VARIATIONS OF CADMIUM LEVELS IN MOOSE TISSUES FROM THE ABITIBI-TÉMISCAMINGUE REGION

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ABSTRACT: In the fall of 1986, 1,147 samples of kidney, liver, and skeletal muscle of 508 moose (*Alces alces*) and 38 black bears (*Ursus americana*) from Abitibi-Témiscamingue in western Québec were analyzed. The cadmium levels measured in the liver and kidney samples made it possible to establish the distribution of cadmium in the regional environment. As has been shown in other studies, cadmium concentration in these tissues increases with age, can differ according to sex, and can vary greatly according to the area sampled. Three homogenous contamination sectors where identified: the highest contamination unit is directly influenced by a copper smelter. The cadmium levels in Abitibi-Témiscamingue are the highest measured in Québec and elsewhere: the mean value (µg/g) ± SE (range) was 72.4 ± 3.9 (0.0 - 440.1) in the kidneys, 11.2 ± 0.7 (0.4 - 232.1) in the liver, and 0.023 ± 0.007 (0.000 - 1.930) in the muscles. In the high contamination zone, we had analyses done on liver and kidney samples from 38 black bears. The cadmium concentrations turned out to be higher than those in moose, namely 282.6 ± 126.0 (55.6 - 572.2) in the kidneys and 22.6 ± 17.6 (2.1 - 70.9) in the liver. A sulfuric acid plant has been in operation at the copper smelter since 1989, which has reduced cadmium emissions significantly. In the fall of 1995, we had analyses done on kidney samples of 35 moose calves from 2 different contamination sectors to make a comparison with the 1986 results. The average cadmium concentrations did not vary during this period in the 2 different sectors. We propose an inexpensive, yet efficient method that would allow us to monitor changes in contamination levels over time.

Key words: age, black bear, cadmium, liver, moose, muscle, quality control, sex

RÉSUMÉ: Nous avons analysé 1147 échantillons de tissus biologiques provenant de 508 orignaux (*Alces alces*) (automne 1986) et de 38 ours noirs (*Ursus americanus*) (printemps 1991) de l'Abitibi-Témiscamingue, dans l'ouest du Québec. Les tissus étudiés pour l'orignal sont le foie, le rein, et un muscle squelettique. Des échantillons additionnels de reins provenant de 35 faons orignaux ont été examinés en 1995. Les teneurs en cadmium mesurées dans les prélèvements de foie et de reins d'orignaux ont permis de dresser la distribution du cadmium dans l'environnement régional. Comme il a été démontré dans d'autres études, la concentration de cadmium dans ces tissus augmente avec l'âge, peut différer selon les sexes, et peut varier grandement en fonction du secteur d'abattage. Trois secteurs homogènes de contamination ont été identifiés et l'unité de contamination la plus élevée subit l'influence directe d'une fonderie de cuivre. Les teneurs en cadmium mesurées en Abitibi-Témiscamingue sont les plus élevées au Québec et ailleurs: les valeurs moyennes (µg/g) ± erreur type (étendue) dans les reins ont été de 72,4 ± 3,9 (0,0 - 440,1), de 11,2 ± 0,7 (0,4 - 232,1) dans le foie, et de 0,023 ± 0,007 (0,000 - 1,930) dans les muscles. Les échantillons de foie et de reins d'ours noirs provenaient de la zone de contamination élevée. Les concentrations de cadmium se sont révélées plus élevées que chez l'orignal, les moyennes étant de 282,6 ± 126,0 (55,6 - 572,2) dans les reins et de 22,6 ± 17,6 (2,1 - 70,0) (µg/g) dans le foie. Une usine d'acide sulfurique est en opération à la fonderie Horne depuis 1989, ce qui a réduit significativement l'émission des poussières dont le cadmium, par le traitement des gaz de procédé. À l'automne 1995, des échantillons de reins de faons orignaux ont été échantillonnés dans deux secteurs de contamination différente afin de les comparer avec ceux de 1986. Les concentrations moyennes de cadmium dans les reins d'orignaux n'ont pas varié au cours de cette période et ce, dans les deux secteurs étudiés. Nous proposons une méthode de suivi peu coûteuse et efficace pour suivre l'évolution temporelle de la contamination par le cadmium.

Mots-clés: âge, cadmium, contrôle de qualité, foie, muscle, ours noir, rein, sexe

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In the mid-1980's, several organizations studied cadmium levels in various tissues of wild animals, particularly cervids, in the United States, Scandinavia, and Canada (Scanlon *et al.* 1986, Crête *et al.* 1987, Glooschenko *et al.* 1988). Recent estimates suggest that human activities yield an annual release of cadmium into the atmosphere that is about 3 - 10 times higher than natural sources. Foundries account for 65 - 85% of these emissions and the combustion of fossil fuels for about 6 - 7% (Yeats and Bewers 1987, Nriagu and Pacyna 1988 *in* Outridge *et al.* 1994).

