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Assessing risk of mercury exposure and nutritional benefits of consumption of caribou (*Rangifer tarandus*) in the Vuntut Gwitchin First Nation community of Old Crow, Yukon, Canada ☆

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ABSTRACT

The contamination of traditional foods with chemical pollutants is a challenge to the food security of Aboriginal Peoples. Mercury levels are generally low in terrestrial animals; however renal mercury levels have been shown to change over time in the Porcupine Caribou Herd, the principal food source for the Vuntut Gwitchin First Nation of Old Crow in Yukon, Canada. Seventy-five Porcupine Caribou muscle, sixty-three kidney and three liver samples were analyzed for total mercury. Average concentrations were 0.003, 0.360 and 0.120 mg/kg wet weight total mercury for muscle, kidney and liver, respectively. Consumption data of caribou muscle, kidney and liver were collected from twenty-six adults in Vuntut Gwitchin households. Women of child-bearing age ($n=5$) consumed a median of 71.5 g/person/day of caribou muscle and 0.0 g/person/day kidney but consumed no liver; median consumptions for all other adults (women aged 40+ and all men, $n=21$) were 75.8, 3.2 and 2.5 g/person/day for meat, kidney and liver, respectively. Median dietary exposures to total mercury from caribou tissues were estimated to be 0.138 μg/kg body weight for women of child-bearing age and 0.223 μg/kg body weight for other adults. Caribou tissues were found to contribute high levels of important nutrients to the diet and pose minimal health risk from mercury exposure.

1. Introduction

Foods from the land represent the fundamental connection between Aboriginal Peoples and their surrounding environment (Wheatley, 1994; Richmond and Ross, 2009) and are an important part of maintaining social cohesion (Egede, 1995; Poppel et al., 2007). Caribou (*Rangifer tarandus*) is an important part of the traditional diet for Indigenous Peoples of the circumpolar north, and Aboriginal Peoples in the Canadian Arctic have relied on caribou as a source of nutritional and cultural sustenance for centuries. Caribou meat is among the most frequently consumed traditional foods in the Yukon (Wein and Freeman, 1995; Batal et al., 2005; Nakano et al., 2005).

Although the health benefits of consuming traditional foods such as caribou are well recognized, ongoing socio-economic and environmental pressures including chemical pollution challenge the security of these northern food sources (Chan et al., 2006; Loring and Gerlach, 2008). Mercury, present in the environment from both natural and anthropogenic sources, is one contaminant of concern. Mercury has a residence time of 1–2 years in the atmosphere, which allows it to be transported long distances via oceanic and atmospheric processes into northern environments (Brooks et al., 2005; Pacyna, 2005). Mercury cycles throughout the environment, and its organic form methylmercury is a well-documented neurotoxin that bioaccumulates and biomagnifies within the food chain (Hansen and Gilman, 2005) and is being investigated for adverse cardiovascular effects (Mozaffarian, 2009). The World Health Organization has developed provisional tolerable weekly intake guidelines based on observable effects of mercury on the central nervous system for adults and women of child-bearing age for the protection of public health (Joint FAO/WHO Expert Committee on Food Additives, 2010).

The main source of human exposure to methylmercury is large predatory fish and marine mammals, as these organisms feed at high levels on the long aquatic food chain in which methylmercury is readily bioavailable (Derome et al., 2005;

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Hansen and Gilman, 2005). Much research with Inuit communities has been conducted to assess the risks posed by contaminants in marine food sources (Muir et al., 2005; Deutch et al., 2007). Risk of mercury exposure in non-coastal northern communities is comparably less than in marine environments since diets in these areas include more herbivorous terrestrial animals (Chan and Receveur, 2000; Hansen and Gilman, 2005). However, the terrestrial food chain has been suggested to be an important pathway of mercury accumulation, and mercury levels have reportedly increased in the Arctic tundra (Poissant et al., 2008). The significance of potential impacts on public health and food safety has not been fully characterized. Clear temporal and geographic patterns for mercury levels in terrestrial mammals have not been established (Braune et al., 2005; Gamberg et al., 2005; Gamberg, 2007). It has recently been shown that renal mercury levels changed over time in the Porcupine Caribou Herd (Gamberg, 2008), which is the single most frequently consumed traditional food in the Vuntut Gwitchin First Nation community of Old Crow (Wein and Freeman, 1995; Vuntut Gwitchin First Nation, 2008b). Therefore it is important to assess the safety of consumption of the Porcupine Caribou, a significant cultural and dietary resource of the Vuntut Gwitchin.

The objective of this study is to estimate mercury exposure and nutrient intake of adults in Vuntut Gwitchin households in Old Crow through consumption of Porcupine Caribou muscle meat, kidney and liver. The goal is to demonstrate the importance of assessing both nutritional risks and benefits in the development of risk management policies for public health and environmental health professionals.

