (since 2016) herds in the Northwest Territories; however at the time of this study, no formal government restrictions exist for these same herds in Nunavut. A harvest quota has since (2017) been implemented for the latter herd in Nunavut. In the ISR harvest restrictions are implemented through community-based management plans for Peary caribou on Banks Island and Victoria Island (since the 1990s). Similarly, Resolute Bay (NU) hunters have implemented harvest limitations for Peary caribou for several decades.

Discussion

While caribou populations experience natural fluctuations (Gunn 2003), declines in recent decades may be more dramatic than any others in recorded history (Gunn et al. 2011). Harvest restrictions are currently implemented for several caribou herds, harvested by tens of Inuit communities across Inuit Nunangat (Table 1). Restricted access to caribou disrupts opportunities for youth to acquire harvesting knowledge and skills; for some individuals, these disruptions coincide with a sensitive period of identity development, such as adolescence (Collings 1997). This may have repercussions for intergenerational dimensions of health and cultural wellness, and for the transfer of traditional knowledge and skills between generations (Tyrrell 2007). Furthermore, given the dietary and nutritional importance of caribou and the high price of nutritious market foods in the North, barriers to caribou access, whether through species decline (i.e., availability) and/or harvest regulations (i.e., accessibility), are of concern to public health due to potential declines in critical micronutrients in local diets (Rosol et al. 2017).

It is important to note, however, that no empirical research has documented how individuals and households adapt their diets (by substituting between country food species or transitioning to greater reliance on market foods) in response to constrained/restricted caribou (or other country food) access in this context. Similarly, changes in food security status have not been examined directly in relation to caribou (or other wildlife) declines and related wildlife conservation measures (e.g., harvest quotas). Accordingly, the dietary, food security, and human health impacts of wildlife declines and harvest restrictions remain unknown in the peer-reviewed literature. Furthermore, wildlife declines and harvest restrictions are among a plurality of other social (e.g., disruptions to the intergenera-

tional transmission of traditional knowledge and harvest skills), economic (e.g., limited time availability due to employment, the high cost of harvest), and policy/program (e.g., changes to harvester support programs that have affected access to harvest equipment and fuel) factors that have affected Indigenous Peoples' ability to harvest, access, and consume country foods (Natcher et al. 2016).

Nevertheless, insights into the dynamics of adaptation may be derived from qualitative research conducted across the North. For example, during the 1992/1993 ban on caribou harvest in Ulukhaktok (ISR), other country food sources remained locally available to the community and caribou meat was shipped in from neighboring communities (Collings 1997). In another example, community members in Paulatuk (ISR) expressed concerns about the impact of a regional caribou quota on household food security and the implications for country food sharing (Todd 2010). While some adapted to the quota by substituting caribou with other country food species, others transitioned to a greater reliance on foods purchased from the store (Todd 2010).

Based on comprehensive population-specific diet and nutrition information collected by the 2007–2008 IHS, caribou, despite its modest energetic contribution to the total Inuit diet ($<$ 12% of total diet energy), was found to be the principal source of several micronutrients, including iron, zinc, copper, riboflavin, vitamin B12, vitamin B6, phosphorous, and potassium. Although many nutrients (e.g., protein) may be provisioned from consumption of alternate country food species (Nancarrow and Chan 2010; Wesche and Chan 2010; Rosol et al. 2017) and/or market foods of high nutritional quality, certain micronutrients may be limitedly available and/or "unaffordable" in the northern food supply. As caribou is the primary source of iron and several micronutrients (zinc, copper, riboflavin, and B6) necessary for the synthesis of red blood cells (erythropoiesis), further research and monitoring are needed to evaluate the impacts of wildlife access restrictions on diet quality, nutritional status, and health (e.g., anemia, diabetes, and immunological effects) (Prasad 1993).

Certain segments of the population (e.g., women of childbearing age, as well as pregnant and lactating women, who are at increased risk of iron deficiency and inadequacies of magnesium and zinc (Duhaime et al. 2002; Berti et al. 2008)) may require special attention in these circumstances. We emphasize, however, that dietary interviews (from which the data used in this study are derived) are designed to document foods *actually* consumed by a population and do not explicitly capture individual *needs* for country foods, *constraints* in the food environment that mediate food choices, nor, the *adaptation* strategies employed by individuals, households, and communities to constrained food access. Importantly, "risk" results from the coupling of hazards, local vulnerabilities, and potential for adaption (Stephen and Duncan 2017). As such, the impact of wildlife declines and harvest constraints on food and nutrition security will be experienced differently depending on individuals (e.g., age and gender), household, community, regional, and broader environmental, and sociopolitical factors (Natcher et al. 2016).

