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Cadmium in caribou and muskoxen from the Canadian Yukon and Northwest Territories

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Abstract

Cadmium, zinc, copper and metallothionein concentrations were measured in liver and kidney tissue of caribou and muskoxen collected from various sites in the Canadian Yukon and Northwest Territories. Cadmium concentrations in caribou tissues were substantially higher than in muskoxen for all age classes and were comparable to concentrations reported for caribou from northern Québec and Norway. No geographical site differences in cadmium concentration were observed. Cadmium concentrations were positively correlated with age for both caribou and muskoxen. The highest cadmium concentration observed (166 μg/g dry wt.) was in renal tissue of a 15-year-old caribou. Metal concentrations tended to be higher in spring than in fall for animals of comparable age. Renal cadmium concentrations were highly correlated with metallothionein concentrations, especially for cadmium concentrations exceeding 20 μg/g (dry wt.). It is estimated that the regular weekly consumption of kidney tissue from Arctic caribou of any age, and from muskoxen older than 1 year, will probably cause the WHO provisional weekly tolerable intake of cadmium to be exceeded.

Key words: Cadmium; Caribou; Copper; Metallothionein; Muskoxen; Zinc

1. Introduction

The mining and smelting of cadmium-bearing ores, and the widespread use of cadmium for industrial purposes, such as electroplating and battery and pigment manufacturing, have considerably increased environmental cadmium contamination over the last 50–100 years (Adriano, 1986). Extractable cadmium from soils is absorbed by plants and is subsequently transferred to herbivorous animals, concentrating in liver and kidney tissue of these animals. Several studies have revealed comparatively high concentrations of cadmium in livers and kidneys of a variety of wild ungulate species, and in some cases have prompted health authorities to recommend against their consumption (Brazil and Ferguson, 1989; Crête et al., 1987, 1989; Froslie et al., 1986; Glooschenko et al.,

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1988; Redmond et al., 1988; Scanlon et al., 1986; Stansley et al., 1991; Wotton and McEachern, 1988).

In Arctic terrestrial ecosystems, lichens constitute a large portion of the tundra vegetation, and they readily absorb atmospheric contaminants, including metallic elements such as cadmium (Crête et al., 1992; Nieboer et al., 1972; Puckett and Finegan, 1980). Because lichens are a major food source for barren-ground caribou (*Rangifer tarandus*), these animals may accumulate significant levels of cadmium in target organs (liver and kidney) over their lifetimes. In turn, consumption of these caribou tissues may constitute a health risk for humans (Crête et al., 1989). In the present study we measured cadmium levels in liver and kidney tissue from two species of arctic ungulate, (a) barren-ground caribou, for which long-lived lichens are a major food source during all seasons of the year (Kelsall, 1968) and (b) muskoxen (*Ovibos moschatus*), which prefer annual herbaceous forage (grasses and sedges) and which consume lichens only incidentally, even in winter (Tener, 1965). These two species were chosen in order to explore possible species differences in cadmium accumulation and to provide baseline data on cadmium levels in arctic caribou and muskoxen.

Metallothionein is a low-molecular-weight metal-binding protein whose synthesis in tissues can be induced by metals, principally cadmium, zinc and copper (Bremner, 1987; Dunn et al., 1987). Furthermore, these three metals can interact in the production of metallothionein in vivo. For example, it is likely that the entry of plasma-zinc into liver after cadmium administration acts additively with cadmium to induce hepatic metallothionein in rats (Scheuhammer et al., 1985). Scheuhammer and Templeton (1990) reported that ring doves (*Streptopelia risoria*) responded to