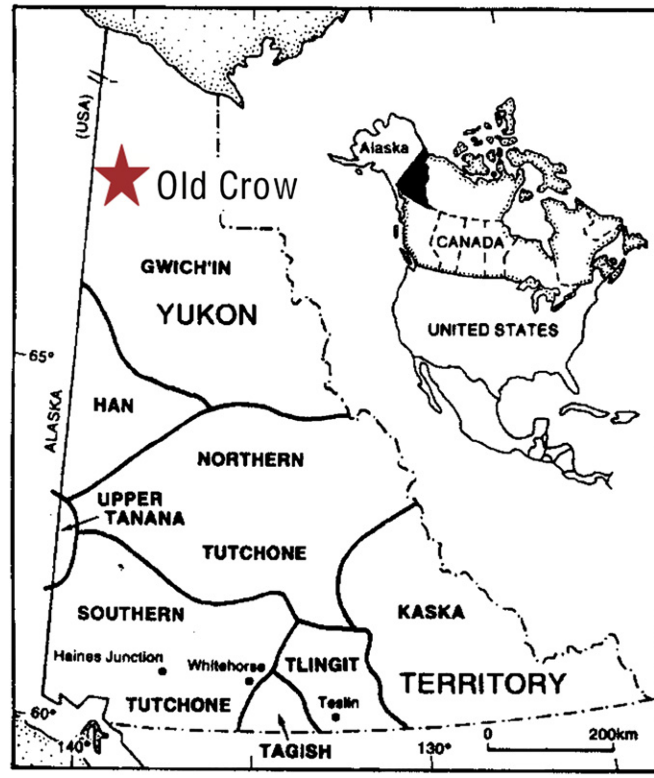

Fig. 1. First Nations traditional territory map of the Yukon (Wein and Freeman, 1995, p. 162) Reprinted with permission from the Arctic Institute of North America.

2. Materials and methods

2.1. Community

The Vuntut Gwitchin First Nation community of Old Crow is the northernmost in the Yukon, located 95 km north of the Arctic Circle (Fig. 1). Historically nomadic people, the Vuntut Gwitchin settled in a location on the Porcupine River that is central to the semi-annual migration of the Porcupine Caribou Herd (Vuntut Gwitchin First Nation, 2008a). Old Crow is accessible only by river during the summer months or by aircraft, and its remote location has allowed community members to continue many aspects of traditional life (Vuntut Gwitchin First Nation, 2008b). The population in Old Crow numbers 253 individuals (Yukon Bureau of Statistics, 2006), and there are 835 members of the First Nation (Rispin, VGFN Enrollment Officer, personal communication, May 28, 2009).

2.2. Ethics

Research followed the Canadian Institutes for Health Research Guidelines for Health Research Involving Aboriginal Peoples, and ethical approval for the study was obtained through the University of Northern British Columbia's Review Ethics Board. Group consent was acquired through a research agreement signed between the researchers and the Vuntut Gwitchin First Nation. In the research agreement, the Vuntut Gwitchin First Nation approved the publications of the findings of this study in scientific journals. Individual informed consent forms were used to describe in detail participant rights and researcher responsibilities. After reading through the consent form, the participants were asked if they understand each of eight separate points central to granting informed consent. Community members assisted with interpretation of the results at community forums in January 2009 and final results of this study were reported back to the community on October 8, 2009.

2.3. Food frequency questionnaires

Thirty-three Vuntut Gwitchin households in Old Crow were randomly selected from a community list provided by the Vuntut Gwitchin Government containing a total of ninety-two households. One eligible male and one eligible female were invited to participate from each household, with eligibility criteria being age of nineteen years and older, membership in a Vuntut Gwitchin household and written consent. Three trained community research assistants conducted twenty-nine interviews (fifteen males and fourteen females) from twenty-seven Vuntut Gwitchin households in the spring of 2008, representing 29% of all households in Old Crow. Not all households had adults of both genders present, five households did not respond to the request to be interviewed and one household declined participation. Therefore, the participation rate was 82%. Information collected from three males initially interviewed was excluded from the analysis, as their reported daily consumption of all traditional foods exceeded three times the standard deviation for the entire population and they are deemed to be outliers. This criterion was employed as the best method to protect against the biases presented by self-reporting and use of the food models. Reporting bias in traditional food studies tends towards an overestimation of frequency (Lawn and Harvey, 2006).

The interviews were comprised of a food frequency questionnaire and additional sections on food security, and methodology is detailed in Schuster et al. (2011). The food frequency questionnaire was developed based on an earlier study conducted in 1991–1992 in Old Crow by Wein and Freeman (1995) and contains a total of 78 commonly consumed traditional foods. Participants were asked how often during spring 2007–winter 2008 they consumed each of the food items on the list. To facilitate recall, participants were asked about consumption starting in the most recent season working backwards. Seasons were divided into equal lengths of 90 days, and so a frequency response of "every day" for each season was 360 times per year. In addition to reporting frequency of food use, the food frequency questionnaire asked participants for their average portion size for each traditional food in order to calculate the quantity consumed. Color photographs were available to assist in participant recall, and food models were used as a guide for reporting standardized portion sizes. This study utilized the information on the quantity (g/person/day) in which caribou muscle meat, liver and kidney were consumed during spring 2007–winter 2008.

2.4. Mercury analysis of caribou tissues

Caribou tissues were collected under a community-based long-term monitoring program. Seventy-five muscle, sixty-three kidney and three liver samples from the Porcupine Caribou Herd were collected with the assistance of local hunters and biologists between 1994 and 2006, with all but one collected during the fall hunting season (August 27–January 30) at the traditional harvesting areas. The average age of the caribou was 5.0 years. Samples were frozen as soon as possible after the death of the animal (specific times unknown since many samples were submitted from individual hunters) and were stored at −20 °C. Kidney and liver (wet samples) were analyzed within one year of collection for total mercury using cold vapor atomic absorption spectroscopy at NLET (Environment Canada) or by the inductively coupled plasma technique with mass spectroscopy by Elemental

Research Inc., Vancouver, BC. Kidneys were thoroughly homogenized before being analyzed whereas livers were simply sub-sampled. Samples were digested using an open vessel in a combination of nitric acid and hydrogen peroxide. Blanks, duplicates and standard reference materials were digested and analyzed concurrently. The detection limit was 0.005 μg/g and recovery of standard reference materials (DORM-2 and DOLT-2, National Research Council Canada, Ottawa, ON) averaged 101%.

