CADMIUM IN MANITOBA'S WILDLIFE

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ABSTRACT: We analyzed livers and kidneys of 228 moose, 105 white-tailed deer, 161 elk, 12 caribou, 94 black bear, 31 wolves, and 75 coyotes from Manitoba for cadmium (Cd) levels. Bears had the highest mean concentration (18.89 ± 11.48 μg/g dry weight in kidney) followed by white-tailed deer, moose, caribou, elk, wolves, and coyotes (0.31 ± 0.23 μg/g dry weight in kidney). Cd levels in renal and hepatic tissues were highly correlated for all species. Concentrations were significantly higher in kidneys than livers. Except for caribou liver, the concentrations of Cd in livers were positively associated with age of the animals. For black bears, we recorded significantly higher mean concentrations of Cd in females than in males. We found no association between the geographic origin of tissue samples and soil acidity, exposed bedrock, or proximity to anthropogenic sources of Cd. Highly mobile animals, however, likely occupy home ranges that include a variety of habitats, which confounds attempts to identify sources of contamination. Concentration ratios of Cd among trophic levels indicate modest bioaccumulation of the metal for ungulates, high bioaccumlation for black bears, and none for wolves and coyotes. Though the levels of Cd we documented are not life threatening, some animals had concentrations that may be hazardous to humans who consume wild meat. The consumption of liver and kidneys from moose, elk, and deer in Manitoba south of 53° N latitude may lead to a daily intake of Cd exceeding recommended levels. Concern is warranted for the health of First Nation Peoples, particularly those with diabetes who regularly consume organs and meat from wild ungulates.

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Although cadmium (Cd) is a naturally occurring heavy metal normally found in trace quantities in plants and animals, little is known about the potential for human consumers of wildlife to ingest toxic levels (Glooschenko *et al.* 1988), nor of the toxic effect on wildlife. Cd concentration in wildlife increases with duration of exposure. Therefore, older animals are more likely to show higher concentrations (Glooschenko *et al.* 1988). Further, mammals bioaccumulate Cd particularly in their liver and kidneys (Sileo and Beyer 1985).

Leafy vegetables and root crops concentrate Cd to levels directly related to soil concentration (Street *et al.* 1977). Gingas *et al.* (1988) found that poplar (*Populus tremuloides*) accumulated proportionally more Cd in foliage than in roots. Sileo and Beyer (1985) documented the ingestion by herbivores of smelter-dispersed Cd present as a direct particulate deposit on vegetation and as a trace element incorporated into plant tissues. Garrett (1994) found elevated but varying Cd levels in rock and soil in western Manitoba, eastern Saskatchewan, and North Dakota. Concentrations of Cd corresponded to Cretaceous shales including the Riding Mountain, Vermilion River, Favel, Ashville, and Pierre shales.

Swedish investigators found that concentrations of Cd in wheat samples doubled from 1916 to 1972 and documented high concentrations of Cd in the organs of roe deer (*Capreolus capreolus*) and moose (*Alces alces)* (Frank *et al.* 1981, Mattson *et*

al. 1981, Frank 1986). Swedish health officials, concerned that roe deer and moose may be consuming and concentrating abnormal amounts of Cd via contaminated forage, continue to advise hunters not to eat kidneys and to reduce consumption of liver from adult animals. In North America, several published studies revealed elevated concentrations of Cd in livers and kidneys of moose, white-tailed deer (*Odocoileus virginianus*), elk (*Cervus elaphus*), caribou (*Rangifer tarandus*), and muskoxen (*Ovibos moschatus*) (Froslie *et al.* 1986; Crête *et al.* 1986, 1987; Isaza and Cavalier 1987, 1988; Glooschenko *et al.* 1988; Brazil and Ferguson 1989; Gamberg and Scheuhammer 1994).

A preliminary study of Cd concentrations in Manitoba moose (McEachern 1986, Wotton and McEachern 1988) showed that Cd levels in kidneys were lower than reported from Ontario, though apparently accumulating to undesirable levels in older animals (Glooschenko *et al.* 1988). Small sample sizes and limited geographic representation precluded statistical analyses. Herein, we expand the original study by increasing the number of tissue samples assayed throughout the Province of Manitoba and include 6 additional large mammals that previously had not been assessed for Cd burden.