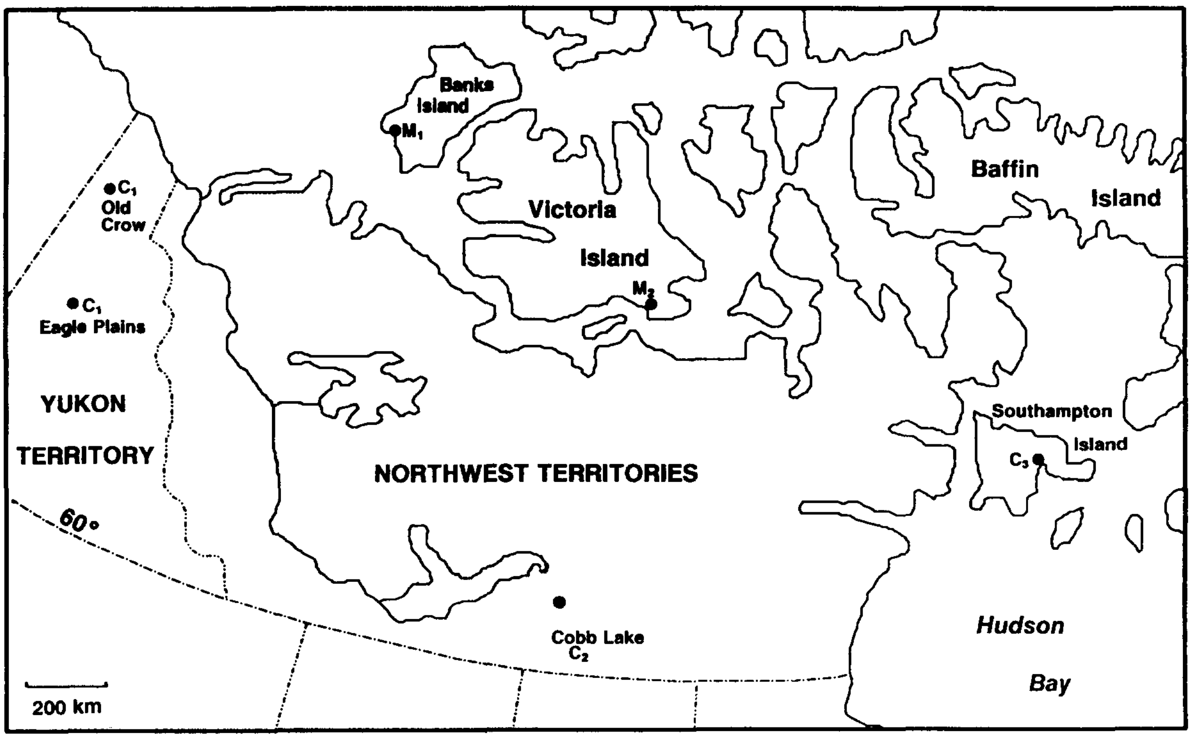

Fig. 1. Locations of sampling sites. C1: Porcupine caribou (two locations); C2: Beverly caribou; C3: Southampton Island caribou (Coral Harbour); M1: Banks Island muskoxen (Sachs Harbour); M2: Victoria Island muskoxen (Cambridge Bay).

Table 1
Caribou sample sizes, herds and collection periods

Year	Beverly		Southampton		Porcupine	
	Kidney	Liver	Kidney	Liver	Kidney	Liver
1986 Spring	—	36	—	—	—	—
1988 Spring	—	—	—	—	—	18
1989 Fall	—	—	—	—	—	15
1990 Spring	—	—	14	—	15	28
1990 Fall	—	—	36	36	32	31

chronic dietary cadmium exposure by changes in hepatic and renal cadmium, zinc and copper concentrations, and that all three of these metals played a role in determining tissue metallothionein concentrations. In the light of these findings, we chose to measure concentrations of zinc, copper and metallothionein in caribou and muskoxen tissues in addition to cadmium, and to determine relationships among the concentrations of metals and metallothionein.

2. Methods

Liver and kidney samples were obtained from caribou and muskoxen collected either in the spring (mid-March to mid-May) or fall (mid-September to early December) between 1985 and 1990. Caribou tissue samples were received from the Beverly, Southampton Island and Porcupine herds, and muskoxen from the Banks Island and Victoria Island herds (Fig. 1). Details of the sample sizes, locations and collection dates are presented in Tables 1 and 2. Usually one or both entire kidneys and approximately 500 g of liver were excised, stored in plastic bags and frozen at −20°C until analysed. Age was determined by tooth cementum analysis for caribou and by tooth eruption and wear for muskoxen (Miller, 1974). Because the tooth section method is more accurate, caribou were probably aged accurately to within 1 year, whereas muskoxen were probably aged accurately up to 4 years. Muskoxen older than 4 years were classified as adults. For convenience, individuals of either species less than 5 years old are referred to as juveniles.

For metals analysis, approximately 0.5 g wet tissue was freeze-dried. Moisture content was determined by recording both wet and dry weights for each sample. Samples were digested in high purity HNO_3 at 100°C for 3–4 h. For kidney tissue we used kidney cortex, because whole kidneys were sometimes not available and cadmium concentrations are known to differ between the renal cortex and medulla (Gunn and Gould, 1957). Cadmium, copper and zinc were measured in tissue digests by flame atomic absorption spectrophotometry using a Perkin-Elmer Model 3030b spectrophotometer. Detection limits were 0.10 μg/ml for copper and zinc and 0.05 μg/ml for cadmium.

Concentrations in sample digests were well above detection limits for copper or zinc but fell below the limit for cadmium in some cases. Where sufficient sample remained in such cases, an atom concentrator tube (Varian ACT-80) was used to improve analytical sensitivity (cadmium detection limit = 0.002 μg/g). For quality assurance, National Bureau of Standards (NBS) bovine liver and International Atomic Energy Agency (IAEA) horse kidney reference materials were digested and anal-

Table 2
Muskoxen sample sizes, locations and collection periods

Year	Banks Island		Victoria Island	
	Kidney	Liver	Kidney	Liver
1985 Spring	8	8	—	—
1989 Fall	6	6	—	—
1990 Spring	34	36	10	14

ysed with each group of samples. Recoveries of cadmium, zinc and copper averaged 100% (range: 88–115%). Metallothionein was measured in wet tissue using the silver-saturation technique (Scheuhammer and Cherian, 1986, 1991).

Data were analysed statistically using the SAS (1988) statistical programs. The SAS General Linear Model (GLM) procedure was used to perform regressions, and the residuals of each analysis were tested for normality using the D'Agostino-Pearson K2 statistic (D'Agostino et al., 1990). Where necessary, variables were log-transformed to ensure normality, and in some cases weighted regressions were used for the same reason. Correlations were performed using Spearman's rank correlation coefficient, because many of the variables were not normally distributed. Where possible, the entire data set was used to perform statistical analyses. However, the opportunistic nature of the sample collections sometimes resulted in unbalanced data groups. In such cases it was necessary either to use sub-sets of the data for certain analyses (as described in the following section) or to forego statistical analysis.

