Contaminants in Arctic Moose and Caribou - 2006
Technical Report

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Executive Summary

Moose and caribou provide an important food resource for Northerners across the Arctic, and have been designated in the NCP blueprint as key species for monitoring contaminants in the terrestrial Arctic ecosystem.

Tissue samples were collected from the Bluenose, Dolphin and Union, Porcupine and Qamanirjuaq caribou herds and from the Deh Cho moose in 2006/7. Samples were also collected from the Bathurst caribou as an adjunct to the program. The moose results have not been interpreted pending receiving the sample collection information. Results from the analysis of the Bathurst and Bluenose caribou herds have been received and analyzed and are currently being interpreted in conjunction with NWT biologists. Results from the Porcupine, Qamanirjuaq and Dolphin and Union herds are presented in this report.

Female Porcupine caribou had higher levels of arsenic, cadmium, lead, mercury and selenium than males. One possible reason for t his is the smaller body size of the females, and the energetic cost of parturition and lactation. This means that they must eat proportionally more than males (in relation to their body size), thus ingesting proportionally more of these toxic elements along with required nutrients.

Concentrations of renal cadmium, lead, mercury, selenium and zinc were higher in spring-collected animals than those taken in the fall, while the opposite was true for copper. This is likely because the winter diet of barren-ground caribou consists mostly of lichens, which are efficient at absorbing elements from the atmosphere. In the summer, the diet switches to more grasses and sedges, which generally have lower concentrations of these elements.

Renal cadmium, mercury and zinc concentrations increased with age in most caribou. The relationship between cadmium concentration and age is well-known and has been documented in the literature for both moose and caribou. Both male and female caribou have similar cadmium concentrations when they are young, but females accumulate cadmium at a greater rate, likely related to their higher requirement for food relative to body weight. The same is true for mercury, although mercury actually decreases with age in male Porcupine caribou. This may be due to females ingesting more mercury than males during their time on the north coast during the calving season while the males range farther south. Research on this is ongoing.

Renal cadmium, copper and zinc were stable over time in all herds, while arsenic and lead declined over time in the Porcupine caribou and possibly in the Qamanirjuaq herd. This is likely reflective of the declining atmospheric emissions of both arsenic and lead in North America and Europe. Renal mercury and selenium increased over time in both male and female Porcupine caribou. This may be due to changing anthropogenic input of mercury to the environment and/or the warming climate changing the dynamics of mercury in the arctic environment.

Those elements that are required in trace amounts for the normal functioning of the animal (copper, selenium and zinc) were found in adequate concentrations in all three caribou herds and there is no evidence that they reached toxic levels in any of the animals measured. The toxic elements (arsenic, cadmium, lead and mercury) were found in measurable amounts, but never higher than is considered ‘normal to high’ for domestic cattle. None of these elements currently approach levels that would be expected to cause toxic effects in the caribou.

Overall, the Dolphin and Union, Porcupine and Qamanirjuaq caribou herds have low levels of contaminants and there is no immediate cause for concern. However, renal mercury concentrations are increasing over time in at least one herd, and given the global concern about potentially increasing levels of mercury in the arctic environment, and declining caribou populations, it is considered essential to monitor this important northern species on an ongoing basis so that we are aware of changes in contaminant burdens as they occur.

Introduction

Moose and caribou provide an important food resource for Northerners across the Arctic, and have been designated in the NCP blueprint as key species for monitoring contaminants in the terrestrial Arctic ecosystem. Two barren-ground caribou herds, one from the eastern and one from the western Arctic, have been designated for annual sampling, and five additional caribou herds and two moose populations have been designated for sampling every five years.

An effective annual hunter collection program of caribou and moose tissues has been carried out in the Yukon since 1993 through the Yukon Contaminants Committee (YCC) Hunter Survey Program. Data gathered through this program has been assessed by Health Canada, and the resulting Health Advisory has been communicated to the Yukon public. Ongoing communication from this long-term project maintains dietary confidence in traditional foods for aboriginal and non-aboriginal hunters. The program has also produced a valuable temporal database that allows a more in-depth understanding of annual variation of contaminant levels in the terrestrial environment and an archival tissue sample set that will enable us to generate trends for any relevant "emerging" contaminants as they are identified.

