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“Is it still safe to eat traditional food?” Addressing traditional food safety concerns in aboriginal communities

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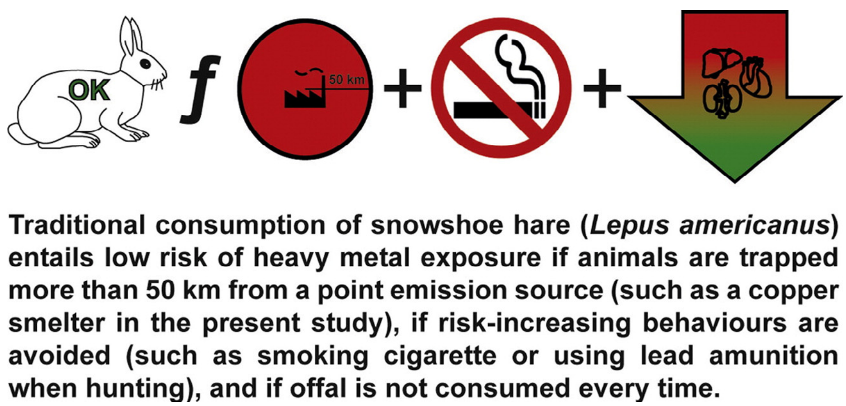
HIGHLIGHTS

- Food insecurity is a growing concern for indigenous communities.
- Few data are available on heavy metal contamination risk in the Boreal zone.
- 196 snowshoe hares were trapped at variable distances from a copper smelter.
- Overall exposition risk was low.
- Nutritional and cultural importance of traditional food must be considered.

GRAPHICAL ABSTRACT



Traditional consumption of snowshoe hare (*Lepus americanus*) entails low risk of heavy metal exposure if animals are tapped >50 km from a point emission source (such as a copper smelter in the present study), if risk-increasing behaviours are avoided (such smoking cigarette or using lead amunition when hunting), and if offal is not consumed every time.

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ABSTRACT

Food insecurity is a growing concern for indigenous communities worldwide. While the risk of heavy metal contamination associated to wild food consumption has been extensively studied in the Arctic, data are scarce for the Boreal zone. This study addressed the concerns over possible heavy metal exposure through consumption of traditional food in four Anishnaabeg communities living in the Eastern North American boreal forest. Liver and meat samples were obtained from 196 snowshoe hares (*Lepus americanus*) trapped during winter 2012 across the traditional lands of the participating communities and within 56–156 km of a copper smelter. Interviews were conducted with 78 household heads to assess traditional food habits, focusing on snowshoe hare consumption. Concentrations in most meat and liver samples were below the detection limit for As, Co, Cr, Ni and Pb. Very few meat samples had detectable Cd and Hg concentrations, but liver samples had mean dry weight concentrations of 3.79 mg/kg and 0.15 mg/kg respectively. Distance and orientation from the smelter did not explain the variability between samples, but percent deciduous and mixed forest cover had a marginal negative effect on liver Cd, Cu and Zn concentrations. The estimated exposition risk from snowshoe hare consumption was low, although heavy consumers could slightly exceed recommended Hg doses. In accordance with the holistic perspective

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commonly adopted by indigenous people, the nutritional and sociocultural importance of traditional food must be considered in risk assessment. Traditional food plays a significant role in reducing and preventing serious health issues disproportionately affecting First Nations, such as obesity, diabetes, and cardiovascular diseases.

1. Introduction

Traditional food carries a great social, cultural, and nutritional importance amongst indigenous people (e.g., Kuhnlein and Receveur, 1996; Pufall et al., 2011). Many communities harvest, prepare and consume a variety of wildlife species, although some species are preferred (Wein et al., 1991; Samson and Pretty, 2006; Hlimi et al., 2011). Consumption of traditional food significantly contributes to a higher daily intake of proteins, vitamins and minerals (Kuhnlein and Receveur, 2007; Gagné et al., 2012). Gradual replacement of traditional food by processed food over the past 30 years has been linked to the declining health in Arctic aboriginal populations (Kuhnlein et al., 2004). Processed food often contains high levels of sugar, fat and salt, and low levels of vitamins and minerals (Gittelsohn et al., 1998). Thus, the prevalence of obesity and diabetes in aboriginal communities is significantly higher than in the overall population, a difference that cannot be explained by genetics alone (Haman et al., 2010). Concurrent with these dietary changes, traditional food has sometimes been found to be contaminated by toxic metals, radionuclides, or persistent organic compounds (Berti et al., 1998; Johansen et al., 2000; Arnold et al., 2006; Liberda et al., 2014).

Pollutants resulting from industrial activities are dispersed in the environment by atmospheric or water transport (Savard et al., 2006; Makinen et al., 2010; Pennington and Watmough, 2015). Along with local geological sources of contamination, anthropogenic point emitting sources can affect specific areas more directly (Aznar et al., 2008). Contaminants can be found in soils, vegetation, lacustrine and marine environments. Bioaccumulation and bioamplification occur along food chains, resulting in excess tissue concentrations for various animal species (Beyer et al., 1996). Chronic exposition to small doses of contaminants can seriously impact animal and human health (Environmental Protection Agency, 2015). Human exposure depends on several factors like geographic location, age, and gender, as well as quantity, frequency and types of food consumed (Chan et al., 1995). However, even if contaminants are commonly found in wild food, the causality between contaminated traditional food consumption and adverse health effects is complex to determine and difficult to confirm (Donaldson et al., 2010).

In recent years, research on environmental health risks has increased exponentially (Furgal et al., 2010). Public health authorities have started to raise awareness and indigenous communities are more than ever concerned about food security and safety (Martin, 2011). Risk assessment and communication requires thoughtful consideration of social and cultural specificities, and a multidisciplinary approach is preferable (Kuhnlein and Chan, 2000; Furgal et al., 2005). Minimizing the risks of a traditional diet, while promoting and maximizing its benefits is an emerging challenge (e.g., Loring et al., 2010; Laird et al., 2013; Lemire et al., 2015).