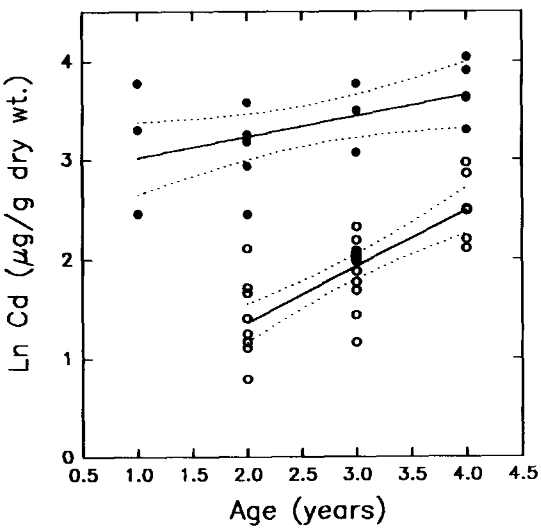

Fig. 2. Relationship between age and cadmium concentrations in kidney cortex of juvenile caribou (●; $r = 0.528$) and muskoxen (O; $r = 0.787$) collected in the spring of 1990. Best fit linear regression lines with 95% confidence intervals are plotted.

3. Results

3.1. General

For both caribou and muskoxen, cadmium levels in kidneys were consistently higher than in livers of the same animals. When tissue cadmium concentrations were compared between juvenile caribou and muskoxen collected in the spring of 1990, levels in both liver and kidney were found to be significantly higher in caribou than in muskoxen. Comparative data for kidney are plotted in Fig. 2. Cadmium concentrations also tended to be substantially higher in adult caribou (Table 3) than in adult muskoxen (Table 4). The two highest cadmium concentrations were 166 and 125 µg/g (dry weight), both in kidney cortex from old (15-year-old) caribou (Table 3). Overall mean concentrations of zinc were 84 ± 33 and 108 ± 21 µg/g (dry weight) in caribou livers and kidneys, respectively, and 98 ± 19 and 134 ± 25 µg/g in muskoxen livers and kidneys. For copper, values were 68 ± 72 and 29 ± 20 µg/g for caribou livers and kidneys, and 67 ± 85 and 11 ± 1.8 µg/g for muskoxen livers and kidneys.

3.2. Caribou

Cadmium levels for caribou liver and kidney are presented by age and collection period in Table 3. The effects of herd, sex, age and season of collection (spring or fall) on cadmium levels were tested using 1990 Southampton and Porcupine herd data. Herd and sex effects were not significant ($P > 0.05$). Age was positively related to cadmium levels in both liver and kidney ($P = 0.0001$ in each case), with no interaction between age and collection period. Season of collection also influenced tissue cadmium concentrations, especially in liver ($P < 0.01$). For animals of the same age, higher cadmium concentrations were often observed in spring-collected individuals (Fig. 3). We did not detect any clear temporal trend in cadmium levels in either liver or kidney. Spearman's rank correlation was used to analyse the entire caribou data-set to investigate relationships between metallothionein and cadmium, copper and zinc for each organ. In both liver and kidney, metallothionein was

Table 3
Cadmium levels (μg/g dry weight) in caribou kidney and liver by age and collection season with all years combined.

Age (years)	Kidney		Liver	
	Spring	Fall	Spring	Fall
0.5	—	13.63 ± 5.99 (12)	—	1.56 ± 1.15 (12)
1	27.63 ± 16.06 (3)	20.63 ± 15.91 (13)	5.54 ± 1.28 (4)	1.95 ± 1.35 (13)
2	23.58 ± 8.07 (6)	25.25 ± 6.16 (11)	4.74 ± 3.39 (9)	2.12 ± 0.81 (11)
3	32.84 ± 11.04 (3)	20.86 ± 9.86 (5)	4.88 ± 2.43 (9)	1.38 ± 0.75 (4)
4	42.01 ± 11.61 (5)	28.34 ± 20.96 (5)	5.69 ± 2.87 (12)	3.41 ± 1.54 (8)
5	87.18 ± 22.94 (2)	24.65 ± 11.53 (4)	6.74 ± 4.84 (9)	4.11 ± 1.19 (5)
6	52.29 (1)	47.37 ± 19.77 (5)	5.72 ± 2.50 (9)	5.62 ± 1.91 (6)
7	68.65 ± 30.00 (2)	—	8.97 ± 5.02 (5)	—
8	61.57 (1)	—	4.62 ± 0.04 (2)	—
9	63.30 (1)	95.68 ± 26.69 (3)	7.52 ± 3.30 (8)	6.96 ± 2.29 (3)
10	—	56.03 (1)	7.72 ± 3.89 (5)	5.81 (1)
11	—	75.00 (1)	—	6.20 (1)
12	—	—	9.17 (1)	—
13	—	—	4.67 ± 3.04 (3)	—
15	166.30 (1)	125.20 (1)	—	5.85 (1)

Values are means ± S.D. of (*n*) individuals.

positively correlated with cadmium ($r = 0.48$, $P = 0.0001$, and $r = 0.69$, $P = 0.0001$, respectively) and zinc ($r = 0.46$, $P = 0.0001$, and $r = 0.38$, $P = 0.0002$, respectively), but not with copper ($P > 0.3$ for both organs). In kidney, the organ having the widest range of cadmium concentrations, increasing metallothionein concentrations were observed when cadmium exceeded about 20 μg/g (dry weight), whereas lower cadmium concentrations were not associated with increased metallothionein levels (Fig. 4).