Muscle samples were stored between 2 and 14 years at −80 °C (long-term storage). The raw muscle samples were then freeze-dried, stored at −20 °C and analyzed at the University of Northern British Columbia using combustion-gold amalgamation atomic absorption spectrometry. The detection limit was 0.002 mg/kg dry weight or 0.0004 mg/kg wet weight. A standard curve was produced using commercial mercury standards before each run. Blanks were run with each batch of samples. The standard reference materials Dolt-4 dogfish liver (National Research Council Canada, Ottawa, ON) and SRM 8414 bovine muscle (collaboration of U.S. National Institute of Standards and Technology, Gaithersburg MD and Agriculture Canada, Ottawa ON) were also run with each batch of samples. Recovery was within ±12% of the mean value for Dolt-4 and ±30% of the mean for bovine muscle and both were within the SD of the certified value. Samples were run in triplicate except when tissue quantity was limited to allow for only duplicate (21 cases) and singular sample (12 cases) analyses.

To estimate methylmercury intake, all total mercury found in the raw caribou meat was assumed to be methylmercury, following the conservative values of percent methylmercury found in flesh of other large mammals (Wagemann et al., 1997; Moses et al., 2009). Methylmercury, however, has been found to comprise a range of 19.9–20.4% and 2.7–26.4% of total mercury in mammalian kidney and liver, respectively (Wagemann et al., 1998; Moses et al., 2009). Thus conservative estimates of 20% of total mercury in kidney and 26% of total mercury in liver were calculated to be methylmercury.

Exposure from the consumption of each caribou tissue was estimated by multiplying the g/person/day consumption reported in the food frequency questionnaire by the measured total mercury or estimated methylmercury level for that tissue (μg/g). Body weight information was not collected in this study as the community deemed the collection of this information to be invasive. Average body weight of 70 kg for men and 60 kg for women were assumed and used to calculate the intake as μg/kg body weight/day. Each participant's total estimated total mercury or methylmercury exposure from consumption of caribou meat, liver and kidney was then calculated by the sum of exposures from each tissue. The total estimated total mercury and methylmercury intakes were compared to provisional tolerable weekly intake guidelines of 4 μg/kg bw/week inorganic mercury (Joint FAO/WHO Expert Committee on Food Additives, 2010) and 3.2 μg/kg bw/week methylmercury for adults other than women of child-bearing age and 1.6 μg/kg bw/week methylmercury provisional tolerable weekly intake for women of child-bearing age as recognized by the World Health Organization (Joint FAO/WHO Expert Committee on Food Additives, 2006). Women aged 19–40 years were considered the women of child-bearing age and their estimated intake levels were evaluated with the appropriate guidelines. Hazard quotients were calculated by dividing the weekly estimated total mercury or methylmercury intake by the World Health Organization guideline levels.

2.5. Nutritional analysis of caribou tissues

Nutritional benefits from consumption of caribou muscle meat and liver were determined using the Canadian Nutrient File (Health Canada, 2008) for cooked meat and baked liver and supplemented with data vitamin A and vitamin E levels for boiled meat, baked liver and cooked kidney (Kuhnlein et al., 2006) and with niacin equivalent values for cooked kidney (Hidiroglou et al., 2008). Intake of energy, total fat, protein, iron, phosphorous, zinc, selenium, niacin equivalent and vitamins A, B_{12} and E were calculated for each tissue by combining the available database levels with the g/person/day consumption reported by the food frequency questionnaire. The total percent contribution of the combined tissues towards the estimated energy requirement based on a physical activity level of low active estimated average requirement for all other nutrients was calculated using Health Canada's Dietary Reference Intakes, with the more stringent requirement in place for collapsed age groups (Health Canada, 2006).

3. Results

3.1. Consumption of caribou meat, liver and kidney

Dietary information from twenty-six individuals (twelve males and fourteen females) representing twenty-five Vuntut Gwitchin households (27% of households in Old Crow) was collected and analyzed. Five of the women were 19–40 years old and considered the women of child-bearing age, with the other eleven aged 41+. All participants reported consuming caribou muscle meat; eleven men, six women aged 41+ and two women aged 19–40 consumed kidney, and eleven men, four women aged 41+ and no women aged 19–40 consumed liver. Women of child-bearing age reported similar median g/person/day intake of caribou muscle meat and kidney compared with all other adults but consumed significantly less caribou liver than all other adults (Table 1).

Table 1
Reported consumption (g/person/day) of Porcupine Caribou muscle, kidney and liver.

	n	Meat		Kidney		Liver	
		Median	90th%	Median	90th%	Median	90th%
Women aged 19–40	5	71.5	396	0.0	11.8	0.0	0.0
All others	21	75.8	161	3.2	23.3	2.5[a]	29.0

[a] All others consumed significantly more liver than did women of 19–40 years (Mann–Whitney $U=12.5$, $p=0.007$).

Table 2
Measured total mercury and estimated methylmercury concentrations in Porcupine Caribou muscle, kidney and liver.