A warning issued by the Ontario Ministry of Natural Resources in 1985 advised the citizens of that province to temporarily avoid the consumption of liver and kidneys from moose, and incited a study of these tissues in the cervids of Québec (Crête *et al.* 1986). That study recommended not consuming, for the moment, the liver and kidneys of any wild cervids living in Québec. Since then, no conclusive evidence has been presented to alleviate these concerns.

Studies by Crête *et al.* (1986, 1987) identified the Abitibi-Témiscamingue region in western Québec as having the highest provincial values for cadmium in moose (*Alces alces*). Our work was intended to identify intra-regional variations in cadmium contamination of liver and kidney samples from moose harvested in the Abitibi-Témiscamingue region. We wanted to verify that cadmium levels in meat present risks for human consumption and determine whether high values in the kidneys can affect the health of moose. A limited sample allowed us to evaluate whether the liver and kidneys of black bears (*Ursus americana*) also showed high rates of contamination. Even if harvested black bears are not used much for human food, it remains possible that some people will consume them. Finally, we propose a method of monitoring temporal variations in cadmium concentration in the environment.

STUDY AREA

The Abitibi-Témiscamingue region is situated in western Québec and covers more than 82,000 km^2 (Fig. 1). The study area was divided into 9 sectors based on the number of samples obtained in each map unit. The southern part of the region is covered with thin glacial deposits of gneiss and Precambrian granite in mountainous relief, while the valleys contain heavy accumulations of fluvial-glacial sediments. Sector 1 and part of Sector 2 are typical of this part of the region. The remainder of Sector 2 is sedimentary rock, principally limestone and shale. Sectors 3, 4, 5, 7, and 8 are covered with thick clay deposits. A significant volume of glacial and fluvial-glacial sediments covers Sector 6.

Forest composition varies from a hardwood dominated mixed forest in the south, to an almost homogenous conifer dominated forest in the north. In Sectors 1 and 2, sugar maple (*Acer saccharum*) and red maple (*Acer rubrum*) dominate. In Sectors 3, 4, and 5, trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) represent 28% and 16% of the forest volume, respectively. In Sectors 6, 7,