The literature review presented above shows that most studies tackling contaminants in traditional food focused on Arctic regions (e.g., Berti et al., 1998; Van Oostdam et al., 2005; Loring et al., 2010; Schuster et al., 2011; Laird et al., 2013; Lemire et al., 2015). However, aboriginal communities with different cultures and living in different environments such as the boreal and temperate forests are also legitimately worried about traditional food safety. This is the case for the Anishnaabeg First Nations of Eastern Canada, whose traditional hunting and trapping grounds include one of the largest smelting plants in Canada.

In collaboration with four Anishnaabeg communities, we investigated the risk of heavy metal exposure associated with traditional food consumption. Our first objective was to evaluate heavy metal contamination in the meat and the liver of snowshoe hare (*Lepus americanus*), a culturally important species that also plays a major role in boreal forest ecosystems (Krebs et al., 2001). We expected the contamination level to decrease with distance from the local smelter, and to be higher at sites oriented in the direction of prevailing winds (Aznar et al., 2007). We also expected higher concentrations of cadmium (Cd) and lead (Pb) in hares sampled in deciduous tree stands, because early successional tree species are choice forage for snowshoe hare (Pease et al., 1979) and tend to accumulate Cd and Pb in foliage and branches (Mcgee et al., 2007). Our second objective was to assess food habits generally, and snowshoe hare consumption specifically within the four Anishnaabeg communities. Finally, our third objective was to evaluate heavy metal exposure and possible health risk for Anishnaabeg communities, with respect to the recommended maximum intake.

2. Material and methods

2.1. Study area

Our study took place in Abitibi-Témiscamingue and Northern Quebec, on the traditional territories of four Anishnaabeg (Algonquin) communities. It covers roughly 50,000 km^2 of hunting and trapping grounds, still frequented regularly by the people of Timiskaming, Winneway, Pikogan and Kitcisakik First Nations (Fig. 1). These communities are located near one of Canada's oldest and most notorious copper smelters, the Horne Smelter in Rouyn-Noranda, in operation since 1927. Although the filtering technology has greatly improved in recent years, resulting in reduced emissions (Savard et al., 2006), ore refining and electronic waste recycling activities still emit important amounts of various heavy metals (Table 1).

2.2. Ethics

This research project was initiated by the four Anishnaabeg communities. The research methodology was developed in close collaboration with the communities to ensure research relevance and legitimacy (Asselin and Basile, 2012). We obtained a certificate from Health Canada's Research and Ethics Board (#2010-0090). The project complies with the aboriginal research guidelines of the Canadian *Tri-Council Policy Statement*: *Ethical Conduct for Research Involving Humans* (Canadian Institutes of Health Research et al., 2014). Participants signed a consent form and were offered a monetary compensation for their contribution. Interviews were conducted with the help of aboriginal collaborators and interpreters, through a participatory research philosophy (Saint-Arnaud et al., 2009). Local collaborators were key to maintain an efficient communication with community members.

2.3. Snowshoe hare sampling

We collected snowshoe hares at different distances and orientations from the Horne smelter (Fig. 1). Typical brass snares were set by skilled aboriginal trappers at strategic and accessible sites, georeferenced for each successful capture. A total of 196 snowshoe hares were collected during winter 2012, and meat (from the thigh) and liver samples were taken. Samples were transported in a cooler and kept in the freezer before being analyzed. All remaining snowshoe hare meat was given to elders and families or reserved for community feasts. Fur was saved for traditional handicraft. For each captured snowshoe hare, distance