Tissue	n	Total mercury Mean+SD (mg/kg wet weight)	Total mercury Range (mg/kg wet weight)	Methylmercury Mean (mg/kg wet weight)
Muscle	71	0.003 ± 0.002	0.001, 0.006	0.003
Kidney	63	0.360 ± 0.120	0.110, 0.640	0.073
Liver	3	0.120 ± 0.070	0.060, 0.190	0.032

3.2. Mercury

Total mercury levels in muscle, kidney and liver were found to be low (Table 2). Estimated intakes of both total mercury and methylmercury using g/day consumption of tissues were below their respective provisional weekly tolerable intakes for women of child-bearing age ($n=5$) and all other adults ($n=21$, Table 3). The hazard quotients including those for high-end consumers (90th percentile) were all well below 1.0, indicating minimal risk.

3.3. Nutrients

The g/person/day consumption of caribou meat and kidney contributed to a median of well over half of the estimated average requirement for protein and zinc and half for iron for women of child-bearing age ($n=5$, Table 4a). The g/person/day consumption of caribou meat, kidney and liver contributed to a median of nearly two-thirds the estimated average requirement for protein and zinc and well over three-quarters for iron for women over 40 years of age ($n=9$, Table 4b). The median niacin equivalent intake was close to the estimated average requirement and the vitamin B12 intake was two and a half times the estimated average requirement for both groups of women. Women over the age of forty years had a median vitamin An intake (9.26%) over three times that of women of child-bearing age (2.75%). In men ($n=12$), caribou tissues contributed to a median of approximately half the estimated average requirement for protein and zinc, two-thirds for vitamin A, nearly 100% for iron, and two and a half times for vitamin B12 (Table 4c). Caribou meat, kidney and liver also contributed low amounts of copper, calcium, sodium, magnesium, manganese, potassium and vitamin A to the diets of men and all women.

Table 3
Estimated mercury exposure through consumption of Porcupine Caribou muscle, kidney and liver.

	Weekly total mercury				Weekly methylmercury			
	(μg/kg bw/day)		Hazard quotient		(μg/kg bw/day)		Hazard quotient	
	Mean (CI)	90th%	Median/PTWI[a,b]	90th%/PTWI	Mean (CI)	90th%	Median/PTWI[c,d]	90th%/PTWI
Women aged 19–40 ($n=5$)	0.187 (−0.064, 0.438)	0.383	NA	NA	0.070 (0.002, 0.128)	0.121	0.047	0.076
All others ($n=21$)	0.394 (0.163, 0.626)	0.587	0.056	0.147	0.107 (0.054, 0.159)	0.148	0.025	0.046

[a] There is not a total mercury or inorganic mercury provisional tolerable weekly intake (PTWI) specifically for women of child-bearing age.
[b] 4 μg/kg bw/week inorganic mercury PTWI for adults other than women of child-bearing age.
[c] 1.6 μg/kg bw/week methylmercury PTWI for women of child-bearing age.
[d] 3.2 μg/kg bw/week methylmercury PTWI for adults other than women of child-bearing age.

Table 4a
Contribution of caribou muscle and kidney to nutrient intake in women aged 19–40 ($n=5$)[a].

Nutrient	Mean (CI)			Estimated average requirement	Total % of estimated average requirement[c]
	Muscle ($n=5$)	Kidney ($n=2$)[b]	Total		
Energy (kcal)	184 (−141, 511)	–	184 (−142, 511)	2100[d]	5.6
Protein (g)	36.2 (−27.8, 100.2)	–	36.2 (−27.8, 100)	38	60.3
Iron (mg)	6.39 (−4.91, 17.7)	–	6.40 (−4.91, 17.7)	8.1	49.9
Phosphorous (mg)	253 (−195, 702)	–	254 (−195, 702)	580	27.6
Zinc (mg)	6.34 (−4.87, 17.5)	–	6.34 (−4.87, 17.5)	6.8	58.9
Selenium (μg)	11.3 (−8.69, 31.3)	–	11.3 (−8.69, 31.3)	45	15.9
Niacin equivalent (mg)	15.2 (−11.6, 42.0)	0.719 (−0.040, 1.48)	15.6 (−10.9, 42.1)	11	93.6
B12 (μg)	7.51 (−5.8, 20.8)	–	7.52 (−5.77, 20.8)	2.0	238
Vitamin A (μg)	14.1 (−10.9, 39.2)	3.77 (−3.21, 10.7)	17.9 (−4.96, 40.8)	500	2.75
Vitamin E (mg)	0.611 (−0.469, 1.69)	0.003 (−003, 0.009)	0.614 (−0.464, 1.69)	12	3.26

[a] Caribou liver was not reported to be consumed.
[b] Data not available for certain nutrients in caribou kidney.
[c] Median % contribution to reference intake.
[d] Estimated energy requirement for an activity level of low active.

Table 4b
Contribution of caribou muscle, kidney and liver to nutrient intake in women aged 41+ ($n=9$).