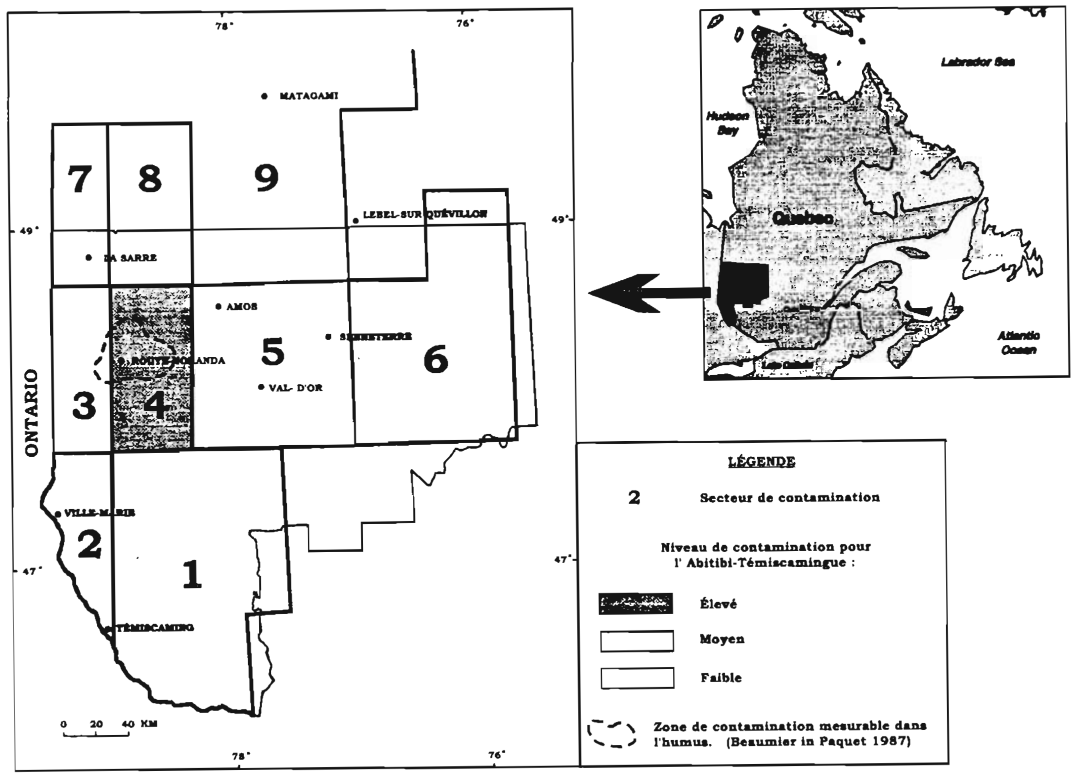

Fig. 1. Cadmium concentration in moose tissues in the Abitibi-Témiscamingue study area in 1986. Dark = high; grey = moderate; white = low; dashed line = contamination detectable in humus. [*Délimitation des secteurs pour l'étude de la contamination des orignaux par le cadmium en Abitibi-Témiscamingue, 1986.*]

8, and 9, trembling aspen and birch are again important but black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*) are more abundant.

Bedrock and soils exposed by erosion are very sensitive to acid precipitation in Sectors 1, 2, 6, and the low-lying portions of Sectors 3 and 4. In the other sectors, this sensitivity varies from moderate to high, with certain very sensitive locations (Shilts 1981).

Annual deposits of sulphate recorded in 1982-1983 were at intermediate levels in comparison with the remainder of the province: 20 - 25 kg/ha in Sectors 1, 2, and portions of Sectors 3, 4, 5, and 9, and 15 - 20 kg/ha elsewhere (Talbot *et al.* 1984).

Based on measurements of trace elements in snow and rain samples collected near Rouyn-Noranda, and results from other sources (lake bottom sediments, stream sediments, organic soil horizon), Lalonde (1979 *in* Paquet 1987) suggested that surface contamination could be found in an area of 2,000 km^2 radiating around this city. He determined that a marked effect of the foundry emissions was measurable in a 40-km radius around the smelter installations (Fig. 1). The effect of acid precipitation (pH = 3.96) is much more apparent in this affected area, which is generally composed of crystalline igneous rocks and other rocks containing insufficient quantities of basic minerals to neutralize the acidity of the precipitation (BEST 1979).

The Horne Inc. foundry has been in

operation since 1927. Copper anodes, zinc concentrate, and sulphuric acid are currently the main products. Several modifications have been introduced since this foundry began production, particularly the progressive replacement of the furnace grating and reverberating furnaces (the last one having been closed in 1991) beginning in 1973 by Noranda and Convertisseur Noranda in 1997. The acid factory began operating in 1989, at first, to remove harmful gasses from the emissions, and later to transform the sulphur dioxide (SO_2) contained in these gasses to sulphuric acid (H_2SO_4). Furthermore, over time the foundry implemented several other purification technologies such as electro-filters and dust collectors to improve the quality of the air in the vicinity of Rouyn-Noranda.

In 1998, more than 70% of the sulphur waste was converted to sulphuric acid and Noranda is engaged in a program to increase this rate to more than 90% by 1 January 2002. Thus, the foundry emissions of SO_2 have decreased by 80% since 1970, from 620,000 metric tonnes (m.t.) to 118,000 m.t. The emissions in 2002 are expected to be about 50,000 m.t.

In the same manner, dust emissions into the atmosphere in 1998 were 0.82 kg/m.t. of material processed (including combustibles), for a total of 930 m.t., and the objective of the foundry is to reduce this rate to 0.4 kg/m.t. by 1 January 2002. In 1980, this rate was 6.24 kg/m.t., for a total of 7,200 m.t. Thus, an 87% reduction of dust emissions has already been achieved.

METHODS

Sample Collection and Analysis

Hunters furnished samples of moose liver and kidneys in 1986 and 1995 when they reported their harvest to 1 of the 8 mandatory game registration stations in the region. A piece of muscle was obtained from the neck of each specimen. About 100 g of muscle and liver tissue and an entire kidney were preserved frozen. Tissue samples from black bears were collected and frozen at the time the game was field-dressed, by the outfitter that furnished the specimens.

Ages of moose were determined by counting *cementum annuli* in roots of the lower 2 incisors (Ouellet 1977). Calves were identified by their size. The location where each moose was harvested, as provided by the hunter, was noted in Universal Transverse Mercator coordinates (± 1 km²).

Samples were prepared according to standard methods, by homogenization using a grinder with stainless steel blades and a commercial meat grinder. To determine the proportion of water in the samples, a portion of about 10 g was dried at 90°C for 24 hours, then weighed again. The samples were analyzed at the Service de l'environnement de Noranda (SEN) laboratory. Some analyses were done by the Centre de toxicologie du Québec (CTQ) to verify the reliability of results provided by the other laboratory. The analysis was carried out by atomic absorption spectrophotometry. For the liver and kidney samples that had cadmium levels below 0.5 μg/g, and for all of the muscle samples, the graphite oven method was used.