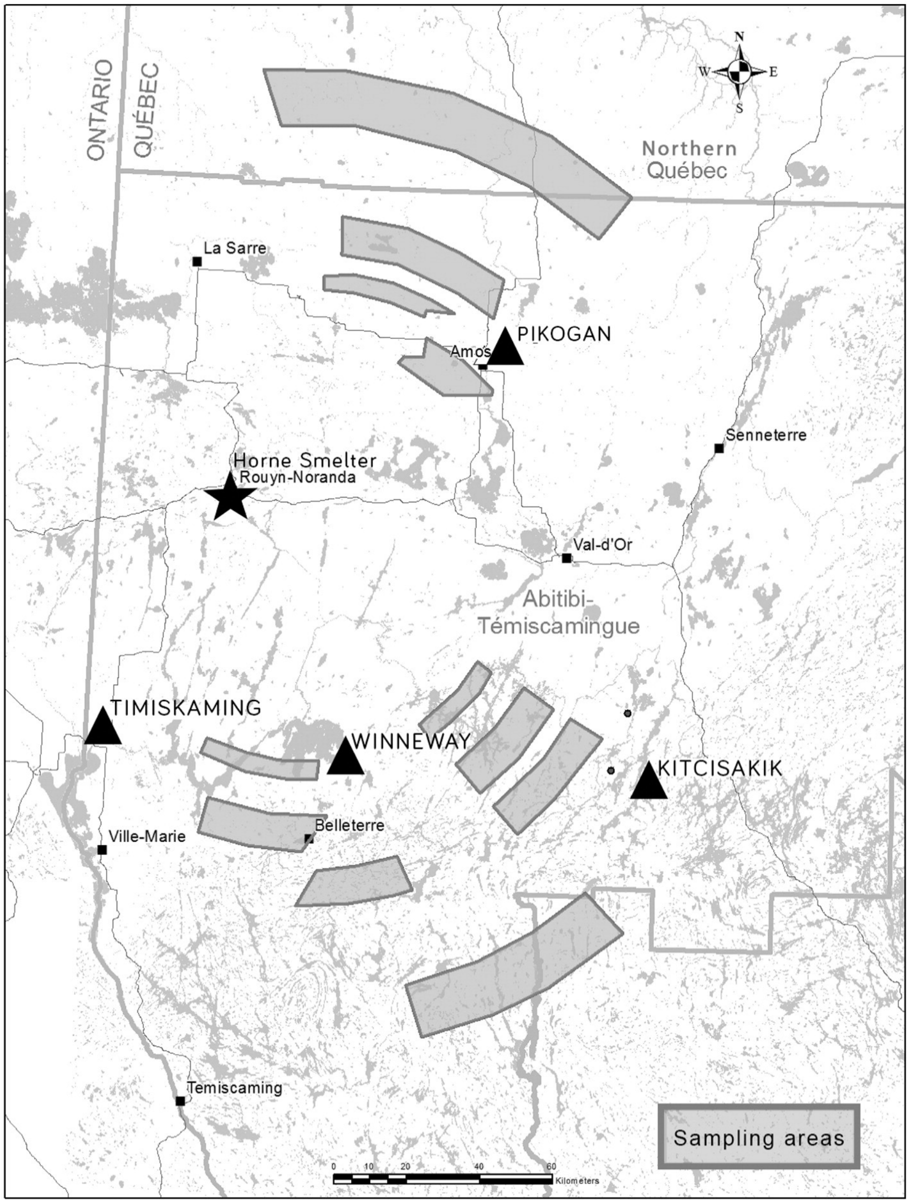

Fig. 1. Snowshoe hare sampling areas in western Québec, Canada. Triangles indicate the location of the four participating aboriginal communities and the star indicates the location of the Horne copper smelter.

and orientation from the Horne smelter were measured. Distance ranged from 56 to 156 km, while orientation ranged from 10° to 210° from the smelter. Using Environment Canada's wind database from Rouyn-Noranda, Qc (http://climate.weather.gc.ca/), we compiled for each site the number of hours under wind blowing from the Horne smelter. We considered data from January 2009 to December 2011 inclusively, covering more than the average lifespan of a snowshoe hare (Hodges, 1999). At each site, percent deciduous, mixed and coniferous forest, as well as non-forest cover were noted, within buffers equivalent to the maximum (17 ha) and minimum (1.6 ha) snowshoe hare home range (Godbout et al., 2001).

Table 1
Total heavy metal output from the Horne Smelter (Rouyn-Noranda, Quebec, Canada) in 2013. Fugitive, air and water outputs combined. Source: Environment Canada (2014).

Heavy metal	Emissions (t)
Cd	0.75
As	12.80
Zn	24.70
Pb	49.00
Hg	0.018

2.4. Heavy metal analysis

Frozen meat and liver samples (approximately 100 g and 45 g of fresh tissue, respectively) were sent for analysis to Multilab Direct facilities in Rouyn-Noranda (Québec, Canada). Fresh tissues were dried and most heavy metal concentrations (dry weight) were obtained using inductively coupled plasma mass spectrometry (ICP-MS) (Rice et al., 2012; Centre d'expertise en analyse environnementale du Québec, 2014). Mercury (Hg) was analyzed through thermal decomposition, gold amalgamation and cold vapor atomic absorption spectrometry (PerkinElmer, inc., 2013; Rice et al., 2012). The following metals were tested (with detection limits): arsenic (As; 1 mg/kg), cadmium (Cd; 0.4 mg/kg), chromium (Cr; 8 mg/kg), cobalt (Co; 2 mg/kg), copper (Cu; 5 mg/kg), iron (Fe; N/A), lead (Pb; 1 mg/kg), mercury (Hg; 0.1 mg/kg), nickel (Ni; 4 mg/kg) and zinc (Zn; 1 mg/kg).

Table 2
Candidate linear mixed-effect models used to explain heavy metal concentrations in snowshoe hare tissue. Trapping site was included as a random effect.

Model	Explanatory variable(s)	Tested hypothesis
mod1	Tissue type	Null model: Heavy metal concentrations depend on tissue type, higher in liver than meat (Klaassen, 2013)
mod2	Distance from smelter + Tissue type	Concentration diminishes with distance from emitting point source (Aznar et al., 2007; Savard et al., 2006).
mod3	Average annual hours under smelter winds + Tissue type	Sampling sites under prevailing winds from emitting point source show greater tissue concentrations (Aznar et al., 2007; Savard et al., 2006).
mod4	Distance from smelter + Average annual hours under smelter winds + Tissue type	Sites near a point emitting source and under prevailing winds show higher tissue concentrations (Aznar et al., 2007; Savard et al., 2006).
mod5	Percent deciduous and mixed forest cover within 1.4 ha + Tissue type + Percent deciduous and mixed forest cover within 1.4 ha * Tissue type	Snowshoe hare habitat affects tissue concentration (Pease et al., 1979; Mcgee et al., 2007).
mod6	Percent deciduous and mixed forest cover within 17 ha + Tissue type + Percent deciduous and mixed forest cover within 17 ha * Tissue type	Snowshoe hare habitat affects tissue concentration (Pease et al., 1979; Mcgee et al., 2007).

2.5. Statistical analyses of heavy metal concentrations in hare

We used a linear mixed model to explain variability in heavy metal concentrations using geographic location of trapping site as a random effect (Pinheiro and Bates, 2000). We considered a number of fixed effects explaining heavy metal concentrations, namely tissue type, distance from smelter, orientation relative to smelter, annual average of hours of wind received from smelter direction computed from weather data spanning 2008–2011 (Environment Canada; http://weather.gc.ca) and percent deciduous and mixed forest cover. We used an information-theoretic approach to compare the support in favor of our different hypotheses (Burnham and Anderson, 2002). We obtained maximum likelihood estimates with the nlme package in *R*3.1.2 (Pinheiro et al., 2014; R Core Team, 2014). Response variables were log-transformed to meet the homoscedasticity assumption. We implemented model selection and multimodel inference (Table 2) with the AICcmodavg package (Mazerolle, 2015).