It is important to continue this monitoring, not only from a human health perspective, but also to extend our temporal data set to understand more fully the temporal trends and cycles in this ecosystem. Almost all caribou herds in the NWT and Nunavut have been sampled in the past, but temporal trend information is limited or non-existent and none of the herds have been sampled annually. Few moose populations in the Canadian Arctic have been sampled outside the Yukon. Expanding the program to encompass NWT and Nunavut is important to understand geographical variation in contaminant trends in the Canadian Arctic, and to provide northerners in diverse communities locally relevant information.

Methods

Tissue samples were collected from the Bluenose, Dolphin and Union, Porcupine and Qamanirjuaq caribou herds and from the Deh Cho moose in 2006/7. Samples were also collected from the Bathurst caribou as an adjunct to the program. Details of collections are shown in Table 1. Sampling information was also collected for each animal, including gender, date and location of collection.

The Bathurst caribou were sampled in 2005 and 2006 by local hunters under the supervision of NWT biologist Bruno Croft. Although this herd is not part of the NCP program, the samples were included in the process of the program to ensure comparability of data among caribou herds. All analyses were funded by the Government of Northwest Territories. Only kidneys were collected from these caribou, so ages are unavailable. This herd was sampled again in the fall of 2007 and spring of 2008. These samples are currently being analyzed.

Samples from the Bluenose caribou herd were taken as part of the Sahtu Wildlife Health Monitoring Project. *'Monitoring Wildlife Populations and Health in the Sahtu:*

Developing Community Expertise' under the supervision of Dr. Susan Kutz. Samples from only 15 caribou were available from the 2006 sampling year, so 5 archived samples from 2005 were added to the analysis.

The Dolphin and Union caribou herd was sampled by local hunters under the supervision of Nunavut biologist Mathieu Dumond and with the help of the local conservation officer. Hunters were paid $50/sample set, and complete sample sets were received from 21 caribou.

The Porcupine caribou were sampled by local hunters as part of the ongoing Yukon Hunter Survey Program. Samples from 15 caribou were collected. Each hunter submitting samples was sent a letter with the background and results of the program, and the age of their animal. As an incentive, all hunters submitting samples had their name put in a draw to win a charter flight with a local airline. Twenty archived kidneys from 2004 were also analyzed. This herd was resampled in the fall of 2007 (and will be sampled annually) and those samples are currently being analyzed.

Samples from the Qamanirjuaq caribou herd were taken by one local hunter, Frank Nutarasungnik, under the supervision of Nunavut biologist Mitch Campbell. The hunter was paid $50/sample set, and complete sample sets were received from 21 caribou. This herd was resampled in the fall of 2007 (and will be sampled annually) and those samples are currently being analyzed.

Table 1. Number of samples collected from moose and caribou 2004-6.

Caribou	**Year of Collection**	**Kidney**	**Liver**	**Muscle**	**Tooth**
Bathurst+	2005*	23	0	0	0
	2006	25	0	0	0
Bluenose	2005*	5	0	0	5
	2006	15	14	15	15
Dolphin and Union	2006	21	21	14	21
Porcupine	2004*	20	20	20	20
	2006	15	12	12	11
Qamanirjuaq	2006	21	21	20	20
Moose					
Deh Cho	2004-6	57	26	0	0
Total		**179**	**114**	**81**	**92**

*Archived samples

+Adjunct to the program

Samples from the Deh Cho moose were sampled by local hunters under the supervision of NWT biologist Nic Larter. Some archived samples from 2004 and 2005 were included in these analyses.

All samples were prepared for analysis in Whitehorse, YT by the program coordinator. All kidneys and moose liver were analyzed for a suite of 31 elements at the National Laboratory for Environmental Testing (Environment Canada) using the inductively coupled plasma technique with mass spectroscopy, and for total mercury using cold vapour atomic absorption spectroscopy, under the supervision of Dr. Derek Muir. Remaining liver and muscle samples were archived at $-50^{o}C$ at the INAC facility in Whitehorse, YT. Caribou teeth were aged by a YTG technician in Whitehorse using the tooth cementum technique. Moose teeth were analyzed using the same technique by Matson's Laboratory, Montana.

Statistical Analysis
Where possible, the effect of gender, age, season of collection and year of collection on element concentration was assessed. When the data were normal, a general linear model was used to determine significant effects. When the data were not normal, an attempt was made to normalize them using log (or natural log) transformations. When this was not successful, non-parametric statistical tests were used. A Spearman's Rank Correlation was used for continuous variables (age and year of collection), and a Mann-Whitney Rank Sum test was used for categorical variables (season of collection and gender). The level of significance was taken at α=0.95 (p=0.05).