Adaptive use of resources is a recognized strategy of risk aversion (Ford et al. 2006a), which has long been practiced by Inuit to sustain food production under changing or uncertain conditions (Sabo 1991). While subsistence-based societies have long adapted to fluctuating species abundance and changing harvest conditions (Sabo 1991; Berkes and Jolly 2002), effective local adaptive responses may conflict with non-Inuit notions of wildlife conservation (Wenzel 2009). Harvest regulation, for example, may alter harvesting behavior and restrict the flexibility with which harvesters adapt to change (Ford et al. 2006b; Ford and Beaumier 2011). Detailed understandings of local harvest context (e.g., economics and cost of hunting, species harvested concurrently) and harvester strategies to constrained wildlife availability or access (e.g., such as substituting one species for another (Hansen et al. 2013), and/or investing greater effort into harvesting (e.g., traveling longer distances and/or spending more time harvesting)) are needed to ascertain the impact of wildlife declines on the local (community and household) country food supply. Furthermore, information regarding intra-community and inter-community dynamics, such as food-sharing networks (a traditional mechanism for maintaining food security and social relations) (Collings et al. 2016), are needed to ascertain how individuals, households, and communities respond to and experience food and nutrition security risks related to wildlife declines and harvest restrictions. More fundamentally, it is important to note that country food species are not equivalent, both in terms of their nutritional profiles and in terms of their cultural favorability. Rosol et al. (2017), for example, investigated the theoretical possibility of substituting caribou meat (weight for weight) with other country food species, such as goose (*Branta canadensis*), noting that intake levels for several nutrients (e.g., zinc and vitamin D) would be substantively diminished (Rosol et al. 2017).

Constraints to country food access must also be situated within the context of food insecurity and the "nutrition transition" (Kuhnlein et al. 2004; Sheikh et al. 2011; Egeland et al. 2011)—a pattern by which country foods are increasingly replaced by lower-cost, energy-dense, nutrient-poor market foods (e.g., sugar-sweetened beverages, chips, and pasta) due to a confluence of economic (e.g., high cost of nutritious market foods), lifestyle (e.g., settlement into permanent communities), cultural, environmental (e.g., climate change) (Chan et al. 2006; Wesche and Chan 2010), and policy factors (e.g., affordable access to harvest equipment and supplies such as snowmobile parts, bullets, and fuel). The high cost of nutritious market foods in remote community stores can be a barrier to food security and healthful diets for many households (Lambden et al. 2006; Chan et al. 2006). For instance, the average price of ground beef (CAD $17.04/kg) in the Qikiqtaaluk Region (NU) (Nunavut Bureau of Statistics 2016) was 38% higher than the national average (CAD $12.36/kg) in 2016 (Statistics Canada 2016). Moreover, a 100-g serving of ground beef (cooked) provides less than half the iron, one-third of the vitamin B12, and much less riboflavin, copper, and thiamin than a 100-g serving of caribou meat (Health Canada 2015). Accordingly, the human health risks of wildlife declines and reductions in availability/access may transcend the decline of micronutrient intakes from country food consumption and include excessive intakes of sugar, sodium, and dietary energy, related to the consumption of lower-cost energy-dense, nutrient-poor, market foods. Furthermore, where individual and households lack the financial means to purchase foods from the store, wildlife declines may also further exacerbate food insecurity.

EcoHealth Approaches to Food and Nutrition Security

While communities have expressed that food security issues need to be considered in the development of wildlife management policies (Fillion et al. 2014), ideological dichotomies, institutional structures, and the lack of common data platforms for human food and nutrition security, public health, and wildlife population information may hinder these efforts (Kenny and Chan 2017). In Nunavut, for example, it is unknown whether the implementation of a community-based harvesting program (with potential to provide considerable food security and cultural wellness benefits to communities) could represent an unreasonable long-term risk to caribou populations, as wildlife populations are not being monitored with sufficient regularity to detect trends in a timely manner (Giroux et al. 2012). Finally, sector-based, species-by-species management and dichotomized conceptions of conservation and Indigenous food security may ultimately undermine food security (Loring and Gerlach 2010).