2.6. Interviews

We assessed general food habits and mean snowshoe hare consumption within each community by interviewing at least 15 randomly selected household heads in each community (walking in the community and asking people to participate upon encountering them). Participants were identified as household heads by other family members and answered on behalf of all family members. A total of 78 participants provided information on the food habits of 266 individuals (Table 3). The total number of individuals for which data was obtained represents, 7, 8, 15, and 20% of the total resident populations of Pikogan, Winneway, Kitcisakik, and Timiskaming, respectively. We used a questionnaire based on typical "food frequency questionnaires" (Schuster et al., 2011), with an emphasis on snowshoe hare. Participants were asked what part(s) of the animal they eat in a typical meal; how many snowshoe hare meals they eat per week, month or year; the seasons during which they eat snowshoe hare; as well as information on risk-enhancing practices such as offal consumption and smoking (Cole and Kearney, 1997). Interviewees were also asked what other wildlife species they eat, the relative importance of these meals compared to snowshoe hare, and the cultural importance of traditional foods. Participants were free to share any information they deemed relevant regarding their consumption of traditional food.

Table 4
Scenarios tested for heavy metal exposure assessment.

Scenario	Meal size	Mean daily intake	Contamination level	Liver consumed
1	Average	Average	Average	No
2	Large portion	High	Average	No
3	Large portion	High	Average	Yes
4	Large portion	High	High	No
5	Large portion	High	High	Yes

2.7. Risk assessment

Oral reference doses (RfDs) for chemical compounds or heavy metals are usually measured in mg/kg bodyweight (BW)/day. For chronic exposure to small doses, we used the most restrictive benchmarks from the World Health Organization (WHO), Health Canada, or US Environmental Protection Agency (EPA). The equation used for average dose calculation was:

$$\text{Dose} = (C \times (1-W) \times \text{Adi})/BW,$$

where C is average heavy metal concentration in dry weight; W is tissue water content; Adi is average daily intake (average meal weight × number of meals per year/365 days); and BW is body weight. Standard bodyweight for toxicological studies was set to 70 kg for men, 60 kg for women and 20.8 kg for a 6 year old child, following standards (Derelanko, 2000; EPA, 2015). Dry weight tissue concentrations from the lab were converted to humid weight concentrations considering 70% water content in meat (Derelanko, 2000).

We used different scenarios in our calculations, to reflect a progressive range of health risks resulting from different plausible exposure situations (Table 4). The base scenario represented average daily intake of snowshoe hare meat (according to interview data), ranging from 0.226 kg to 0.465 kg, without consumption of offal. The second scenario represented high snowshoe hare consumption, i.e., mean number of snowshoe hare meals plus two standard deviations, and a large portion of 0.885 kg of meat at each meal, comprising all the muscles of a 1.5 kg

Table 3
Information on interview participants from four Anishnaabeg communities.

Community	Household heads interviewed	Individual household members					
		Elders		Adults		Children	Total
		Men	Women	Men	Women		
Pikogan	16	5	3	13	8	10	39
Winneway	14	2	2	11	7	13	35
Kitcisakik	15	0	0	13	18	31	62
Timiskaming	33	5	3	31	44	47	130

Table 5
Mean heavy metal concentration (±SD) in snowshoe hare meat and liver collected on the traditional territories of four Anishnaabeg communities. "–" = below detection limit.

Heavy metal	Meat (mg/kg$_{dry\ weight}$)			Liver (mg/kg$_{dry\ weight}$)		
As	–		–	–		–
Cd	–		–	3.79	±	3.65
Co	–		–	–		–
Cr	–		–	–		–
Cu	8.98	±	2.90	12.24	±	6.88
Fe	122.75	±	46.74	1323.23	±	457.49
Hg	0.05	±	0.10	0.15	±	0.62
Ni	–		–	–		–
Pb	0.07	±	0.45	0.17	±	0.70
Zn	40.82	±	36.80	103.74	±	45.89

standard snowshoe hare. The third scenario considered an additional heavy metal input from liver consumption to the high consumption scenario:

$$\text{Additional liver dose} = (\text{L} \times (1 - \text{W}) \times \text{AiL})/\text{BW},$$

where L is liver heavy metal concentration; W is tissue water content; AiL represents average daily intake of liver; and BW is body weight. Snowshoe hare liver intake was obtained by using a standard rabbit liver ratio of 2.94% of an average total weight of 1.5 kg (Derelanko, 2000).

Finally, we considered two "worst case scenarios", to reflect the possibility of randomly sampling amongst the most contaminated snowshoe hares in the study area. For these scenarios, we used the highest daily intake, added two standard deviations to the mean tissue concentrations and made calculations with and without liver intake.

3. Results

3.1. Heavy metal concentrations

Concentrations were below the detection limit for most samples for As, Co, Cr, Ni and Pb in both liver and meat. For Hg and Cd, very few samples had detectable concentrations in meat, but most liver samples had detectable concentrations. Concentrations were always higher in liver than meat. Almost all samples had detectable amounts of Cu, Fe and Zn in both liver and meat (Table 5). The top-ranked models for Cd, Cu and Zn included forest cover at the scale of 17 ha. In contrast, the top-ranked models for Fe and Hg consisted of the null model. Distance and orientation from the smelter, and annual average of hours under smelter winds did not influence heavy metal concentrations. However, the Cu concentration in liver and meat as well as the Zn concentration in liver decreased with increasing percentage of deciduous and mixed forest cover within 17 ha (Table 6; Fig. 2). Cd concentration followed a similar trend, though much weaker. Furthermore, the Zn concentration in meat increased with the combined deciduous and mixed cover within 17 ha (Table 6; Fig. 2).

3.2. Traditional food consumption

On average, Pikogan families ate the most snowshoe hare, whereas Kitcisakik families ate the least amongst the four participating communities (Table 7). However, many families did not consume snowshoe hare, most notably in Timiskaming. Snowshoe hare consumption data are not normally distributed for any of the participating communities. More than half of the participants (58%, $n = 78$) said their snowshoe hare consumption had declined over the years, whereas 38% mentioned their snowshoe hare intake was stable. An elder reported: "*We used to eat more hare than moose*!". Snowshoe hare was considered slightly important (40%) or not important (27%) in most participants' diet. However, most participants said that snowshoe hare was very (48%) or extremely (16%) important to their communities, and very (51%) or extremely important (33%) to their culture. Boiling was the most common way to cook hare, with all edible parts—including the offal (liver, kidneys, heart)—for 41% of participants. All participants also consumed other species at greater frequencies (moose [*Alces alces*], fish—mostly walleye [*Sander vitreus*] and pike [*Esox lucius*]); at comparable frequencies (ruffed grouse [*Bonasa umbellus*]); or at lower frequencies (beaver [*Castor canadensis*]). Some species were only eaten occasionally (various ducks, goose [*Branta canadensis*] and bear [*Ursus americanus*]). About a quarter (24%) of the participants were smokers.