Nutrient	Mean (CI)				Estimated average requirement	Total % of estimated average requirement[b]
	Muscle ($n=9$)	Kidney ($n=6$)[a]	Liver ($n=4$)[a]	Total		
Energy (kcal)	126 (74.7, 177)	–	13.5 (−3.07, 30.1)	139 (75.1, 204)	2000/1850[c,d]	6.67
Protein (g)	24.7 (14.7, 34.7)	–	2.22 (−0.504, 4.95)	26.9 (14.7, 39.1)	38	63.8
Iron (mg)	4.36 (2.59, 6.13)	–	1.85 (−0.420, 4.12)	6.21 (2.44, 9.98)	8.1/5.0[d]	85.6
Phosphorous (mg)	173 (103, 243)	–	34.3 (−7.77, 76.3)	207 (102, 312)	580	29.3
Zinc (mg)	4.32 (2.56, 6.08)	–	0.555 (−0.126, 1.24)	4.88 (2.58, 7.18)	6.8	62.4
Selenium (μg)	7.71 (4.58, 10.9)	–	–	7.72 (4.58, 10.9)	45	16.8
Niacin equivalent (mg)	10.34 (6.13, 14.5)	0.742 (0.229, 1.26)	–	11.4 (6.38, 16.4)	11	92.4
B12 (μg)	5.12 (6.13, 14.5)	–	–	5.12 (3.04, 7.21)	2.0	252
Vitamin A (μg)	9.65 (5.73, 13.6)	9.27 (−1.33, 19.9)	932 (−212, 2075)	951 (−206, 2110)	500	9.26
Vitamin E (μg)	0.004 (0.002, 0.006)	0.008 (−0.001, 0.016)	183 (−41.5, 407)	2.25 (−0.126, 4.63)	12	3.65

[a] Data not available for certain nutrients in caribou kidney and liver.
[b] Median % contribution to reference intake.
[c] Reference intakes different for each age groups (41–60/61+).
[d] Estimated energy requirement for an activity level of low active.

4. Discussion

It is challenging to conduct a representative sampling in a small community such as Old Crow. However, if the estimated average daily total mercury and methylmercury exposure of the sample of adults in Vuntut Gwitchin households in this study (27%) is representative of the population, then exposure through consumption of caribou muscle meat, liver and kidney is low and minimal risk of toxic effects exists from consumption of caribou in this community. Caribou is clearly a major component of the traditional diet of the participants and nearly all parts of a harvested caribou are used by the Vuntut Gwitchin. Our study focused only on the muscle meat, liver and kidney but it can be assumed that the majority of methylmercury exposure via caribou consumption has been accounted for as the organs are targets for methylmercury accumulation and the muscle meat is consumed in the largest quantities. Cooking methods, which have been shown to affect total mercury and methylmercury in tissues (Moses et al., 2009), were not taken into account in this analysis; however since the estimated exposures were well below the guideline levels, the variations caused by different preparation methods would likely not affect the results of the assessment.

There are limitations to the representativeness of the study. The small initial sample size ($N=29$) for the food frequency

Table 4c
Contribution of caribou muscle, kidney and liver to nutrient intake in men ($n=12$).

Nutrient	Mean (CI)				Estimated average requirement	Total % of estimated average requirement[b]
	Meat ($n=12$)	Kidney ($n=11$)[a]	Liver ($n=11$)[a]	Total		
Energy (kcal)	137 (69.1, 202)	–	7.43 (3.30, 11.6)	143 (77.1, 209)	2700/2600/2350[c,d]	5.1
Protein (g)	26.6 (13.6, 29.7)	–	1.22 (0.542, 1.90)	27.9 (14.9, 40.8)	46	56.0
Iron (mg)	4.70 (2.40, 7.01)	–	1.02 (0.452, 1.58)	5.72 (3.43, 8.01)	6	92.0
Phosphorous (mg)	186 (95.0, 278)	–	18.8 (8.36, 29.3)	205 (115, 296)	580	33.0
Zinc (mg)	4.66 (2.38, 6.95)	–	0.305 (0.136, 0.475)	4.97 (2.70, 7.23)	9.4	49.0
Selenium (μg)	8.32 (4.24, 12.4)	–	–	8.32 (4.24, 12.4)	45	16.8
Niacin equivalent (mg)	11.2 (5.68, 16.6)	0.740 (0.352, 1.13)	–	11.9 (6.60, 17.2)	12	91.0
B12 (μg)	5.52 (2.82, 8.24)	–	–	5.53 (2.82, 8.24)	2.0	252
Vitamin A (μg)	10.4 (5.3, 15.5)	6.66 (3.17, 10.2)	512 (227, 797)	529 (243, 815)	625	66.0
Vitamin E (μg)	449 (229, 670)	5.64 (2.69, 8.60)	101 (44.6, 156)	1.46 (0.891, 2.03)	12	9.9

[a] Data not available for certain nutrients in caribou kidney and liver.
[b] Median % contribution to reference intake.
[c] Reference intakes different for each age group (19–40/41–60/61+).
[d] Estimated energy requirement for an activity level of low active.

questionnaire is reflective of the nature of conducting research in a small community. However, our sample already represents 29% of all households in Old Crow. The small number of participants ($n=26$) affects the calculation of sample distribution, e.g. the 90th percentile and introduces inaccuracy in the estimated exposure of the high-end consumers. Moreover, the exclusion criterion of exceeding three times the standard deviation for total g/person/day traditional food consumption, while it is important to make sure the collected data are reliable, may artificially eliminate the high-end consumers of traditional food. Therefore, we calculated the hazard quotient for the three outliers separately and they are still less than 1.0 (data not shown), suggesting that the risk of methylmercury exposure is low even at unrealistic consumption levels.