The objectives of this paper are to: (1) assay and compare the levels of Cd in moose, elk, white-tailed deer, caribou, wolf (*Canis lupus)*, coyote (*C. latrans*), and black bear (*Ursus americanus*) from different geographic regions of Manitoba; (2) examine the relationship between animal age and Cd accumulation; (3) determine the relationship of soil on the levels of Cd; (4) assess the potential for bioaccumulation of Cd in the environment; and (5) evaluate potential health effects for humans who ingest wild meat, particularly subsistence (First Nation) hunters. We hypothesized that greater concentrations of Cd would occur in older animals, animals in areas where soils are highly sensitive to acidic precipitation, animals where large quantities of bedrock are exposed, animals living close to or in the pathway of Cd pollution, and animals at higher trophic levels (Glooschenko *et al.* 1988).

METHODS

Sample Collection

This study was conducted in Manitoba between 1987 and 1989. Tissue samples of liver and kidney were obtained from moose, elk, white-tailed deer, caribou, black bear, wolf, and coyote during spring, fall, and winter. Hunters, trappers, and staff from Manitoba Natural Resources submitted samples identified by species, age, sex, and location. Most samples were collected south of 53° North latitude. Hunters with licenses to hunt in quota areas (licenses obtained via a draw) were contacted by mail and asked to submit organ tissues and skulls or jaws. We also advertised for samples in the local media. We usually obtained one entire kidney and ~250 g of liver. Only those samples that included both liver and kidney tissues were retained. Tissue samples were placed in plastic bags, labelled, and stored at -20° C.

Adult moose, elk, white-tailed deer, and black bear were aged using tooth *cementum* analysis. Sub-adults of these species were aged using tooth eruption. Wolves and coyotes were aged by closure of the incisor canal, tooth eruption, and wear patterns (Paquet and McKinley, *unpubl. data*). Using a Geographical Information System (IDRISI, Clark University, Worcester, MA), we referenced sample locations to one or more of the following categories: game hunting area (GHA); moose management zone; distance to industrial sources of Cd; large expanses of exposed bedrock (Wotton and Haluschak 1986); and, soils with low,

moderate, and high sensitivity to acidic deposition (Wotton and Haluschak 1986).

Tissue Analysis

Terrestrial Standards and Studies, Manitoba Department of Environment, and Workplace Safety and Health (Winnipeg, MB) analyzed tissues for Cd concentration. Approximately 5 g of wet tissue were freeze-dried. For analysis of kidney tissue, we used the cortex and medulla (Gunn and Gould 1957). Moisture content was determined by recording wet and dry weight for each sample. Dried samples were ashed in a muffle furnace incrementally from 200° to 500° C. If samples contained carbon particles following ashing, a few drops of concentrated HNO^3 were added and the sample re-ashed for approximately 1 h. This procedure was repeated until the ash was completely white. The ash was dissolved in concentrated HCl and 0.5 ml concentrated HNO^3 and diluted to volume. Digested samples were stored in polyethylene containers and analyzed as soon as practicable. Each batch contained samples, a reagent blank, and a duplicate. A reference sample was analyzed with every batch (U.S. National Institute of Standards and Technology). Cd was measured in the tissue samples by flame atomic absorption spectrophotometry using a Perkin-Elmer 2380 spectrophotometer. The analytical sensitivity limit was 0.10 μg/g.

Statistical Analysis

Data were analyzed using SAS Institute's (1985) statistical programs. Data sets were first evaluated for each species by computing all possible subset regression models using potential explanatory (predictor) variables such as age, sex, and geographic location. We also evaluated the variables soil and bedrock, which were classified according to their capability to reduce acidity (Wotton and Haluschak 1986). For species where sample sizes were small and did not conform to a normal frequency distribution, data were bootstrapped (Krebs 1989). If an independent variable was too highly correlated with a linear combination of other independent variables (collinearity), it was dropped from the model. We used Mallow's C (Snedecor and Cochran 1980: 359) and adjusted R^2 (Weisberg 1985) as criteria for evaluating and comparing regression model subsets. For specified subsets, we used multiple regression analyses to identify relationships between Cd concentrations in tissues and associated independent variables. Residuals resulting from multiple regression analyses were examined for conformation to normal distribution using Wilk-Shapiro/Rankit Plots (Weisberg 1985). To examine the contribution of subsets of independent variables we conducted a stepwise analysis of variance (ANOVA). For each species, we used a paired *t*-test to determine whether the mean concentration of Cd was different in liver and kidney samples.