3.3. Exposure to heavy metals

For the average snowshoe hare consumer, there was no apparent risk of exposure for any heavy metal tested, given that the calculated doses were at least 10 times below reference doses (Fig. 3). Risk of exposure increased when snowshoe hare was consumed more frequently and when liver was included in a meal. However, none of these exposure situations reached the reference doses (RfDs), where adverse health effects could occur. When considering the worst case scenarios with a high proportion of highly contaminated snowshoe hare (with and without liver), we found that RfDs were exceeded for Cd and Hg in Pikogan and Hg in Winneway.

4. Discussion

"Is it still safe to eat traditional food?" Answering this apparently simple question from Anishnaabeg communities is more complex than it seems. Few data exist on the possible effect of a smelter facility on the heavy metal contamination of snowshoe hare. We chose this species mainly because of its cultural importance for Anishnaabeg communities and its abundance. It is important to mention that none of the studies previously conducted on Anishnaabeg traditional species had a cultural dimension that also included food consumption surveys, essential to understand and assess exposure. While it is possible to evaluate the health risk of heavy metal contamination from traditional food intake, other elements—sometimes hard to quantify—are equally important to consider. Global exposure to heavy metals and other contaminants can be enhanced by diverse factors, whereas numerous benefits of traditional food can compensate the drawbacks. Moreover, heavy

Table 6
Akaike weight of candidate models and variables influencing heavy metal concentrations in snowshoe hare tissue collected from four Anishnaabeg communities.

Metal	Top model	Akaike weight	Variable	Model averaged estimate (95% unconditional confidence interval)
Zn	Percent deciduous and mixed forest cover within 17 ha + Tissue type + Percent deciduous and mixed forest cover within 17 ha * Tissue type	0.96	Percent deciduous and mixed forest cover within 17 ha * Tissue type	0.5 (0.25, 0.76)
Cu	Percent deciduous and mixed forest cover within 17 ha + Tissue type	0.37	Percent deciduous and mixed forest cover within 17 ha	−0.16 (−0.29, −0.03)
Cd*	Percent deciduous and mixed forest cover within 17 ha	0.47	Percent deciduous and mixed forest cover within 17 ha	−0.49 (−1.01, 0.03)

* Only liver tissue could be analyzed for Cd.

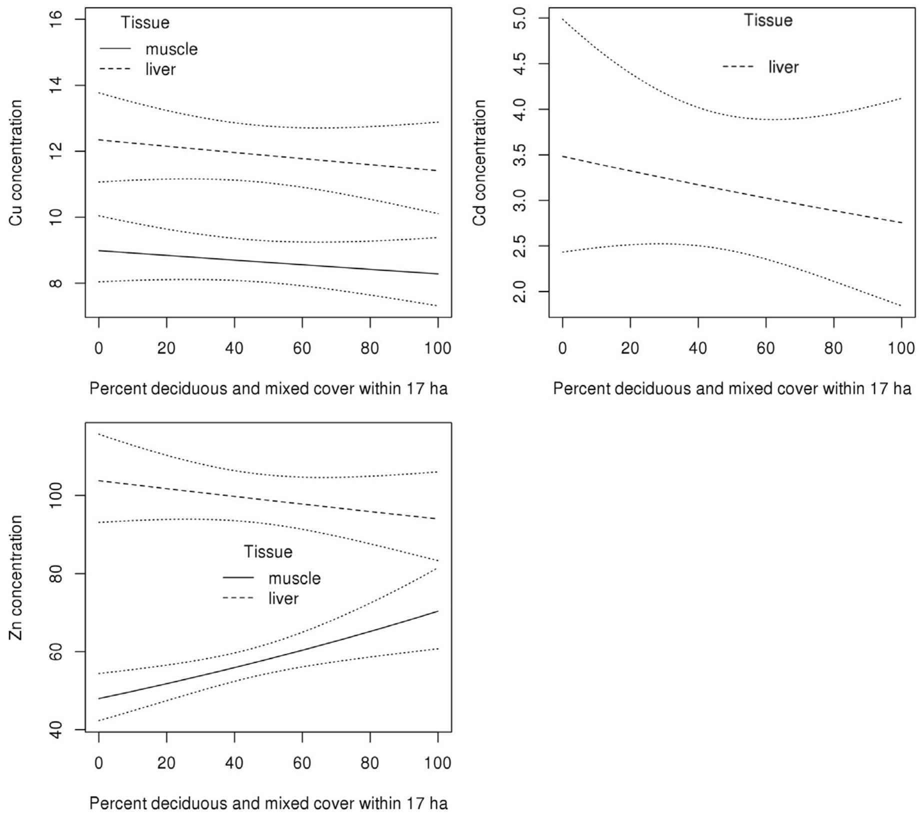

Fig. 2. Heavy metal concentrations in snowshoe hare tissues (mg/kg), as a function of habitat composition (combined percentage of deciduous and mixed forest cover). Slopes illustrate model-averaged predictions and dotted curves represent 95% confidence intervals. Note that only liver tissues were analyzed for Cd, because concentrations were below detectable levels in meat.

metal contamination is not the only threat to aboriginal and Anishnaabeg health.