3.3. Muskoxen

Cadmium levels for muskoxen liver and kidney are presented by age and collection period in Table 4. Using Banks Island adult data, a significant effect of collection period was noted for cadmium in liver ($P < 0.05$) and kidney ($P < 0.001$). This effect was in part due to a tendency towards higher tissue cadmium concentrations in spring-collected samples. Using 1990 Banks Island juvenile data, we tested for possible sex differences in cadmium

Table 4
Cadmium levels (μg/g dry weight) in muskoxen liver and kidney by age and collection period.

Age (yr.)	1985 Spring	1989 Fall	1990 Spring
Liver			
1	—	—	0.23 ± 0.12 (4)
2	0.72 (1)	—	0.49 ± 0.09 (10)
3	1.04 (1)	—	0.66 ± 0.20 (18)
4	—	—	1.15 ± 0.33 (6)
A[a]	1.11 ± 0.30 (6)	0.51 ± 0.13 (6)	0.86 ± 0.61 (12)
Kidney			
1	—	—	< 0.1 (3)
2	2.41 (1)	—	4.25 ± 1.73 (10)
3	3.63 (1)	—	6.19 ± 2.40 (17)
4	—	—	13.1 ± 4.50 (6)
A	5.45 ± 2.07 (6)	5.41 ± 2.31 (6)	12.4 ± 11.1 (10)

Values are means ± S.D. of (*n*) individuals.
[a]A = adult (4 years +).

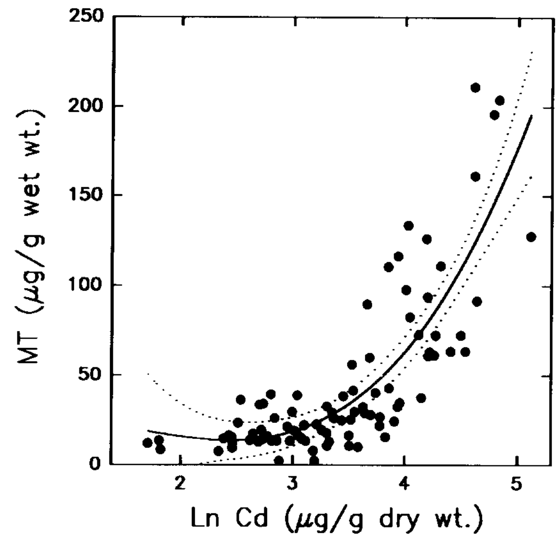

Fig. 4. Relationship between cadmium and metallothionein concentrations in caribou kidneys. The third-order polynomial regression ($r = 0.821$; $P < 0.01$) with 95% confidence intervals is plotted.

accumulation and found none. Insufficient data prevented us from testing for herd differences in cadmium accumulation. We were able to test the effect of age on cadmium concentration using data from 1990 juveniles from the Banks Island and Victoria Island herds. Weighted regressions were used for both organs to normalize the regression residuals (weighting factor = 1/age). Age was positively related to cadmium concentration in muskoxen liver ($r = 0.769$) and kidney ($r = 0.670$).

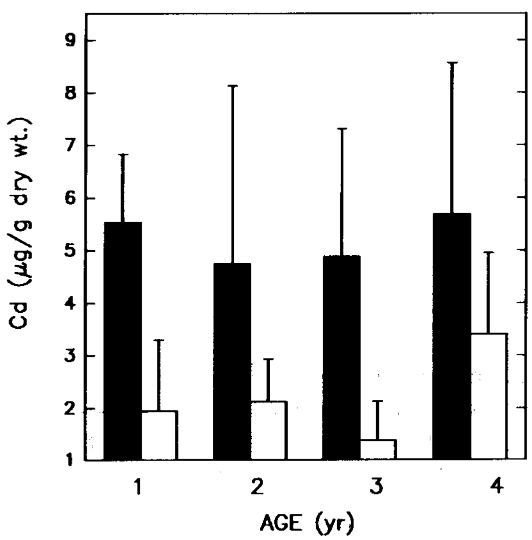

Fig. 3. Liver cadmium concentrations in juvenile caribou, demonstrating the tendency for higher values in samples collected in spring (■) versus fall (□). Refer to Table 3 for sample sizes.

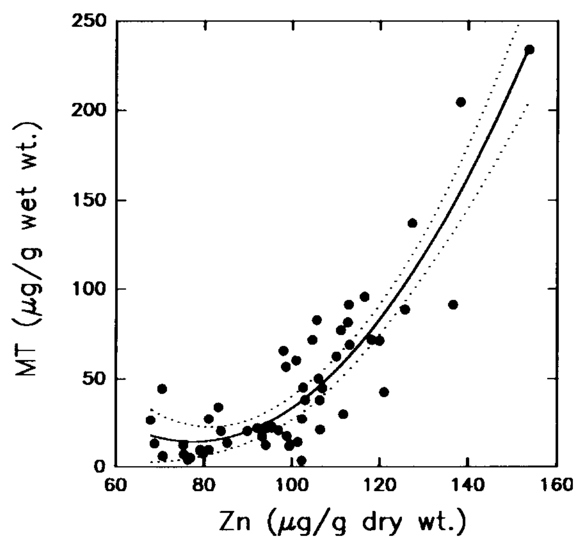

Fig. 5. Relationship between zinc and metallothionein concentrations in livers of muskoxen. The second-order regression ($r = 0.896$) with 95% confidence intervals is plotted.