Homogeneity of variance within data subsets was tested using the Bartlett test (Sokal and Rohlf 1995). Subsets that did not meet the assumptions of bivariate normality were treated with non-parametric tests. Analysis of covariance was used to correct for age effects on Cd accumulation. Tests for homogeneity of variance indicated that some subsets were non-normal. Therefore differences among groups were tested using the Kruskal-Wallis test and the significantly different subsets identified using Dunn's test. All tests were considered significant at $\alpha \leq 0.05$.

Concentration ratios, expressing the relative concentration of Cd between 2 compartments of the food chain, were calculated according to the following modified formula:

$$CR_{ab} = C_a/C_b,$$

where, C_a = mean metal concentration in

animal tissue (μg/g dry weight) and C_b = mean metal concentration in the preceding food chain compartment (μg/g dry weight). Data were available on concentrations of Cd in vegetation in and near Riding Mountain National Park (Province of Manitoba, *unpubl. data*), that allowed us to compare accumulation of the metal within species groups occupying different trophic levels. Ratios were calculated using an average vegetation value (0.485 μg Cd/gm) for Cd found in aspen, birch, willow, dogwood, fireweed, and pond plants.

RESULTS

We collected 706 samples comprising 228 moose, 105 deer, 161 elk, 12 caribou, 94 bear, 31 wolves, and 75 coyotes. The 7 wildlife species represented 3 trophic levels, 3 orders of magnitude in body size (8-500 kg), and a variety of feeding habits. The highest concentrations of Cd occurred in black bears followed by white-tailed deer, moose, and elk (Table 1). For all species, Cd concentration in liver and kidney did not vary significantly in relation to year of collection, geographic location, or buffering capacity of soil and bedrock. Cd burdens in renal and hepatic tissue were correlated for all species (Table 2). Kidneys contained significantly higher concentrations of Cd than livers. With the exception of caribou liver, the concentration of Cd in livers and kidneys was positively associated with age (Table 3). Age explained a greater proportion of variance in Cd concentration in kidney than liver. For black bears, a significant sex-dependency was evident with females accumulating higher mean concentrations of Cd. Other species showed no difference in concentrations between sexes.

Cd accumulation among trophic levels varied by species (Table 4). Accordingly, mean concentrations of Cd increased from vegetation to ungulates (CR_{ab} = 14.00 in kidneys) but decreased in wolves and coyotes (CR_{ab} = 0.78 in kidneys). Black bears, which regularly consume vegetation and meat accumulated the highest concentration of Cd (CR_{ab} = 38.55 in kidneys).

DISCUSSION

The highest concentrations in vegetation were found near the Hudson Bay Mining and Smelting Company Ltd. at Flin Flon MB, where the concentrations in soil were also high (D. Jones, MB Dep. Environ., 1987, *unpubl. data*). Cd levels reached 22.4 μg/g in willow. The concentrations found in plant tissue were well within ex-

Table 1. Mean[1] concentrations of Cd (mg/g dry wt) in the kidney cortex and liver of selected mammals collected in Manitoba, 1986-1989.

		Kidney			Liver		
Species	*n*	Mean	SD	Range	Mean	SD	Range
Moose	228	6.84	5.96	0.18-38.00	1.19	0.88	0.01-4.70
White-tailed deer	105	7.25	6.50	0.10-23.69	0.56	0.47	0.10-1.80
Elk	161	6.48	4.75	0.20-39.20	0.39	0.32	0.10-3.10
Caribou	12	5.03	1.84	2.10-8.00	1.31	0.51	0.50-2.20
Black bear	94	18.89	11.48	0.30-26.00	2.92	2.26	0.10-8.20
Wolf	31	0.45	0.61	0.10-2.70	2.18	0.24	0.10-1.00
Coyote	75	0.31	0.23	0.10-1.40	0.23	0.14	0.10-0.70

[1]Sample means have not been adjusted for age

Table 2. Relationship of Cd accumulation in livers and kidneys of large mammals sampled in Manitoba, 1986-1989.