Integrative approaches and methodologies are therefore needed to harmonize wildlife population and management status, subsistence harvest, and food and nutrition security information (for further discussion, see limitations section below). Stephen and Duncan (2017) highlight that despite the potential for wildlife health information to assist communities and public health managers in anticipating or managing vulnerability to wildlife threats, there is inadequate integration of wildlife health information in community adaptation planning. Such efforts would require information on local wildlife populations (e.g., species spatial distribution, abundance, health and other parameters related to the availability, quality, and safety of country food), and relative changes in the contribution of wildlife to food security, and other social determinants of health (Stephen and Duncan 2017). Systematic ways to collect, integrate, and communicate wildlife health information for public health purposes are needed to identify effective local solutions (Stephen and Duncan 2017). Such efforts must be predicated upon local understandings of the human–wildlife context and be undertaken through participatory, community-based research processes (Berkes and Jolly 2002; Tomaselli et al. 2018). Although wildlife management systems have not always included Inuit perspectives and systems of knowledge related to wildlife and harvesting (Kendrick and Manseau 2008; Dowsley and Wenzel 2009), there are many recent examples of successful achievements through co-management arrangements and community-based monitoring programs (Brook et al. 2009; Natcher et al. 2012a). Nevertheless, there remain significant ideological, epistemological, and cultural challenges in efforts to integrate distinct worldviews and political systems (Kendrick and Manseau 2008; Dowsley and Wenzel 2009).

Limitations

Several important study limitations warrant discussion. First, dietary data in this study were derived from a 24-h recall and reflect species availability and accessibility only during the study period. Dietary data may have been asynchronous with the timing of caribou harvest, and/or

caribou availability may have been restricted due to declining population status. For instance, caribou contributed < 5% of total energy intake for Inuit in Nunatsiavut (Fig. 2); however, at the time, despite being at peak numbers, the relevant caribou herds were not in proximity to the communities and were likely not frequently consumed. It is important to note that data derived from dietary assessments are designed to capture foods *actually consumed* rather than *desired* diets. Accordingly, lower caribou consumption rates must not be understood as a reflection of lower reliance on caribou or of dietary/cultural preferences, but rather as a reflection of various contextual factors that could have constrained caribou availability and access at the time of the study. Furthermore, a decade has elapsed since dietary information was collected as part of the 2007–2008 IHS. As caribou populations have continued to decline and new harvest restrictions have been implemented, the discrepancy between reported consumption and desired consumption may be more pronounced than at the time of the IHS.

Second, while we have mapped caribou herd/population ranges and community locations and confirmed herd utilization through document analysis and/or direct consultation with northern wildlife experts from Inuit and northern wildlife management/co-management organizations, results from this study have not been verified at the community level. Participatory and culturally appropriate approaches to map Indigenous knowledge can contribute to this gap, but require special attention to the political, power, and Indigenous data sovereignty implications (Chapin et al. 2005; Kendrick and Manseau 2008; Bryan 2011).

Results regarding the abundance and population status of caribou herds were based on published reports which favored the representation of scientific knowledge generated by government organizations and academics. Inuit possess extensive multi-generational knowledge regarding the distribution, movements, and abundance of caribou, which can be more complete than the written record (Ferguson et al. 1998). However, there are challenges to representing and meaningfully considering both scientific and traditional knowledge (see for example Dowsley and Wenzel 2009), particularly with this type of pan-Inuit Nunangat study. There may be significant disagreement between the conclusions drawn from scientific assessments and traditional knowledge, and between the conclusions drawn by respective institutions/organizations and governments involved in co-management. Accordingly, results from this study should be interpreted with caution, as they do not embody the full scope and depth of knowledge about caribou. While our intent was not to privilege the representation of scientific knowledge, this type of information was prevalent in the documented literature which we relied upon to enable the consolidation of information over a vast geographic scope.

Conclusion

From a food systems perspective, ecosystem conservation and food security are highly connected objectives. Barriers to caribou harvest may represent a concern for human health through the decline of critical micronutrients in the diet. Further research is needed to ascertain the degree to which constrained/restricted caribou access further exacerbates food insecurity or prompts substitution with other country food species or market foods. Integrative approaches are needed to promote the sustainable harvest of country foods within ecological limits of species sustainability, but also to recognize and address implications for food security, public health, and cultural wellness. Future initiatives to support nutrition and food security in the Arctic will necessitate a transdisciplinary food systems approach that includes the active participation of Indigenous organizations and both the wildlife and public health/nutrition sectors. Such an approach requires co-development with active community participation in a way that is congruent with Indigenous cultural values, is based on a combination of traditional knowledge, local observations, and scientific information, and affirms Indigenous Peoples' rights to harvest and culture.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Data Availability Statement The IHS data are not publically available due to research participants' privacy/consent and data ownership agreements with the participating communities. Requests for access to raw data will be reviewed by the National Inuit Health Survey Working Group which represents the interests of the participating communities.

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