Spearman's rank correlation was used to analyse the entire muskoxen data-set to determine the relationships between metal (cadmium, copper and zinc) and metallothionein concentrations for each organ. Metallothionein was positively correlated with zinc ($r = 0.78$, $P = 0.0001$) and cadmium ($r = 0.33$, $P = 0.015$), and negatively correlated with copper ($r = -0.44$, $P = 0.0008$) in muskoxen liver. Increasing liver metallothionein concentrations were particularly associated with zinc concentrations ≥ 100 μg/g (dry weight) (Fig. 5). In kidney, metallothionein was positively correlated with cadmium ($r = 0.48$, $P = 0.0002$) and zinc ($r = 0.81$, $P = 0.0001$), but not with copper ($r = -0.07$, $P = 0.61$).

4. Discussion

Cadmium concentrations were generally higher in caribou than in muskoxen. This may be because long-lived lichens, a major food source for caribou in northern Canada (Miller et al., 1988; Parker, 1975; Thomas and Barry, 1991) are particularly susceptible to the accumulation of atmospheric pollutants, whereas it is likely that the current annual growth of sedges preferred by muskoxen (Parker, 1978) would accumulate lower concentrations of contaminants. Although we did not measure cadmium concentrations in lichens or other forage in the present study, it is known that dietary ingestion is generally the major route of contaminant exposure for most wild birds and mammals. We thus expected the consumption of lichens by caribou to result in a greater body burden of cadmium than would be the case for muskoxen of comparable age. Our data are consistent with this expectation.

Not all previous reports of cadmium concentrations in ungulates have included age-class analysis of tissue cadmium concentrations. For those instances where age groupings have been used to report cadmium levels, results can be compared to those of the present study. To compare with other similar studies, we converted our dry weight cadmium concentration data to a wet weight basis using the known moisture content of each individual sample. Table 5 shows that in Norway, caribou tend to have higher cadmium levels than moose (*Alces alces*) from the same areas (Froslie et al., 1986) and that caribou from our study have levels comparable to those in Norwegian caribou. Cadmium levels in caribou from our study were also within the range of those reported for moose and white-tailed deer (*Odocoileus virginianus*) from Ontario (Glooschenko et al., 1988; Table 6). In addition, caribou from northern Québec had comparable or slightly lower concentrations of cadmium than those in our study. In northern Québec (Crête et al., 1989) calves averaged 1.7 μg/g (dry weight), and yearlings 2.0 μg/g in liver, compared with 2.6 and 3.1 μg/g in our study. Cadmium concentrations in kidney tissue also tended to be somewhat higher in our study: 13.6 μg/g in calves and 20.6 μg/g in yearlings collected in the

Table 5
Mean cadmium levels (μg/g wet weight) for (n) moose and caribou from Norway (Froslie et al., 1986) and from the Canadian arctic

Age (yr.)	Liver			Kidney		
	Moose[a] (Norway)	Caribou[a] (Norway)	Caribou[b] (Canada)	Moose[a] (Norway)	Caribou[a] (Norway)	Caribou[b] (Canada)
≤0.5	0.3 (152)	—	0.5 (12)	0.8 (160)	—	2.9 (12)
0.5–1.5	0.5 (161)	0.7 (48)	0.9 (17)	2.0 (154)	2.6 (35)	5.1 (16)
1.5–3.5	0.7 (167)	1.0 (39)	1.1 (33)	3.1 (155)	4.4 (24)	5.4 (25)
3.5–5.5	0.8 (58)	1.2 (43)	1.6 (34)	4.4 (57)	6.5 (29)	8.5 (16)
5.5–8.5	0.7 (30)	1.8 (29)	1.8 (23)	5.3 (31)	12.8 (19)	11.0 (9)
>8.5	0.7 (21)	1.8 (10)	2.2 (23)	6.4 (20)	19.8 (4)	19.0 (8)

[a]Data from Froslie et al., 1986 (whole liver, whole kidney).
[b]Data from this study (whole liver, renal cortex).

Table 6
Mean cadmium levels (μg/g wet weight) for moose and white-tailed deer from Ontario (Glooschenko et al., 1988) and for Arctic caribou

Age (y)	Liver			Kidney		
	Moose[a]	Deer[a]	Caribou[b]	Moose[a]	Deer[a]	Caribou[b]
≤0.5	0.1–1.4 (5)	0.1–0.3 (4)	0.5 (12)	0.6–4.4 (5)	0.8–2.9 (4)	2.9 (12)
0.5–1.5	0.4–3.4 (5)	0.2–1.5 (4)	0.9 (17)	4.4–12.8 (5)	1.4–9.2 (4)	5.1 (16)
1.5–4.5	1.1–4.1 (5)	0.3–1.0 (4)	1.2 (53)	4.4–20.3 (5)	4.4–15.1 (4)	6.1 (35)
≥4.5	1.6–5.7 (5)	0.4–1.9 (4)	1.9 (59)	15.1–51.4 (5)	4.6–34.0 (4)	13.4 (23)

[a]Data from Glooschenko et al., 1988 (whole liver and kidney); values are ranges of means from *n* different sampling locations.
[b]Data from this study (whole liver and renal cortex); values are means of (*n*) individual samples.

fall, compared with 5.6 and 13.5 μg/g in calves and yearlings collected during the same season in Québec (Crête et al., 1989). Because only kidney cortex was used in the present study, our kidney cadmium values may be higher than levels derived from analysis of homogenized whole kidney.