Species	*n*	Spearman's Coefficient (R)	[1]Adjusted R^2
Moose	228	0.78	0.61
White-tailed deer	105	0.58	0.34
Elk	161	0.46	0.22
Caribou	12	0.52	0.27
Black bear	94	0.71	0.50
Wolf	31	0.88	0.77
Coyote	75	0.51	0.26

[1]All values statistically significant at $P \leq 0.05$

Table 3. Relationship between age (yrs) and Cd concentration in livers and kidneys sampled in Manitoba, 1986-1989.

Species	*n*	Adjusted R^2 (liver)	*P*-value	Adjusted R^2 (kidney)	*P*-value
Moose	228	0.53	0.0000	0.71	0.0000
White-tailed deer	105	0.51	0.0000	0.47	0.0000
Elk	161	0.22	0.0068	0.69	0.0000
Caribou	12	0.20	0.5344	0.67	0.0456
Black bear (F)	29	0.66	0.0000	0.62	0.0000
Black bear (M)	63	0.40	0.0039	0.69	0.0000
Wolf	31	0.42	0.0269	0.51	0.0059
Coyote	75	0.30	0.0039	0.35	0.0009

pected ranges for plants growing on soils with elevated levels of Cd. Levels found in other vegetation samples from elsewhere in Manitoba were within the expected normal range. We believe that some browse species could be a source of Cd for moose and other ungulates. In places such as near the smelter in Flin Flon, the numbers of moose are almost non-existent.

Cadmium and the Pathology of Moose Incisors

Anomalous wear of moose incisors in western Manitoba was noted in the late 1970's (V. Crichton, *unpubl. data*) and subsequently described by Young and Marty (1986). This phenomenon continues today. Laboratory studies using rats and sheep confirm that Cd affects the hardness of tooth enamel resulting in atypical and accelerated wear patterns (W. G. Young, Univ. Queensland, *pers. comm.*). Excessive wear is observed in moose at an early age and the efficiency of the cutting edge of incisors is significantly reduced. In older animals, the cutting edge differs substantially from normal tooth wear. Madden (1974) and Garrett (1994) documented high levels of Cd in

Table 4. Concentration ratios (CR_{ab}) of Cd based on mean concentrations assayed in tissue samples collected in or near Riding Mountain National Park, Manitoba, 1986-1989. Ratios are based on an average vegetation value of 0.49 μg Cd/g dry wt.

Trophic level	Kidney (μg Cd/g dry wt)	Liver (μg Cd/g dry wt)	Concentration ratio (CR_{ab})	
			Kidney	Liver
Vegetation				
Herbivore (moose, elk, deer)	6.86	0.71	14.00	1.45
Omnivore (black bear)	18.89	2.92	38.55	5.96
Carnivore (wolf, coyote)	0.38	1.21	0.78	2.47

various shales in the Riding Mountain region of western Manitoba where this described pathology is most prominent in moose. Cd may be the cause of this anomaly. Teeth from elk and deer in the same area show no evidence of similar pathologies, which may reflect dietary differences and therefore a difference in the bioaccumulation of Cd from different plant species.

Human Health Risk Assessment

Cadmium (Cd), lead (Pb), mercury (Hg) (as methyl mercury), nickel (Ni) (as nickel carbonyl), and beryllium (Be) represent known human health hazards. Of the 5 heavy metals, Cd represents the most serious threat from contaminated food (Schroeder 1965, 1971, 1973; Nilsson 1970; McCaul 1971; Oak Ridge National Laboratory 1973; Fleischer *et al.* 1974; Friberg *et al.* 1974). In the United States, the estimated daily intake of Cd is between 0.02 and 0.1 ppm with major sources being grains and cereals, potatoes, dairy products, leafy crops, and cigarettes (USFDA 1979). Reduction of life span may occur with continuous exposure to 0.01 ppm (Oak Ridge National Laboratory 1973) and kidney damage may occur with a 50-year exposure to 0.08 ppm. Trace levels of Cd have also been linked to hypertension (Schroeder *et al.* 1963, Kanisawa and Schroeder 1969, Schroeder 1973).