4.1. Heavy metals in snowshoe hare

Table 8 compares the heavy metal liver concentrations measured in our study with other studies on snowshoe hare or parent species conducted in northern Quebec, northern Canada, and Europe. Cd and Hg concentrations were higher in our samples than for snowshoe hare from northern Quebec (Langlois and Langis, 1995), European brown hare and mountain hare from Finland and Slovakia (Venäläinen et al., 1996; Kolesarova et al., 2008). The proximity of a smelter within our study area likely explains the difference. However, Cd and Hg concentrations were slightly lower than for Arctic hare (Pedersen and Lierhagen, 2006), and substantially lower than for European brown hare from Poland (Wajdzik, 2006). Cu, Pb and Zn concentrations were lower in our samples, compared to Arctic hare and European brown hare from Finland, Poland and Slovakia (Venäläinen et al., 1996; Wajdzik, 2006; Kolesarova et al., 2008). Higher concentrations found in Arctic hare, far from any industrial facilities, are likely due to local geochemistry, habitat composition and type of species grazed (Pedersen and Lierhagen, 2006). The nature of nearby industrial activities could account for some of the differences with European brown hare. Within our study area, other studies reported bear and moose liver with Cd concentrations higher than in our snowshoe hare samples (Paré et al., 1999; Paré and Jolicoeur, 2005). The longer lifespan of moose and bear likely increases Cd bioaccumulation.

Table 7
Mean (±SD) and median snowshoe hare consumption in four Anishnaabeg communities.

Community	Average meals per year	Median
Pikogan	17.1 ± 32.6	5
Kitcisakik	3.9 ± 5.6	2
Winneway	7.6 ± 18.1	1
Timiskaming	4.7 ± 11.3	0

4.2. Influence of a smelting facility

None of the variables we used to measure smelter effect (distance, orientation, wind) were linked to heavy metal concentration in snowshoe hare. Our collecting distance ranged from 56 to 156 km. Smelter emissions normally tend to disperse radially and to dilute with distance, especially after 50 km (Savard et al., 2006; Aznar et al., 2008). Particle deposition rates decrease exponentially with distance from source, although particles can be detected at >116 km, and possibly travel well beyond this distance (Hou et al., 2006). Although previous studies would suggest an effect of distance and orientation from a smelting facility, we did not detect such an effect in our samples and conclude that deposition rates were relatively constant across our sampling areas. It is also likely that the four communities are beyond the area under direct influence of the smelter.

4.3. Influence of habitat type and quality

Within our study area, deciduous and mixed forests usually include high proportions of poplars, birches and willows, all of which are important Cd bioaccumulators (Brekken and Steinnes, 2004; McGee et al., 2007). Because snowshoe hare preferably feed on these species, we expected greater Cd concentrations in samples from deciduous or mixed forest stands (Pease et al., 1979). Instead, our analysis showed a marginally *negative* effect of combined mixed and deciduous forest cover on snowshoe hare liver Cd concentrations. This could be due to high Cd

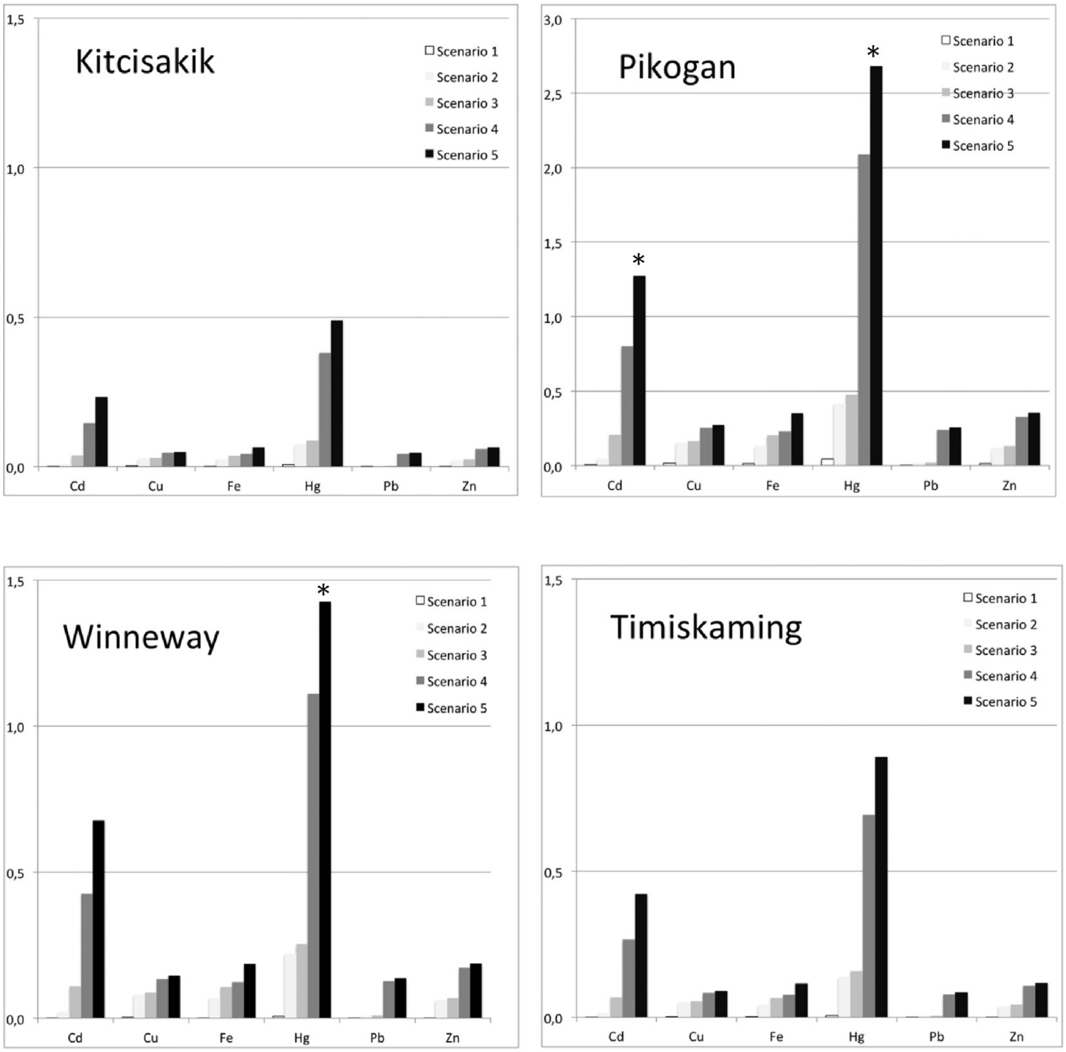

Fig. 3. Heavy metal intake from snowshoe hare tissues in four Anishnaabeg communities, expressed as relative ratio from reference doses for chronic, oral exposure (RfDs, mg/kg BW/day). See Table 4 for scenario details. * RfDs exceeded for Cd and Hg in Pikogan and Hg in Winneway for the worst case scenarios only.