Comparisons using the muskoxen data are difficult, because accurate aging can be done only up to 4 years. However, in all cases cadmium levels in Arctic muskoxen tissues were substantially lower than those reported for Norwegian moose and caribou (Froslie et al., 1986), Ontario moose and white-tailed deer (Glooschenko et al., 1988) and caribou from northern Québec (Crête et al., 1989). Cadmium concentrations in kidney tissue from Victoria Island muskoxen were previously reported to range from undetectable up to 1.92 μg/g wet weight (~8–10 μg/g dry weight), with older animals having the higher cadmium concentrations (Salisbury et al., 1992). The highest levels reported by Salisbury et al. are comparable to data reported here, especially for animals more than 2 years old (Table 4).

The above comparisons indicate that caribou from the Canadian Arctic generally have cadmium burdens equal to or greater than other species of wild North American ungulates studied so far, and have concentrations comparable to those reported for Norwegian caribou. Comparable levels found in our study and in a previous report from northern Québec (Crête et al., 1989) indicate that distance from centres of industrial activity does not necessarily result in low cadmium accumulation by herbivorous wildlife.

Geographical site was a significant factor influencing cadmium levels in Ontario moose (Glooschenko et al., 1988), Norwegian moose, caribou and red deer (*Cervus elaphus*) (Froslie et al. 1986) and moose and white-tailed deer from southern Québec (Crête et al., 1987). Although Scanlon et al. (1986) found site differences in moose in Telemark (Norway), they found no such differences in moose from Maine (United States). No significant site effect on cadmium levels was found for Newfoundland moose (Brazil and Ferguson, 1989), and no differences were found among sites (herds) for caribou in this study. These apparently disparate findings may be due to different patterns of contamination encountered by wildlife in each case. In sites near sources of industrial pollution, cadmium exposure is largely from point source contamination (e.g. smelters). Initial fall-out from smelters is rapid, and wildlife in the vicinity of the source would be expected to accumulate higher tissue cadmium concentrations than those living in more distant habitats. Indeed, the highest cadmium concentrations reported for wild ungulates are from locations near point sources of contamination (Sileo and Beyer, 1985). Such a pattern of contamination would be expected to result in site differences in cadmium concentrations in wildlife tissues. However, in more pristine areas, contamination is primarily from long-range transport within large air masses, a process that results in a more uniform pattern of deposition over wide geographical areas. Under such conditions, in the absence of point sources of contamination, fewer site differences in cadmium accumulation would be expected. In some locations, differences in the buffering capacity and degree of environmental acidification may also contribute to site differences in cadmium accumulation by herbivorous wildlife (Crête et al., 1987; Froslie et al., 1986; Glooschenko et al., 1988).

Collection period significantly affected cadmium levels in both caribou and muskoxen in this study. Where it could be confidently tested statistically, a seasonal effect was apparent, with spring levels higher than fall levels. Crête et al. (1989) also reported that season affected cadmium concentrations in caribou tissues, and suggested that seasonal weight fluctuations in caribou liver and kidney might explain these seasonal differences in cadmium concentration. In the spring (March to May), weights of these organs are low compared with early fall weights (Dauphine, 1975), probably in part because tissue-fat stores are depleted through spring migration and are replenished over the summer. Because very little of a tissue's metal burden is associated with lipid, the absolute amount of cadmium in the organ could remain constant, yet cadmium concentrations would be higher in spring than in fall. Through the summer, liver and kidney weights increase with body weight at a greater rate than tissue cadmium concentrations increase, resulting in lower apparent cadmium concentrations in early fall. This interpretation is strengthened by the observation that liver zinc and copper concentrations also tended to be statistically higher in spring samples ($P < 0.01$, data not shown). The fact that lichens form a proportionately greater part of the caribou diet during winter than during summer (Kelsall, 1968) may also contribute to seasonal differences in tissue cadmium concentrations. These seasonal effects should be considered when samples are collected for cadmium analysis, especially from caribou, a species for which this annual fluctuation in cadmium concentrations has been particularly noted.

Age was positively correlated with cadmium levels in livers and kidneys of both caribou and muskoxen in our study. Similar results have been reported by others for a variety of wild ungulate species (Brazil and Ferguson, 1989; Crête et al., 1989, 1987; Froslie et al., 1986; Glooschenko et al., 1988; Redmond et al., 1988; Scanlon et al., 1986; Woolf et al., 1982; Wotton and McEachern, 1988). Age should be considered when estimating cadmium intake by human consumers and when making intraspecific and interspecific comparisons of tissue cadmium concentrations.

Ours is the first study to report metallothionein concentrations in tissues of wild ungulates. The strong positive relationships between cadmium and metallothionein in caribou and muskoxen tissues are consistent with findings reported for other species of mammals and birds (Elliott et al., 1992; Heilmaier et al., 1987; Kagi and Vallee 1961; Onosaka and Cherian, 1981; Scheuhammer and Templeton, 1990). The cellular production of metallothionein is induced by a number of metals, principally cadmium, zinc, copper and inorganic mercury. It is generally accepted that this unique protein is involved in the normal metabolism of the essential trace metals zinc and copper, as well as protecting cells from the toxic effects of metals such as cadmium by the formation of metal-metallothionein complexes that prevent metal binding to enzymes and other essential biomolecules (Bremner, 1987; Dunn et al., 1987).