Isaza and Cavalier (1988) assessed whether levels of Cd in organs collected from deer and moose in New Hampshire posed unacceptable risks to human health if ingested. They used 2 criteria. The first was the provisional daily intake for Cd of 57-71 μg/day established by the Food and Agriculture Organization/World Health Organization (FAO/WHO). The second was a 35 μg/day intake for 50 years developed by the New Hampshire Division of Public Health Services (DPHS). Based on U.S. EPA (1980) and U.S. FDA (1979) estimates, the daily intake of Cd from a normal diet (35-75 μg/day) may already exceed these criteria. Because about 95% of the daily intake of Cd comes from other food groups, the additional contribution of moose, deer, elk, or caribou liver and/or kidneys could lead to daily consumption greatly exceeding acceptable levels. A 168-g serving of liver with a Cd content of 0.56 μg/g would contribute 95 μg of Cd to an individual's total daily intake. This amount is in excess of DPHS's acceptable level of 35 μg/day (an excess of 280%) and the FAO/WHO criterion of 57-71 μg/day (130-170%) (World Health Organization 1989). Concern that

humans were being affected by consumption of large amounts of Cd prompted health advisories to Manitoba hunters.

Approximately 1,100 moose, 31,000 deer, 786 elk, and 458 caribou were taken by licensed Manitoba hunters in 1997. The number taken by subsistence hunters is unknown but probably equals or exceeds that taken by recreational hunters. An estimated two-thirds of licensed hunters in Manitoba consume the liver of the animal they take. Fewer kidneys are consumed (V. Crichton, *pers. comm.*). The use of these organs by subsistence hunters is probably higher than for recreational hunters (V. Crichton, *pers. comm.*). Concerns about the adverse health effect of Cd on First Nation Peoples have been raised since elevated Cd levels in some traditional food items have been reported (Archibald and Kosatsky 1991, Barrie *et al.* 1992, Gamberg and Scheuhammer 1994, Kim *et al.* 1998).

First Nation Peoples living in rural areas of Manitoba may be at a higher risk of Cd contamination because of their reliance on wild game and a high incidence of diabetes. The latter is disproportionately prevalent in aboriginal adults compared with other segments of Manitoba's population (Manitoba Health 1998). Notably, Buchet *et al.* (1990) suggest that toxic effects of Cd may occur at lower levels in diabetics. They also caution that individuals with diabetes are at a higher risk of developing kidney dysfunction from Cd exposure than those without diabetes. A comprehensive investigation of Cd levels in big game animals consumed by First Nation Peoples should be undertaken to ascertain if health concerns are warranted.

Wildlife Assessment

Chemical contamination of wildlife may be influenced by factors such as proximity to industrial pollutants, plant species consumed, forage availability, and enrichment from natural sources of heavy metal in surficial soils (Kovalesky 1984). High concentrations of Cd in moose and deer are often attributed to direct deposition of the metal from industrial pollution or secondary leaching of the metal as a consequence of acid rain falling on exposed bedrock. The free Cd is made available to plants, which increase their uptake of the metal above trace amounts normally accumulated from background levels. Herbivores consume plants and absorb a portion of the ingested Cd, which is subsequently concentrated in the kidneys and liver.

In our study, Cd levels in tissue samples of moose, elk, and white-tailed deer from environments where soils are low to moderately sensitive to acidic inputs (i.e., soils high in clay and organic matter) did not differ significantly from samples associated with acid sensitive soils or broad expanses of bedrock. The coarseness of soil and bedrock mapping (scale 1:1,000,000) used in our analyses, combined with the wide ranging nature of the study animals, may have confounded our ability to detect effects of soil on Cd accumulation. Moreover, the sample distribution for elk and white-tailed deer was limited by the species geographic range, which does not overlap all soil and bedrock types.

The strong linear correlation between Cd concentrations in moose livers and kidneys in our study is consistent with Crête *et al.* (1987). The positive relationship between age and Cd accumulation shown for all study species is also consistent with other investigations (Crête *et al.* 1987, Lamothe 1991). Levels of Cd were lower in deer and elk livers than in moose livers, whereas the mean kidney level was higher in deer than in moose or elk. Some of these differences may be explained by diet, but the reason or reasons for the higher kidney level in deer are unknown. Certain plants accumulate more Cd than others (Gingas *et*

al. 1988) and, as a consequence of a varied diet, this may be reflected in the levels measured in different ungulate species. If this is the case, knowledge of dietary differences will help isolate plant species or stages of plant development that accumulate Cd.