To ensure the reliability of results, 19 random samples were divided into 5 replicates and submitted for verification. Also, reference samples originating from the National Bureau of Standards (NBS) were included. A total of 180 control samples were analyzed, which was 15% of the entire 1,200 samples analyzed. Finally, 35 reference samples having known contents of cadmium were obtained from the NBS and analyzed by the CTQ laboratory to confirm the validity of results and allow a valid comparison with the results of the Crête *et al.* (1986) study, which were also generated by the CTQ laboratory.

At the Rouyn-Noranda registration station, we preserved kidney slices in concentrated 10% formalin when an animal had been dead for less than 3 days. The thickness of these longitudinal slices varied from 0.5 - 1.0 cm. This material was forwarded to the St.-Hyacinthe Faculty of Veterinary Medicine, where sub-samples of tissues were taken, almost always from the same part of each slice. Next, the specimens were embedded in paraffin blocks and cut to a thickness of 4 μm. Colorimetry was determined by the hemothoxyline-phloxine safran (HPS) technique, using the 3-colour process of Masson and PAS. A histopathological examination was conducted using the same parameters as Elinder *et al.* (1981).

Statistical Analyses

Statistical analyses of results were carried out with SAS software (SAS Institute 1985) and were intended to determine the effect of age, sex, and harvest sector, on the concentrations of cadmium in moose tissues. The liver and kidney data were transformed by $\log_{10}$ to normalize their distribution and homogenize the variances (Norstrom *et al.* 1986 *in* Crête *et al.* 1987). Covariance analysis was applied to estimate the degree of significance of the 3 factors and their interaction, using the GLM procedure. The least squares method was used to improve the fit of the general linear models. If an interaction was not significant ($P > 0.05$), it was excluded from the model. Analysis of variance and the 2 x 2 probability matrices for geographic unit comparisons (i.e., probability of identical averages for the cadmium levels in the liver and kidneys of moose from each unit) allowed distinction of zones with different levels of contamination. *A posteriori* tests were realized to compare sectors within the region with the help of the LSMEANS test of the GLM procedure. Concentrations below the detectable threshold of the analytical method were rounded to 0.00.

RESULTS

Coefficients of variation (100 x standard deviation/mean) for the results of liver and kidney replicates were less than 10%, indicating that the repeatability of sample analyses was very good. The accuracy of analyses was excellent considering the low relative error values of 10% that were obtained (i.e., the difference between the value measured and the actual NBS value in %). When the anticipated content was low, as in the case of muscle samples, the accuracy of the laboratory values was considerably higher (relative error < 1%).

A regression between the 2 sets of results originating from the 2 laboratories showed a very strong correlation (r^2 = 0.996). The quality of results from the present study is excellent, in terms of both precision and accuracy. These data are comparable to those described in the Crête *et al.* (1986) study since the CTQ laboratory was also used to analyze samples in this study.

In 1986, the SEN laboratory analyzed 1,147 samples collected from 508 moose, of which 474 were liver, 276 were kidney, and 397 were muscle samples. Age was determined for 433 specimens. Considering the quantity and quality of the samples provided (24% of the moose harvested and registered in Abitibi-Témiscamingue in 1986 were studied), the co-operation of hunters was excellent.

The water content of liver samples was determined to be 71% and, for the kidneys, 80%. The mean concentration of cadmium in the liver samples was 11.22 μg/g dry weight ± 0.709 (0.43 - 232.1) (mean ± standard error (range)) (Table 1). The majority of values measured (98%) were < 32.5 μg/g dry weight. The average concentration of cadmium in the kidney samples (72.43 mg/kg ± 3.884 (0.01 - 440.0)) was a

Table 1. Cadmium concentration in moose tissues (μg/g dry weight) and age of moose sampled from the Abitibi-Témiscamingue region in 1986. [*Concentration de cadmium dans des tissus d'orignaux (μg/g poids sec) et âge des spécimens échantillonnés en Abitibi-Témiscamingue en 1986.*]

Tissues *Tissus*	*n*	Mean *Moyenne*	Standard error *Erreur type*	Minimum	Maximum
Liver *Foie*	474	11.22	0.709	0.43	232.1
Kidneys *Reins*	276	72.43	3.884	0.01	440.1
Muscles *Muscles*	397	0.023	0.007	0.0	1.93
Age (years) *Âge (années)*	433	2.89	0.007	0.5	16.5

lot higher, namely 6.5 times greater than the estimated mean value in the liver, and 92% of the values were between 0 and 165 ppm. In the skeletal muscle, almost all the values were located below the detection threshold of the analytical method, the average being 0.023 μg/g dry weight ± 0.007 (0 - 1.93; 98% of the values were between 0 and 0.25).