The kidney is the main target organ in which chronic cadmium toxicity may become manifest. Significant renal tubular dysfunction occurs when cadmium concentrations exceed 100–200 μg/g wet weight(~400–800 μg/g dry weight) for most mammals and birds so far studied (Elliott et al., 1992; Kjellstrom, 1986). None of the samples that we measured had cadmium concentrations approaching these levels. Assuming that critical concentrations for caribou and muskoxen are similar to those of most other mammals studied, we conclude that there is little risk of cadmium toxicity in these animals. However, a study by Elinder et al. (1981) reported that, in horses chronically exposed

(4–20+ years) to low dietary cadmium concentrations, the incidence of moderate to severe kidney lesions increased markedly at a renal cadmium concentration of about 75 μg/g (wet weight), and the incidence of lesions was significantly correlated with cadmium concentration down to about 25 μg/g. In dogs exposed to cadmium for 4 years, Anwar et al. (1961) reported that renal cadmium concentrations above 30μg/g (wet weight) were associated with morphological alterations in tubular cells. Thus there is some indication that the renal effects of cadmium exposure begin to occur at about 25–30 μg/g (wet weight) in certain mammalian species. Older caribou can occasionally have renal cadmium levels of this magnitude; therefore the possibility of sub-lethal renal toxicity in these animals cannot at present be ruled out.

4.1. Intake by human consumers

One of the earliest indicators of adverse functional changes in the kidney caused by chronic cadmium exposure is low-molecular-weight proteinuria (LMWP) (Bernard and Lauwerys, 1990). LMWP in elderly people has been associated with sustained dietary cadmium intakes of 980–1785 μg/week. Buchet et al. (1990) have reported that about 10% of the general population of Belgium have a body burden of cadmium sufficient to cause slight renal dysfunction, a conclusion that probably applies to other industrialized countries as well. Based on analyses of the toxicokinetics of cadmium in humans and experimental mammals, it has been estimated that a 10% prevalence rate for LMWP in a population would occur after 45 years of regular dietary cadmium intake of 20 μg/kg body weight/week, or 1400 μg/week for a 70 kg individual, whereas a 2% prevalence rate would result from a weekly intake of 10 μg/kg body weight. To minimize the risk for cadmium-induced renal effects, the World Health Organization has recommended that the weekly intake of cadmium not exceed 400–500 μg for an adult, or 7 μg/kg body wt. (WHO 1989; 1972). This 'provisional tolerable weekly intake' (PTWI) assumes an absorption rate for cadmium of 5% and a daily excretion rate of 0.005% of current body burden (WHO, 1989).

To judge whether human consumption of caribou or muskox organ meats represents a potential health hazard, and to estimate the magnitude of the risk, the normal intake of cadmium in the absence of the consumption of these tissues should first be assessed. Estimates of the average dietary intake of cadmium in most western countries range from about 100 to 300 μg/week (Elinder, 1986). A survey by Health Canada indicates that dietary ingestion of cadmium by urban Canadian adults averaged 102 μg/week (Dabeka and McKenzie, 1992), and earlier surveys reported higher intakes. However, the diets of urban residents can be very different from those of people with a subsistence life-style, as is the case for most consumers of caribou and muskoxen organ meats, and for these people data on dietary cadmium intake are unavailable. For the present discussion we will use the estimated average weekly dietary cadmium intake of 210 μg/week (~3 μg/kg/week) suggested by Archibald and Kosatsky (1991) in their study of James Bay Cree consuming a largely subsistence diet. This estimate is the approximate average of estimates from various countries and does not include cadmium intake from consumption of caribou, moose or deer liver or kidney.

In addition to food, the major non-occupational source of cadmium exposure is cigarette smoking. For the general population, smokers are predicted to accumulate approximately twice the lifetime renal cadmium burden of non-smokers (Kjellstrom and Nordberg, 1986). Smoking twenty cigarettes per day contributes about 7–28 μg cadmium to the weekly cadmium intake (WHO, 1989). Because inhaled cadmium is more efficiently absorbed than cadmium consumed in food (20–50% vs. 5%, respectively; Elinder et al., 1983), smoking twenty cigarettes a day adds about 2–14 (or an average of about 8) μg/week to the body burden of cadmium. The consumption of about 160 μg cadmium in food would be required to achieve an equivalent amount of absorbed cadmium, assuming a 5% gastrointestinal absorption rate. Thus, smoking twenty cigarettes per day contributes the equivalent of about 2 μg/kg/week ingested orally, in addition to the normal 3 μg/kg/week from food. Archibald and Kosatsky

(1991) estimated that an average Cree non-smoker normally experiences approximately 46% of the WHO recommended maximum weekly exposure to cadmium, while smoking twenty cigarettes per day increases exposure to, on average, about 86% of the recommended maximum. These estimates represent cadmium exposure exclusive of consumption of liver or kidney tissue from wild ungulates. Unfortunately, for most residents of the Canadian Arctic, reliable information on the consumption patterns of caribou and muskoxen organ meats is at present unavailable.