The other limitation is that the food use data were collected only over a one-year period. When a discussion of the results of this study with the community, a key message reported by community members was that the caribou harvest was affected by the irregular fall 2007 migration of the Porcupine Caribou Herd, which led Vuntut Gwitchin households to turn towards other protein sources such as fish to supplement their diet (Schuster et al., 2011). Thus, the food frequency questionnaire data may be an underestimation of average caribou consumption.

Levels of total mercury in caribou organs generally increase with animal age and vary with season, as seasonality dictates both the size of the organs and the proportion of mercury-accumulating lichens in the caribou diet (Robillard et al., 2002). Total mercury levels in Porcupine Caribou kidney have been shown to be higher in spring harvested animals compared with those harvested in the fall, and total mercury levels have been shown to be higher in female Porcupine Caribou than in males, which is hypothesized to result from the females eating more mercury-containing lichen in relation to body size in order to meet their high energetic costs associated with calving (Gamberg, 2008). Samples analyzed for this study were collected only from male caribou and all but one were harvested during the fall hunting season. Although the harvesting of both males and females was legal at the time of collection, the Porcupine Caribou Management Board has been encouraging the hunting of male caribou as a strategy to maintain a healthy herd population (Porcupine Caribou Management Board, 2009), and in 2009 the licensed harvest was restricted to males. Therefore the sampled male caribou can be considered representative of fall harvested animals. In addition, since a conservative approach was employed to estimate the proportion of methylmercury in the tissue samples, actual methylmercury levels may be lower than reported here.

Regardless of all the uncertainties discussed above, the risk of mercury exposure from caribou consumption would still be low as the hazard quotients were lower than 1.0. It is highly unlikely that the variations due to the uncertainties would exceed this high safety margin.

Even though caribou tissues (muscle meat, liver and kidney combined) only contributed a median of 5.1–6.7% of the estimated energy requirement, they contributed half or more of the median estimated average requirement for protein, iron, zinc, B12 and niacin equivalent for all groups. Total B12 intake exceeded the estimated average requirement by two and half times; however there is not an upper limit for vitamin B12 as available research does not suggest adverse effects from high levels of consumption. All groups were close to the estimated average requirement for niacin but are not at risk of exceeding the upper limit, which is set for synthetic forms such as supplements and fortified foods. Men had a median percent reference intake of vitamin A twenty-four times higher than that of women of child-bearing age and seven times higher than women aged 40+, due to the statistically significantly greater consumption of liver by men compared to women (Schuster et al., 2011) and the significantly greater consumption of liver by men and women 40+ compared with the women of child-bearing age reported here. It is worth noting that post-menopausal women and men over 65 who are at risk of osteoporosis should be limiting their intake of vitamin A. However, since only a small number of women consumed liver and two of those women consumed a relatively large amount, there is a positive skew for mean nutrient intakes for those nutrients present at high levels in the liver.

Nutrient intake in Aboriginal communities has been found to be higher on days when traditional foods are part of the diet than on days when market foods are consumed exclusively (Kuhnlein et al., 1996; Receveur et al., 1997). A survey of four Yukon First Nations communities that included Old Crow found that even when traditional foods comprise just 17% of the daily energy, they contribute 50% or more of daily intakes of protein, vitamin B12, riboflavin, niacin, iron and zinc (Wein, 1995). The results of this study suggest that caribou tissues are critical in meeting the nutrient requirements of individuals in the community of Old Crow. The community of Old Crow has been proactive in addressing issues of food security (Arctic Health Research Network—Yukon, 2009), and no overall change in frequency of traditional food use was found between 1992 and 2008 (Schuster et al., 2011). As social, environmental and economic pressures continue to challenge traditional and market food security, it is important to be aware that the nutrition transition from traditional foods to market foods may decrease dietary quality and increase the risk for diabetes, obesity and cardiovascular diseases (Kuhnlein et al., 1996; Kuhnlein et al., 2004; Damman et al., 2007; Martens et al., 2007).

The study results resonate with comprehensive risk–benefit assessments conducted with other northern First Nations communities. A 1995 study found mercury levels to be low in Yukon wildlife and freshwater fish with the exception of loche and concluded that mercury contamination was not a significant issue in the Yukon First Nations communities that participated (Receveur et al., 1998). Similarly, sixteen surveyed Dene/Métis communities in the Northwest Territories including the Teetl'it Gwich'in community of Fort McPherson reported low risk from dietary mercury exposure (Berti et al., 1998). These studies encouraged continued consumption of traditional foods because the nutritional benefits were considered important to the health of the communities and contaminant risk was low, recognized as the best practice particularly when considering the social and economic impacts (Egeland and Middaugh, 1997). Yukon First Nations communities have been concerned about the presence of contaminants in their traditional foods for decades (Kassi, 1998); two of the seven Old Crow participants in this study that reported consuming less mammals compared to fifteen years ago (Schuster et al., 2011) reported decreasing their consumption due to the concern for contaminants, especially in the "liver and meat." In light of these community concerns, the low estimated exposure and the important cultural and nutritional roles of the Porcupine Caribou Herd, this paper does not make recommendations for limiting the consumption of caribou muscle, liver or kidney.

Caribou consumption contributes high levels of nutrients to the diet of Vuntut Gwitchin households in Old Crow. The average daily risk posed by mercury exposure is low when evaluated on a g/person/day consumption basis of caribou muscle meat, kidney and liver. Results were reported back to the community to inform dietary choice as well as to the local health authorities for the development of regional and culturally appropriate nutritional policy and risk management, following international guidelines for mercury risk communication (United Nations Environmental Programme and World Health Organization, 2008).