uptake in the canopy (McGee et al., 2007), reducing Cd availability in the lower strata where snowshoe hares feed. To refine our approach, we could further investigate lower plant strata, including herbs and shrubs, and conduct snowshoe hare fecal pellet analysis to determine habitat use and its influence on heavy metal concentrations in snowshoe hare. Furthermore, additional studies will be needed to decipher the mechanisms involved in the effect of combined deciduous and mixed forest cover on Cu and Zn concentrations.

Table 8
Average heavy metal concentration in hare species around the world (liver tissue, mg/kg wet weight, ± SD when available). *Data in dry weight were converted to wet weight, considering a 70% water content.

Species	Location	Cd	Cu	Hg	Pb	Zn	Industry	Reference
*Lepus americanus** ($n = 196$)	North western Quebec	1.14 ± 1.1	3.67 ± 2.06	0.045 ± 0.19	0.05 ± 0.21	31.12 ± 13.62	<150 km from copper smelter	Present study
Lepus americanus ($n = 10$)	Northern Quebec	0.29	N/A	0.13 ± 0.22	0.210	N/A	>200 km from copper smelter	Langlois and Langis (1995)
*Lepus arcticus** ($n = 9$)	Nunavut	1.37	4.37	0.05	0.06	35.07	>500 km from copper smelter	Pedersen and Lierhagen (2006)
Lepus timidus ($n = 43$)	Finland	0.45 ± 0.27	4.71 ± 0.80	N/A	0.29 ± 0.22	31.70 ± 3.70	Industrial area	Venäläinen et al. (1996)
Lepus europaeus ($n = 28$)	Finland	0.16 ± 0.15	5.15 ± 1.08	N/A	0,17 ± 0.13	37.10 ± 12.30	Industrial area	Venäläinen et al. (1996)
Lepus europaeus ($n = 74$)	Slovakia	0.16 ± 0.14	N/A	0.02 ± 0.30	0.22 ± 0.19	N/A	Agriculture + industry	Kolesarova et al. (2008)
Lepus europaeus ($n = 164$)	Poland	1.65 ± 1.36	N/A	N/A	1.24 ± 0.59	N/A	Industrial area	Wajdzik (2006)

4.4. Anishnaabeg exposure to heavy metals

On average, the level of exposure to heavy metals from snowshoe hare consumption was low in the participating Anishnaabeg communities. Loring et al. (2010) found great variability in exposure to methylmercury in Alaska and warned against wall-to-wall consumption restrictions. In Anishnaabeg communities, exposure can fluctuate depending on food habits and the frequency at which snowshoe hare and other traditional foods, such as walleye and pike (high Hg) are consumed. Some individuals were likely to be more exposed to Hg and Cd than others, depending on traditional food consumption frequency. Furthermore, elders and members of a household where an elder lives tended to eat a greater quantity and diversity of traditional food than younger generations, as was previously noted in the Arctic (Kuhnlein et al., 2004). This is shown here as Kitcisakik had the lowest mean snowshoe hare consumption with no elders represented and the highest proportion of children, whereas Pikogan had the highest mean consumption and the greatest proportion of elders with the lowest proportion of children. Men also generally consumed more traditional food than women. Because of their smaller bodyweight and ongoing development, children and infants can be more vulnerable to contaminants. For this reason, children and women of childbearing age are often the first groups targeted by restrictions on traditional foods (Furgal et al., 2005).

4.5. Additional exposure to heavy metals

Aboriginal food habits can comprise dozens or even hundreds of different species that can contribute to the global exposure to heavy metals and other contaminants (Kuhnlein and Chan, 2000). Many species present on or near Anishnaabeg traditional lands are contaminated with heavy metals, to a point where certain tissues should be avoided (Table 9). Amongst the most popular species harvested and eaten on Anishnaabeg traditional lands, moose and bear are known to present high levels of Cd in the liver and kidneys (Paré and Jolicoeur, 2005), whereas walleye, pike and lake trout have high levels of flesh Hg (Beaulne et al., 2012). Processed food can also contribute to the daily intake of some heavy metals such as Cd, As or Hg, although regulations should limit this type of input (Satarug et al., 2010).

Another source of heavy metals includes the use of lead ammunition for hunting, which increases lead intake from game meat (Iqbal et al., 2009). Smoking also increases Cd intake by a factor of 30 (INAC, 2003). The proportion of smokers within the 4 participating communities (24%) is lower than amongst Inuit communities (65%), lower than average aboriginal communities (40%), and equivalent to the Canadian average (24%) (McDonald and Trenholm, 2010). While it has been suggested that aboriginal smokers should refrain from consuming offal to reduce Cd intake (Jin and Joseph-Quinn, 2003), it seems more efficient to consider quitting smoking, as this habit causes a plethora of other health issues (Cole and Kearney, 1997; Charania et al., 2014).

4.6. Health risk assessment

The most extreme scenarios presented in this study can be avoided by different precautionary measures. Trappers that vary their trapping areas are likely to increase the variability of the heavy metal concentration in their food. In turn, this can lower the possibility of recurrently trapping highly contaminated snowshoe hare. Liver consumption can also be avoided, to prevent additional heavy metal intake. Although liver represents a small contribution in terms of weight (0.0441 kg for a standard snowshoe hare liver), it can reach very high concentrations of heavy metals. Kidneys usually show even higher concentrations, especially for older specimens, in the case of Cd (\Danielson and Frank, 2009). If food waste is a concern, offal could be shared amongst family members, or saved in a community freezer for communal use (Martin, 2003). Assuredly, moderation in meal frequency and size can help limit heavy metal intake from specific foods. However, avoiding to eat traditional food would deprive communities of numerous health benefits. By maintaining a diversified diet, one can effectively limit the risks and prevent an excess accumulation of certain contaminants from specific species, while increasing health benefits from traditional foods.