The high concentrations of Cd in black bears are intriguing. Most samples were collected from animals killed in the spring following emergence from hibernation. Thus, Cd levels may reflect dietary intake and unique physiological adaptations of the kidney and liver related to hibernation. Physiological processes might also account for the higher level of Cd observed in female black bears compared to males. Studying humans, Buchet *et al.* (1990) found higher Cd body burdens in female than in male non-smokers. He suggested this might be due to higher gastrointestinal uptake of Cd in women, since the absorption of oral Cd rises with decreasing iron stores.

Based on our analyses, Cd is not accumulating in summit predators. Wolves and coyotes living in our study area primarily depend on ungulates for sustenance (Meleshko 1986). Diets of both species are supplemented by small rodents and lagomorphs. These smaller mammals constitute about 1-3 % of total biomass consumed. Wolves typically kill and eviscerate ungulate prey before consuming other body parts, whereas coyotes scavenge wolf kills (Paquet 1992). Consequently, coyotes rarely have access to the soft organs (kidney, liver) of adult ungulates.

Social behavior may partially explain why the levels found in wolves are lower than expected. Dominant animals are usually the first to feed at a kill. Most often, soft organs are consumed before lower ranking animals have the opportunity to feed. Thus, the social status of animals included in our sample may have affected the results. Moreover, the wolves we examined were all young animals. Thus, the accumulation of Cd would have been limited by age and social status. Older wolves may have higher levels than the ones sampled in this study.

Cd has been identified as a metal toxic to wildlife with high potential for biomagnification (Wren 1983). Therefore, the abnormally high concentrations of Cd observed in individual moose, elk, white-tailed deer, and black bear are of concern. Chronic Cd ingestion causes bone deterioration in small mammals (Hamilton and Smith 1978). According to Eisler (1985) Cd residues exceeding 10.0 mg/kg (ppm) wet weight in the kidney or liver should be viewed as evidence of probable Cd contamination and levels of 13.0-15.0 ppm may represent a significant hazard to animals such as moose and deer. He also suggested that levels of 20 ppm or more in the liver should be considered life threatening. Although sublethal effects may occur in those animals with the highest concentrations, there are no data suggesting that the populations of those species we examined are being adversely affected by Cd. The highest Cd concentrations found are below the 50-160 ppm Cd in liver and 100-250 ppm Cd in kidney reported to adversely affect cattle (Puls 1988).

CONCLUSIONS AND RECOMMENDATIONS

Few data on the levels of Cd in various wildlife species are available. Prior to this study, no data were available on the occurrence of Cd in Manitoba's wildlife. Exposure of deer, elk, moose, and caribou to Cd is primarily via ingestion of vegetation, soil, and/or water. The most likely source of Cd for predators such as wolves and coyotes is through consumption of prey. Based on our interpretation of the data, we make the following conclusions and recommendations;

1. Cd contamination is occurring in some mammals in Manitoba. The high concentrations in the species assayed to

date suggest the possibility of a significant health risk to humans. Accordingly, we suggest assaying additional tissue samples (including skeletal muscle) of wild species consumed by humans from all regions of the province. In conjunction with this study, additional analyses should show if animals from specific areas have a high probability of contamination. Further, it would confirm if new health warnings should be issued to those eating wild game.

2. The high levels of Cd in bears warrants a closer look to ascertain what pathologies of kidney and liver may be occurring and if these concentrations are localized geographically.
3. Cd concentrations in ungulates are highest in the western part of Manitoba, particularly in the Riding Mountain area. The consumption of liver and/or kidney from moose, elk, and deer in Manitoba south of 53^0 N latitude and west of Lakes Manitoba and Winnipegosis as well as caribou in the north may lead to a daily intake of Cd exceeding recommended levels. Because Cd intake in normal diets may already be at or exceed acceptable levels, consumption of liver and kidney from these species should be minimized.
4. Those wishing to eat kidney and liver should do so only from young animals. Meals should be infrequent (no more than 1 per week) and in small quantities.
5 An effort should be made to ascertain the amount of Cd in the diet of First Nation Peoples who consume wild ungulates. In the interim, Manitoba Health and Health Canada authorities should provide First Nation Communities advice regarding consumption of liver and kidneys from ungulates.
6. Moose are a potential bioindicator of Cd levels in the environment. Consideration should be given to using moose to monitor Cd levels over time.

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