The covariance analysis of cadmium concentration in liver tissue according to sex, age, and harvest sector, as well as interactions between these factors, indicated intra-regional differences ($P < 0.001$). The significant interaction between age, sector, and sex ($P < 0.03$), as well as between the sectors and sex ($P < 0.03$), revealed that the accumulation of cadmium in liver tissue did not vary uniformly according to age, sex, and harvest sector (Tables 2 and 3).

The comparison of sectors showed similarities among some units. Sector 4, where the copper foundry is situated, had the highest cadmium levels (Fig. 1). Sectors 1, 2, 3, and 6 had moderate levels of contamination, while Sectors 5, 7, 8, and 9 had low levels.

Among the 33 kidney samples submitted for histopathological examination, all originating from Sector 4, the average cadmium content was 123.1 μg/g dry weight ± 17.98 (21.0 - 440.1). No lesions characteristic of renal disease were found. As for chronic lesions (i.e., glomerular lesions), corresponding to the parameters used by Elinder *et al.* (1981), they were absent or very small (Dr. Lagacé, Univ. Montréal, *pers. comm.*).

The liver and kidney samples from the 38 black bears were collected in contamination Sector 4. The average concentration of cadmium in the liver samples (± standard error (range)) was 22.6 μg/g dry weight ± 2.9 (2.1 - 70.9) and in the kidney samples it was 282.6 μg/g ± 20.4 (55.6 - 572.2) (Table 4). The results obtained from these samples, and the statistical analyses, demonstrate that cadmium contamination is positively related to age, sex, and the interaction of these factors, as well as the distance between the collection point and the Horne foundry: relationships between $\log_{10}$ cadmium concentration in the liver and age and sex are both significant, $F > 0.002$ and 0.008 at $\alpha < 0.05$, respectively. The same variable is significantly related to the interaction between age and sex ($F > 0.031$), age and distance ($F > 0.042$), and distance and sex ($F > 0.035$) at $\alpha < 0.05$. The same relationships between the interactions of age, dis-

Table 2. Cadmium concentrations in moose liver, kidneys, and muscles (μg/g dry weight), by sex, in 3 sectors of the Abitibi-Témiscamingue region with different contamination levels in 1986. [*Concentration de cadmium (μg/g poids sec) dans le foie, les reins, et les muscles d'orignaux selon leur sexe dans trois secteurs de contamination différente en Abitibi-Témiscamingue, 1986.*]

Tissues *Tissus*	Sector[1] *Secteur[1]*	Males *Mâles*			Females *Femelles*		
		Mean *Moyenne*	Standard error *Erreur type*	*n*	Mean *Moyenne*	Standard error *Erreur type*	*n*
Liver / *Foie*	Low / *Faible*	6.7	0.44	101	6.4	0.53	74
	Moderate / *Moyen*	12.4	1.36	74	14.1	2.74	100
	High / *Élevé*	20.8	3.38	31	13.3	1.89	33
Kidneys / *Reins*	Low / *Faible*	45.4	4.39	61	58.9	8.47	40
	Moderate / *Moyen*	78.1	9.83	36	77.1	9.44	53
	High / *Élevé*	111.7	18.22	26	102.2	17.10	28
Muscles	Low / *Faible*	0.008	0.004	91	0.007	0.006	67
	Moderate / *Moyen*	0.042	0.032	62	0.0019	0.010	73
	High / *Élevé*	0.094	0.065	28	0.014	0.009	31
Age (years)	Low / *Faible*	2.3	0.16	101	2.7	0.26	79
Âge (années)	Moderate / *Moyen*	2.4	0.20	79	2.7	0.20	105
	High / *Élevé*	2.4	0.31	30	3.0	0.41	36

[1]Low = Sectors 5, 7, 8, and 9; Moderate = Sectors 1, 2, 3, and 6; High = Sector 4 [*Faible = Secteurs 5, 7, 8, et 9; Moyen = Secteurs 1, 2, 3, et 6; Élevé = Secteur 4*]

tance, and sex are also significant ($F >$ 0.081) but at $\alpha < 0.10$.

In 1987, samples of plants originating from different contamination sectors were analyzed. The results showed that, among the 4 sectors studied, the one situated in Sector 4 had the highest contamination levels. For the 5 species compared, the values were all at least 3 times greater in this zone than in the other 3 sectors (2, 8, and 9), where concentrations were similar (Table 5) (Walsh and Paré 1989).

In the fall of 1995, the analysis of kidney samples from moose calves in Sectors 4, 5, and 9 did not show any decrease in cadmium concentrations (Table 6) (Sector 4: $t_c = 0.0$; $t_{\alpha/2} = 2.05$ at $\alpha = 0.05$; Sectors 5 and 9: $t_c = 0.85$; $t_{\alpha/2} = 2.08$ at $\alpha = 0.05$).