4.7. Nutritional benefits of traditional foods

There are major health disparities between aboriginal people and the rest of the population (Haman et al., 2010). Health conditions seem difficult to maintain when location, income, and aboriginal status contribute to a greater occurrence of deleterious behaviours, higher occurrence of diseases, and lack of opportunities to enforce good health (Frohlich et al., 2010). However, traditional food can be a significant asset in the prevention of the serious health issues that disproportionately affect aboriginal people, namely cardiovascular diseases, obesity, and diabetes (Loring and Gerlach, 2008; Loring et al., 2010). Contaminants aside, traditional food is considered part of a healthy lifestyle and offers great nutritional value (Samson and Pretty, 2006). Individuals eating traditional food on a regular basis have a greater uptake of essential nutrients, vitamins and minerals, and they tend to be less affected by obesity, diabetes and anemia (Gittelsohn et al., 1998; Gagné et al., 2012). Conversely, the historical emergence of processed food in aboriginal communities is correlated with the advent of obesity, diabetes, and many other diet-related chronic diseases (Kuhnlein et al., 2004; Haman et al., 2010).

4.8. Cultural benefits of traditional foods

The cultural importance of traditional food cannot be overstated. Researchers must be sensitive and open-minded to fully understand the cultural context of research with aboriginal communities (Asselin and Basile, 2012; Koster et al., 2012). Historically, food harvesting, processing, consuming, and sharing were fundamental to the social, political, economic, domestic, spiritual, and cultural organization of aboriginal societies (Kuhnlein and Chan, 2000). Even if the wage-driven economy has now supplanted the traditional hunting and gathering economy and altered its corresponding food systems, the shift is recent and traditional activities have not turned into folkloric hobbies. Considered the "true food", traditional food continues to be appreciated and valued, as it embodies the Anishnaabeg traditional way of living (Bousquet, 2002). The interviews we conducted confirm this perspective: snowshoe hare was deemed very important culturally, although its

Table 9
Heavy metal concentration in traditional food found in the vicinity of four Anishnaabeg communities (liver tissue, except pike flesh).

Species	Heavy metal	Mean (mg/kg)	Weight	Location	Recommendations	Reference
Bear	Cd	16.9	Dry	Abitibi-Temiscamingue	Avoid consuming liver	Paré and Jolicoeur (2005)
Moose	Cd	22.4	Dry	Abitibi-Temiscamingue	Avoid consuming liver	Paré and Jolicoeur (2005)
Pike	Hg	0.72 (flesh)	Fresh	Abitibi-Temiscamingue	–	Beaulne et al. (2012)
Willow Ptarmigan	Cd	25.8	Dry	Northern Quebec	No guideline necessary	Rodrigue et al. (2007)
Rock Ptarmigan	Cd	6.6	Dry	Northern Quebec	No guideline necessary	Rodrigue et al. (2007)
Rock Ptarmigan	Cd	8.9	Fresh	Northern Quebec	–	Langlois and Langis (1995)
Elk	Cd	1.1	Fresh	Sudbury, Ontario	–	Parker and Hamr (2001)
Elk	Pb	1.47	Fresh	Sudbury, Ontario	–	Danielson and Frank (2009)

consumption is currently lower than it was before contact with Canadian-European settlers.

Extensive experience and observation of the land over many generations has led aboriginal people to accumulate a vast amount of empirical knowledge of the various species and diverse ecological interactions between them (Berkes, 2012; Parlee et al., 2012; Asselin, 2015). Despite profound environmental and socio-economic changes, traditional ecological knowledge (TEK) is adaptive, maintaining aboriginal people's capacity to accurately evaluate both land and food healthiness, through subtle indicators and specific observations (Tanguay et al., 2013). Notwithstanding this wealth of knowledge, environmental contamination is a recent and invisible threat to aboriginal health, possibly undetectable by traditional means (Wheatly, 1997; Furgal et al., 2005).

5. Conclusion

We evaluated heavy metal concentration in snowshoe hares from western Quebec. The tissue analyses we conducted in conjunction with food consumption questionnaires suggest that, on average, the Anishnaabeg population experience a low risk of exposure to heavy metals from snowshoe hare consumption. Specifically, snowshoe hare meat is not a problem, especially when consumed occasionally and without the offal. However, the risk of exposure can theoretically rise for those who frequently consume large quantities of snowshoe hare meat and offal. The additional input of other food items and certain life habits such as smoking also need to be considered. An extensive evaluation of all the traditional food species, along with thorough food habit surveys (including processed food) would be required to better evaluate the global health risk experienced by Anishnaabeg communities. There is growing evidence that certain traditional food, carrying contaminants such as PCBs, heavy metals or perfluorooctane sulfonate (PFOS), can increase the risk of cardio metabolic illnesses or endocrinal disorders (Singh et al., 2014). Children and women of childbearing age can be particularly sensitive to such health issues. However, risk assessment does not reflect a certainty, but rather represents a possibility (Cardona, 2003). In many cases, socioeconomic factors like poverty, remoteness and lack of economic opportunities can have the most detrimental effects on aboriginal health (Frohlich et al., 2010). Even if environmental health is a key factor to human health, there are other immediate and significant threats to aboriginal health that should be addressed in priority, such as diabetes and obesity. Confidence and trust can suffer when the harmlessness of traditional food is questioned, without proper communication of a sensible, nuanced and understandable message (Jack et al., 2010; McAuley and Knopper, 2011). Because of its many cultural and nutritional benefits, traditional food is more likely part of the solution rather than part of the problem of food insecurity in aboriginal communities.

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