Table 7 shows estimated cadmium intakes from a single 'meal' (250 g fresh weight or ~60 g dry weight; Crête et al., 1989) of caribou and muskoxen liver or kidney cortex, calculated from the dry-weight cadmium concentrations summarized in Tables 3 and 4. Notwithstanding the small sample sizes on which these estimates are based, it is clear that the regular weekly consumption of a single meal of caribou kidney cortex would result in an adult consumer substantially exceeding the PTWI of cadmium for all caribou age classes regardless of other sources of cadmium exposure. The same result would probably be obtained from an analysis of whole kidney, for which cadmium concentrations are about 80% of those in kidney cortex (Nordberg et al., 1986). In addition, smokers (smoking twenty cigarretes per day) might well exceed the PTWI by consuming a weekly meal of liver from caribou of any age. For non-smokers, the consumption of one meal per week of caribou liver would probably not cause the PTWI to be exceeded if the caribou was less than 4 years of age. Muskoxen liver contains low concentrations of cadmium, and one meal per week would not cause the PTWI to be exceeded for smokers or non-smokers. However, the weekly consumption of a meal of muskoxen kidney from animals 2 years of age might cause the PTWI to be exceeded for both smokers and non-smokers, assuming a normal dietary cadmium intake of at least 3 μg/kg/week exclusive of muskoxen kidney consumption. It should be noted that cadmium does not accumulate to high concentrations in muscle tissue. Although we did not receive muscle tissue for analysis in the present study, Crête et al. (1989) reported that cadmium concentrations in caribou

Table 7
Estimated cadmium intake (μg/kg body weight) by 70 kg adult from consumption of one meal[a] (250 g fresh weight or 60 g dry weight) of caribou or muskoxen liver or kidney cortex for different ungulate age classes

Age (y)	Caribou		Muskoxen	
	Liver	Kidney	Liver	Kidney
0.5	1.3	11.7	—	—
1	2.4	18.8	0.20	—
2	2.8	21.1	0.44	3.5
3	3.3	21.7	0.59	5.2
4	4.1	30.2	0.99	11.2
5	5.0	39.0	0.71[b]	7.4[b]
6	4.9	41.3		
7	7.7	58.8		
8	4.0	52.8		
9	6.3	75.1		
10	6.3	48.0		
12	7.9	64.3		
13	4.0	—		
15	5.0	107.3		

Calculations are based on dry weight cadmium concentrations, summarized in Tables 3 and 4.
[a]The weights of individual caribou kidneys with perirenal fat removed range from about 70 to 170 g for animals ≥2 years old (Allaye-Chan, 1991; Dauphine, 1975). Whole caribou livers weigh about 0.6–2.1 kg (Allaye-Chan 1991).
[b]Adult muskoxen (>4 years old).

Table 8
Overall weighted recommended maximum weekly intakes (RMWI)[a] (g/week) for 60 kg human consuming caribou and muskoxen liver and kidney cortex for different ungulate age classes, all herds combined

	Age (y)[b]	Liver	Kidney cortex
Caribou	0–2	656	132
	3–6	547	69
	7–15	255	32
Muskoxen	0-2	—[c]	—[c]
	3–4	—[c]	531
	> 4	—[c]	295

[a]Calculations are on a wet weight basis independent of other possible sources of cadmium exposure.
[b]Age classes as suggested by the Yukon Porcupine Caribou Management Board.
[c]RMWI >2 kg.

skeletal muscle seldom exceeded 0.1 μg/g (dry weight). Consumption of muscle meat from caribou or muskoxen of any age poses virtually no risk of exceeding the PTWI for cadmium.

Table 8 summarizes recommendations regarding consumption of liver or kidney tissue from caribou or muskoxen, adapted from Health Canada calculations using the data collected in this study. Recommendations are made in the form of 'recommended maximum weekly intakes' (RMWIs), which are the amounts of liver or kidney that can be consumed weekly over a lifetime without exceeding the PTWI for cadmium. It should be noted that these RMWIs were calculated without attempting to account for any other possible sources of cadmium exposure.

5. Conclusions

Cadmium levels in caribou tissues from the Yukon and Northwest Territories of Canada are comparable to those found in Norwegian caribou and in caribou from northern Québec. Cadmium levels in Arctic muskoxen tissues are substantially lower than in caribou, and are also lower than those reported for most other wild North American ungulates that have been examined. Tissue cadmium concentrations are strongly affected by age, higher concentrations being found in older animals, and may also be affected by season, higher concentrations being found in spring. Only the very highest concentrations observed, however, constitute a possible health risk for these animals, based on the known toxicology of cadmium in humans and other mammals. As has been observed for other species, higher concentrations of cadmium in caribou and muskoxen tissues are correlated with higher concentrations of the metal-binding protein metallothionein. For human consumers, assuming a normal dietary cadmium intake of ~3 μg/kg body weight per week in the absence of the consumption of ungulate organ meats, the regular weekly consumption of kidneys from caribou of any age, or from muskoxen older than 1 year, will probably cause the PTWI of the WHO for cadmium to be exceeded. Regular weekly consumption of liver from older caribou may also result in cadmium ingestion exceeding the PTWI, especially for smokers. Consumption of muskoxen liver, caribou liver from young animals (<4 years) or muscle tissue from either species should not be of concern to human consumers with respect to cadmium intake.

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