DISCUSSION

Our analyses allowed us to identify 3 areas in the Abitibi-Témiscamingue region within which the presence of cadmium in moose seems fairly homogeneous. Sector 4, which includes the Horne foundry, has the highest levels of cadmium in the 3 tissues sampled, for both bulls and cows in all 3 age classes (Tables 3 and 4). The only

Table 3. Cadmium concentrations in moose liver and kidneys (µg/g dry weight), by sex and age class, in 3 sectors of the Abitibi-Témiscamingue region with different contamination levels in 1986. [*Concentration de cadmium (µg/g poids sec) dans le foie et les reins d'orignaux par sexe et catégorie d'âge dans trois secteurs de contamination différente, Abitibi-Témiscamingue, 1986.*]

Tissues	Sector[1]	Age class	Males	Females
Tissus	*Secteur*[1]	*Groupe d'âge*	*Mâles*	*Femelles*
Liver	Low / *Faible*	Calf / *Faon*	2.0 ± 0.3 (12)[2]	2.2 ± 0.5 (14)
Foie		1.5 year / *1,5 an*	7.1 ± 0.5 (51)	5.5 ± 0.7 (24)
		Adult / *Adulte*	7.7 ± 0.9 (38)	8.6 ± 0.8 (36)
	Moderate / *Moyen*	Calf / *Faon*	3.0 ± 0.7 (7)	3.3 ± 0.9 (10)
		1.5 year / *1,5 an*	12.2 ± 2.2 (34)	10.5 ± 3.8 (38)
		Adult / *Adulte*	14.6 ± 1.9 (33)	18.9 ± 4.4 (52)
	High / *Élevé*	Calf / *Faon*	7.7 ± 3.3 (4)	3.7 ± 0.6 (5)
		1.5 year / *1,5 an*	24.3 ± 6.1 (15)	7.7 ± 1.4 (11)
		Adult / *Adulte*	20.8 ± 3.7 (12)	19.8 ± 2.7 (17)
Kidneys	Low / *Faible*	Calf / *Faon*	6.1 ± 0.9 (9)	8.8 ± 4.8 (8)
Reins		1.5 year / *1,5 an*	42.0 ± 4.1 (31)	30.9 ± 3.6 (11)
		Adult / *Adulte*	67.1 ± 8.6 (21)	92.5 ± 11.6 (21)
	Moderate / *Moyen*	Calf / *Faon*	5.8 ± 1.2 (3)	9.1 ± 2.9 (6)
		1.5 year / *1,5 an*	48.5 ± 3.4 (15)	43.7 ± 4.8 (25)
		Adult / *Adulte*	114.8 ± 14.7 (18)	133.5 ± 15.2 (22)
	High / *Élevé*	Calf / *Faon*	47.3 ± 30.9 (3)	14.9 ± 3.9 (4)
		1.5 year / *1,5 an*	100.1 ± 31.7 (12)	60.0 ± 9.7 (12)
		Adult / *Adulte*	141.9 ± 22.1 (11)	173.4 ± 26.9 (12)

[1]Low = Sectors 5, 7, 8, and 9; Moderate = Sectors 1, 2, 3, and 6; High = Sector 4 [*Faible = Secteurs 5, 7, 8, et 9; Moyen = Secteurs 1, 2, 3, et 6; Élevé = Secteur 4*]

[2]Mean ± Standard error (*n*) [*Moyenne ± Erreur type (n)*]

exceptions are the concentrations in the liver and muscles of cows, which overlap the concentrations found in the moderate contamination area. Three factors may explain the observed contamination levels in Sector 4: the natural mineralization of the sector, the historical human contribution, and the recent human contribution to the sector. Using current methods it is not possible to precisely determine the contribution of each of these factors to the overall contamination.

It is generally accepted that cadmium deposition decreases exponentially with distance from a source of atmospheric contamination (Nriagu 1980, Glooschenko 1986). However, in our study we observed a fairly abrupt drop in cadmium content at about 40 km to the east and north of the foundry. The average cadmium content (± standard error) in the liver decreases from 16.9 ± 3.5 µg/g dry weight in Sector 4 to 9.3 ± 2.1 µg/g dry weight in Sector 5. Thus, the difference is only 6.6 ± 1.3 towards the north. To the south, the concentrations vary from 10.8 - 19.5 µg/g dry weight in 4 sectors. Paquet (1987) concluded that the zone of direct influence was situated within a 40-

Table 4. Cadmium concentrations in black bear liver and kidneys (µg/g dry weight) in Sector 4 of the Abitibi-Témiscamingue region in 1991. [*Concentration de cadmium dans le foie et les reins d'ours noirs (µg/g poids sec) provenant du secteur 4, en Abitibi-Témiscamingue en 1991.*]