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References

Arctic Health Research Network—Yukon, 2009. Climate Change, Food Security and Health Research. Available at: ⟨http://www.arctichealth-yt.ca/ourProjects/climateChangeFoodSecurityHealthResearch⟩ (accessed February 21, 2011).

Batal, M., Gray-Donald, K., Kuhnlein, H.V., Receveur, O., 2005. Estimation of traditional food intake in indigenous communities in Denendeh and the Yukon. Int. J. Circumpolar Health 64 (1), 46–54.

Berti, P.R., Receveur, O., Chan, H.M., Kuhnlein, H.V., 1998. Dietary exposure to chemical contaminants from traditional food among adult Dene/Métis in the Western Northwest Territories, Canada. Environ. Res. 76 (2), 131–142.

Braune, B., Outridege, P., Wilson, S., Bignert, A., Riget, F., 2005. Chapter 5: Temporal Trends AMAP Assessment 2002: Heavy metals in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Brooks, S., Lindberg, S., Gordeev, V., Christensen, J., Gusev, A., Macdonald, R., Marcy, S., Puckett, K., Travnkov, O., Wilson, S., 2005. Chapter 3: Transport pathways and processes leading to environmental exposure. AMAP Assessment 2002: Heavy Metals in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Chan, H.M., Fediuk, K., Hamilton, S., Rostas, L., Caughey, A., Kuhnlein, H., Egeland, G., Loring, E., 2006. Food security in Nunavut, Canada: barriers and recommendations. Int. J. Circumpolar Health 65 (5), 416–430.

Chan, H.M., Receveur, O., 2000. Mercury in the traditional diet of Indigenous peoples in Canada. Environ. Pollut. 110 (1), 1–2.

Damman, S., Eide, W.B., Kuhnlein, H.V., 2007. Indigenous people's nutrition transition in a right to food perspective. Food Policy 33 (2), 135–155.

Derome, J., Fairbrother, A., Marcy, S., Wirtz, J., Harding, K., 2005. Chapter 6: Biological effects. AMAP 2002: Heavy Metals in the Arctic. Arctic Environmental Assessment Programme, Oslo, Norway.

Deutch, B., Dyerberg, J., Pedersen, H.S., Aschlund, E., Hansen, J.C., 2007. Traditional and modern Greenlandic food—dietary composition, nutrients and contaminants. Sci. Total Environ. 384 (1–3), 106–119.

Egede, I., 1995. Inuit food and Inuit health: contaminants in perspective. In: Proceedings of the Inuit Circumpolar Conference. Seventh General Assembly, Nome, Alaska.

Egeland, G.M., Middaugh, J.P., 1997. Balancing fish consumption benefits with mercury exposure. Science 278 (5345), 1904–1905.

Gamberg, M., 2007. Arctic Caribou and moose contaminant monitoring program. Synopsis of Research Conducted 2006–2007 Northern Contaminants Program, pp. 127–130.

Gamberg, M., 2008. Contaminants in arctic moose and caribou—2006. Technical Report. Northern Contaminants Program, Whitehorse, p. 21.

Gamberg, M., Braune, B., Davey, E., Elkin, B., Hoekstra, P.F., Kennedy, D., Macdonald, C., Muir, D., Nirwal, A., Wayland, M., Zeeb, B., 2005. Spatial and temporal trends of contaminants in terrestrial biota from the Canadian Arctic. Sci. Total Environ. 351–352 (Dec 1), 148–164.

Hansen, J.C., Gilman, A.P., 2005. Exposure of Arctic populations to methylmercury from consumption of marine food: an updated risk–benefit assessment. Int. J. Circumpolar Health 64 (2), 121–135.

Health Canada, 2006. Dietary reference intake tables. Available at: ⟨http://www.hc-sc.gc.ca/fn-an/nutrition/reference/table/index-eng.php⟩ (accessed March 1, 2009).

Health Canada, 2008. The Canada Nutrient File. Available at: ⟨http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/cnf_aboutus-aproposdenous_fcen-eng.php⟩ (accessed March 1, 2009).

Hidiroglou, N., Peace, R.W., Jee, P., Leggee, D., Kuhnlein, H., 2008. Levels of folate, pyridoxine, niacin and riboflavin in traditional foods of Canadian Arctic Indigenous. J. Food Comp. Anal. 21 (6), 474–480.

Joint FAO/WHO Expert Committee on Food Additives, 2006. Sixty-seventh Meeting: Summary and Conclusions. Rome, p. 11.

Joint FAO/WHO Expert Committee on Food Additives, 2010. Seventy-second Meeting: Summary and conclusions. Rome, p. 16.

Kassi, N., 1998. Contaminants in the Yukon. North. Perspect. 25 (2).

Kuhnlein, H.V., Barthet, V., Farren, A., Falahi, E., Leggee, D., Receveur, O., Berti, P., 2006. Vitamins A, D, and E in Canadian Arctic traditional food and adult diets. J. Food Comp. Anal. 19 (6,7), 495–506.

Kuhnlein, H.V., Receveur, O., Soueida, R., Egeland, G.M., 2004. Arctic Indigenous peoples experience the nutrition transition with changing dietary patterns and obesity. J. Nutr. 134 (6), 1447–1453.