Variable	Sex / *Sexe*	Mean ± Standard error (*n*) / *Moyenne ± Erreur type (n)*	Range / *Étendue*	Minimum	Maximum
Liver	Males / *Mâles*	15.8±2.1 (23)	52.3	2.1	54.5
Foie	Females / *Femelles*	32.9±8.5 (15)	21.7	64.9	6.0
	Total	22.6±2.9 (38)	68.8	2.1	70.9
Kidneys	Males / *Mâles*	231.7±18.3 (23)	363.0	114.5	477.5
Reins	Females / *Femelles*	360.5±35.7 (15)	516.6	55.6	572.2
	Total	282.6±20.4 (38)	516.6	55.6	572.2
Body Weight (kg)	Males / *Mâles*	78.9±6.5 (22)	255.0	80.0	205.0
Poids (kg)	Females / *Femelles*	71.0±4.5(15)	125.0	80.0	205.0
	Total	75.7±4.3 (37)	255.0	80.0	335.0
Age (years)	Males / *Mâles*	6.6±0.5 (23)	12.0	3.5	15.5
Âge (années)	Females / *Femelles*	8.8±0.9 (15)	11.0	4.5	15.5
	Total	7.5±0.5 (38)	12.0	3.5	15.5

Table 5. Mean cadmium concentration in plants (µg/g dry weight) from 4 sectors of the Abitibi-Témiscamingue region in August 1987. [*Concentration moyenne de cadmium dans des plantes (µg/g poids sec) de l'Abitibi-Témiscamingue, en août 1987.*]

Species / *Espèce*	Sector / *Secteur*			
	4	2	8	9
White birch / *Bouleau blanc*	3.08 (13)[1]	0.82 (13)	1.37 (11)	0.91 (11)
Balsam fir / *Sapin*	0.99 (4)	0.35 (7)	0.35 (7)	0.32 (8)
Moss (*Politrichum* sp.) / *Mousses*	2.8 (6)	0.44 (7)	0.69 (6)	0.76 (4)
Pond Lily (*Nuphar* sp.) / *Nénuphars*	4.63 (8)	0.70 (9)	—	0.58 (10)
Cat-tail (*Typha* sp.) / *Quenouilles*	0.05 (11)	—	0.01 (10)	0.02 (10)

[1]Mean (*n*) [*Moyenne (n)*]

km radius of smelter installations (Fig. 1). The fact that the cadmium contamination level is higher in Sector 6, even though it is further away from the foundry than Sector 5, could be explained by the high sensitivity of the soil to acid precipitation (Shilts 1981).

The absorption of contaminants by plants is often increased with proximity to a foundry because of the increase in the acidity of the soil caused by SO_2 emissions; these emissions increase the solubility of heavy metals and their availability to plants (Hutchinson 1977, Nriagu 1980, Glooschenko 1986, Glooschenko *et al.* 1988,

Table 6. Cadmium concentration in kidneys (μg/g dry weight) of moose calves in 2 sectors of the Abitibi-Témiscamingue region with different contamination levels, measured in 1986 and 1995. [*Concentration de cadmium (µg/g poids sec) dans les reins de faons orignaux en 1986 et 1995 dans deux secteurs de contamination différente, Abitibi-Témiscamingue.*]

	Year / *An*	
	1986	1995
Sector of High contamination (Sector 4)	11.0±3.5 (12)[1]	11.0±4.1 (19)
Secteur de contamination élevée (Sector 4)		
Sector of Low contamination (Sectors 5 and 9)	5.0±2.6 (7)	6.0±0.6 (16)
Secteur de contamination Faible (Secteurs 5 et 9)		

[1]Mean ± Standard error (*n*) [*Moyenne ± Erreur type (n)*]

Steinnes 1989, Outridge *et al.* 1994). Cadmium can accumulate to highly variable levels in the food chain, since several factors are involved in the process. Studies have shown that cadmium concentration levels in the liver and kidneys of cervids may be related to the plant species present in the area occupied, to the natural mineralization of the various habitats, the buffering capacity of soils and their potential to neutralize the effects of acid precipitation, to the sources of emissions, as well as the interaction between these factors and the demography of the animal population (Kovalesky 1984, Glooschenko *et al.* 1988, Kronberg and Glooschenko 1994). Due to several interacting factors, the current and historic contribution of the Horne foundry emissions to the contamination of liver and kidneys of moose in the region cannot be precisely quantified. Nevertheless, it appears from our study that this area can be clearly distinguished from other sectors. The natural mineralization of the soil surface, the generalized mining activity in this zone, and the progressive urbanization in the region are other important factors.