Kuhnlein, H.V., Soueida, R., Receveur, O., 1996. Dietary nutrient profiles of Canadian Baffin Island Inuit differ by food source, season, and age. J. Am. Diet. Assoc. 96 (2), 155–162.

Lawn, J., Harvey, D., 2006. Northern river basins food consumption survey (NRBFCS): Final Nutrition Report.

Loring, P.A., Gerlach, S.C., 2008. Food, culture, and human health in Alaska: an integrative health approach to food security. Env. Sci. Pol. 12 (4), 466–478.

Martens, P.J., Martin, B.D., O'Neil, J.D., MacKinnon, M., 2007. Diabetes and adverse outcomes in a First Nations population: associations with healthcare access, and socioeconomic and geographical factors. Can. J. Diabetes 31 (3), 223–232.

Moses, S.K., Whiting, A.V., Bratton, G.R., Taylor, R.J., O'Hara, T.M., 2009. Inorganic nutrients and contaminants in subsistence species of Alaska: linking wildlife and human heath. Int. J. Circumpolar Health 68 (1), 53–74.

Mozaffarian, D., 2009. Fish, mercury, selenium and cardiovascular risk: Current evidence and unanswered questions. Int. J. Environ. Res. Public Health 6 (6), 1894–1916.

Muir, D.C.G., Shearer, R.G., Van Oostdam, J., Donaldson, S.G., Furgal, C., 2005. Contaminants in Canadian arctic biota and implications for human health: conclusions and knowledge gaps. Sci. Total Environ. 351–352 (Dec 1), 539–546.

Nakano, T., Fediuk, K., Kassi, N., Kuhnlein, H.V., 2005. Food use of Dene/Métis and Yukon children. Int. J. Circumpolar Health 64 (2), 137–146.

Pacyna, J., 2005. Chapter 2: Sources and emissions. AMAP 2002: Heavy Metals in the Arctic Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Poissant, L., Zhang, H.H., Canário, J., Constant, P., 2008. Critical review of mercury fates and contamination in the arctic tundra ecosystem. Sci. Total Environ. 400 (1–3), 173–211.

Poppel, B., Kruse, J., Duhaime, G., Abryutina, L., 2007. SLiCA: Results. Institute of Social and Economic Research, University of Alaska Anchorage, Anchorage.

Porcupine Caribou Management Board, 2009. Harvest Management Plan for the Porcupine Caribou Herd in Canada. Whitehorse (p. 41).

Receveur, O., Boulay, M., Kuhnlein, H.V., 1997. Decreasing traditional food use affects diet quality for adult Dene/Métis in 16 communities of the Canadian Northwest Territories. J. Nutr. 127 (11), 2179–2186.

Receveur, O., Kassi, N., Chan, H.M., Berti, P.R., Kuhnlein, H.V., 1998. Yukon First Nations' Assessment of Dietary Benefit/risk. Center for Indigenous Peoples' Nutrition and Environment, Québec City (p. 159).
Richmond, C.A.M., Ross, N.A., 2009. The determinants of First Nations and Inuit Health: a critical population health approach. Health Place 15 (2), 403–411.
Robillard, S., Beauchamp, G., Paillard, G., Bélanger, D., 2002. Levels of cadmium, lead, mercury and ^{137}caesium in caribou (*Rangifer tarandus)* tissues from northern Québec. Arctic 55 (1), 1–9.
Schuster, R.C., Wein, E.E., Dickson, C., Chan, L.H.M., 2011. Importance of traditional foods for the food security of two First Nations communities in Yukon, Canada. Int. J. Circumpolar Health 70 (X) 〈http://www.ncbi.nlm.nih.gov/pubmed/21631967PMID:21631967〉.
United Nations Environmental Programme, World Health Organization, 2008. Guidance for identifying populations at risk from mercury exposure. In: Inter-organization Programme for the Sound Management of Chemicals. UNEP DTIE Chemicals Branch and WHO Department of Food Safety, Zoonoses and Foodborne Diseases, Geneva.
Vuntut Gwitchin First Nation, 2008a. Old Crow, Home of the Vuntut Gwitchin: History. Available at: 〈http://www.oldcrow.ca/history.htm〉 (accessed February 1, 2008).
Vuntut Gwitchin First Nation, 2008b. Old Crow, Home of the Vuntut Gwitchin: Caribou Coordination. Available at: 〈http://www.oldcrow.ca/caribou.htm〉 (accessed May 4, 2009).
Wagemann, R., Trebacz, E., Boila, G., Lockhart, W.L., 1998. Methylmercury and total mercury in tissues of arctic marine mammals. Sci. Total Environ. 218 (1), 19–31.
Wagemann, R., Trebacz, E., Hunt, R., Boila, G., 1997. Percent methylmercury and organic mercury in tissue of marine mammals and fish using different experimental and calculation methods. Environ. Toxicol. Chem. 16 (9), 1859–1866.
Wein, E.E., 1995. Nutrient intakes of First Nations people in four Yukon communities. Nutr. Res. 15 (8), 1105–1119.
Wein, E.E., Freeman, M.R., 1995. Frequency of traditional food use by three Yukon First Nations living in four communities. Arctic 48 (2), 161–171.
Wheatley, M.A., 1994. Aboriginal health and the environment. Arctic Med. Res. 53 (S2), 265–267.
Yukon Bureau of Statistics, 2006. Census 2006: Population and Dwelling Counts. Available at: 〈http://www.eco.gov.yk.ca/stats/census/census06/popdwell.pdf〉 (accessed February 4, 2008).