In the moderate contamination area, the cadmium levels are sometimes as high as those close to the foundry. In southern Témiscamingue, in the sector that is contiguous with the Algonquin region of Ontario, cadmium levels in the liver and kidneys of moose are all also high (Glooschenko *et al.* 1988). The important levels recorded in Sectors 1 and 2 could be related to the interplay of moose diet, contamination of the habitat by atmospheric cadmium (Sudbury and Horne foundries), and mobilization of cadmium from the soil by the effect of acid precipitation.

Cadmium concentrations in the 5 species of plants sampled were not higher in Sector 2 than in Sectors 8 and 9, even though the cadmium concentrations in the liver and kidneys of moose were 2 - 3 times higher. However, the number of plants sampled ($n = 36$) was very low considering the size of the region. In Témiscamingue, which corresponds to Sectors 1 and 2, sugar maple is relatively abundant and represents 11% of the commercial wood volume. Although the food habits of moose were not studied in this region, this tree species could constitute an important part of the diet. Furthermore, a large part of this region is strewn with lakes and streams, often of small size, totalling 14% of the entire surface area. Elsewhere this proportion varies from 4 - 10% and lakes may occupy particularly large surface areas. Both aquatic and semi-aquatic vegetation can contain high levels of cadmium (Glooschenko *et al.* 1988).

In Sector 3, the causes of high cadmium levels in the organs of harvested moose are most likely a combination of several factors. This area is strongly mineralized from a large number of mine tailings. The principal commercial forest species are paper birch and trembling aspen. The soils of this sector have a higher buffering capacity than those of Sectors 1 and 2, but the predominance of rocky outcrops can favour greater mobilization of cadmium in the environment.

The cadmium concentration in moose tissues from the other sectors (5, 7, 8, and 9) is quite low. The soils in these sectors have a higher buffering capacity and are less mineralized than elsewhere in the region. The Abitibi clay belt covers a large portion of the area and hardwood species are less abundant. Aquatic vegetation is probably less available and the effects of acid precipitation are possibly the lowest in the region.

The cadmium levels measured in this study are the highest measured in Québec. The average concentration of cadmium in the low contamination part of the region corresponds to the provincial average values (Crête *et al.* 1986). Elsewhere, among previously published data for moose, only the Ontario portion of the Algonquin region presents comparable values to those of the moderate contamination zone that we have described (Glooschenko *et al.* 1988). For all herbivores, only 1 study of deer in Virginia ($n = 4$) living close to a foundry (< 8 km) in Pennsylvania (Sileo and Beyer 1985) revealed cadmium concentrations in the liver close to those of Sector 4 in this study.

Our results on black bears showed important levels of cadmium contamination that were previously unknown for this species. The only published information of this kind originates from polar bears (*Ursus maritimus*) and shows clearly lower values: 2.16 - 73.0 μg/g dry weight in the liver and kidneys of bears from Greenland and Norway (Dietz 1987 *in* Norheim *et al.* 1992, Outridge *et al.* 1994). In the Canadian Arctic, the cadmium content in the liver of polar bears varies from 0.6 - 2.3 μg/g dry weight ($n = 67$) (Norstrom *et al.* 1986). The cause of high cadmium levels in black bears may be attributable to food habits, to which trembling aspen can make an important contribution. The relatively older age attained by black bears in comparison with moose may also explain the difference between the 2 species.

Based on the analysis of the 35 samples of moose kidneys from calves, contamination levels did not change after 1986, even though the sulphuric acid factory began operating in 1989. Cadmium emissions have declined from more than 100 tons per year at the beginning of the 1980's to values varying between 1.5 - 3.0 tons yearly over the last 5 years. This may indicate that the direct contribution of atmospheric fallout emanating from the foundry is not significant on the foliage browsed by moose and that soil condition may have a greater influence on contamination levels in plants. Other studies will be necessary, however, to specify the real contribution of industrial activity to this contamination.

CONCLUSIONS

This study allowed a description of intra-regional variations in cadmium contamination of moose liver and kidneys. Nevertheless, it is not possible to precisely determine the contribution of emissions generated by the Horne foundry because of several factors intervening in the contamination process. In any event, this was not the goal of the study.

Significant differences between the

sexes and age classes of moose were confirmed, and the values found in the immediate vicinity of the foundry remain the highest in the available literature. The concentrations found in black bears were higher than in moose. Public notices were put out yearly to inform the public of the risks of consuming liver and kidney of these species.

The simple and inexpensive protocol that was set up in 1995 should allow us to follow the development of cadmium contamination, at a frequency of about 5 years. For this, the analysis of about 30 samples collected from calves living in 2 different contamination sectors should suffice.

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