Results
Laboratory analysis has been completed for all the samples collected in 2006/7. The moose results have not been interpreted pending receiving the sample collection information. Once the sample collection information has been received, the data will be fully analyzed, interpreted and compared with existing data from Yukon moose.

Results from the analysis of the Bathurst and Bluenose caribou herds have been received and analyzed and are currently being interpreted in conjunction with NWT biologists.

Results from the Porcupine, Qamanirjuaq and Dolphin and Union herds have been fully analyzed and interpreted and are presented in this report.

Although 31 elements were measured, only 7 elements of concern will be discussed in detail for each herd (Table 2). Means and standard deviations of all elements may be found in Appendix 1.

The Dolphin and Union caribou herd was previously sampled for contaminants in 1993 by GNWT and those data have been made available for comparison. The 1993 sampling took place Oct – Nov while the 2006 sampling took place Oct – Jan (2007). The similarity in season of collection renders the data appropriate to determine differences between years, which may indicate a temporal trend or simply differences between years. The Northern Contaminants Program proposes to monitor this herd every five years,

Table 2. Average element concentrations (± SD) from three caribou herds collected in the fall of 2006.

Herd	**Dolphin and Union**		**Qamanirjuaq**		**Porcupine**	
Sex	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
N	17	3	7	14	3	11
Age	5.8 ± 3.1	3.7 ± 1.5	7.3 ± 3.4	5.8 ± 2.8	4.0 ± 1.4	4.9 ± 1.5
As	0.05 ± 0.01	0.05 ± 0.02	0.03 ± 0.02	0.01 ± 0.01	0.07 ± 0.00	0.07 ± 0.03
Cd	8.4 ± 6.7	5.3 ± 4.1	18.7 ± 13.9	14.0 ± 8.9	41.4 ± 22.9	38.7 ± 22.3
Cu	25.5 ± 5.0	22.5 ± 2.2	26.3 ± 2.0	25.8 ± 1.8	22.8 ± 2.7	25.3 ± 3.0
Pb	0.2 ± 0.1	0.1 ± 0.1	0.6 ± 0.8	0.3 ± 0.2	0.1 ± 0.1	1.2 ± 3.2
Hg	3.8 ± 1.5	2.7 ± 0.2	3.4 ± 1.0	2.6 ± 0.9	3.2 ± 1.7	2.1 ± 0.5
Se	4.0 ± 0.8	3.4 ± 0.5	3.6 ± 0.5	3.6 ± 0.5	4.2 ± 0.3	4.9 ± 0.8
Zn	105.8 ± 17.5	104.4 ± 16.7	104.1 ± 8.5	112.3 ± 14.0	129.0 ± 13.8	129.4 ± 13.4

which should clarify if temporal trends exist for particular elements. The Dolphin and Union data set was tested for the effect of gender, age and year of collection on element concentrations.

The Qamanirjuaq caribou herd was previously sampled for contaminants in 1992 by GNWT and those data have been made available for comparison (Elkin and Bethke 1995). The 1992 sampling took place in February, while the 2006 sampling took place July-August. As a result it is impossible to determine whether differences between datasets are attributable to a change in concentration of an element over time, changes between years, or natural seasonal fluctuations of the element. Ongoing annual monitoring of this herd should clarify this ambiguity. The Qamanirjuaq data set was tested for the effect of gender, age and [season or year of collection] on element concentrations.

The Porcupine herd has been sampled annually since 1994, and some of those collections have included both genders and both seasons, making this an ideal data set for exploring temporal trends. This data set was tested for the effect of gender, age, season and year of collection on element concentrations.

Female caribou had significantly higher concentrations of renal arsenic than males in the Porcupine and Qamanirjuaq caribou ($p<0.001$ and $p=0.008$ respectively) but not in the Dolphin and Union herd (Figure 1). Renal arsenic concentrations declined significantly over time in the Porcupine herd ($p<0.001$). Since arsenic was not measured previously in the Dolphin and Union or Qamanirjuaq herds, differences among years/season was unable to be tested for those herds. Renal arsenic levels are currently low in all three herds.

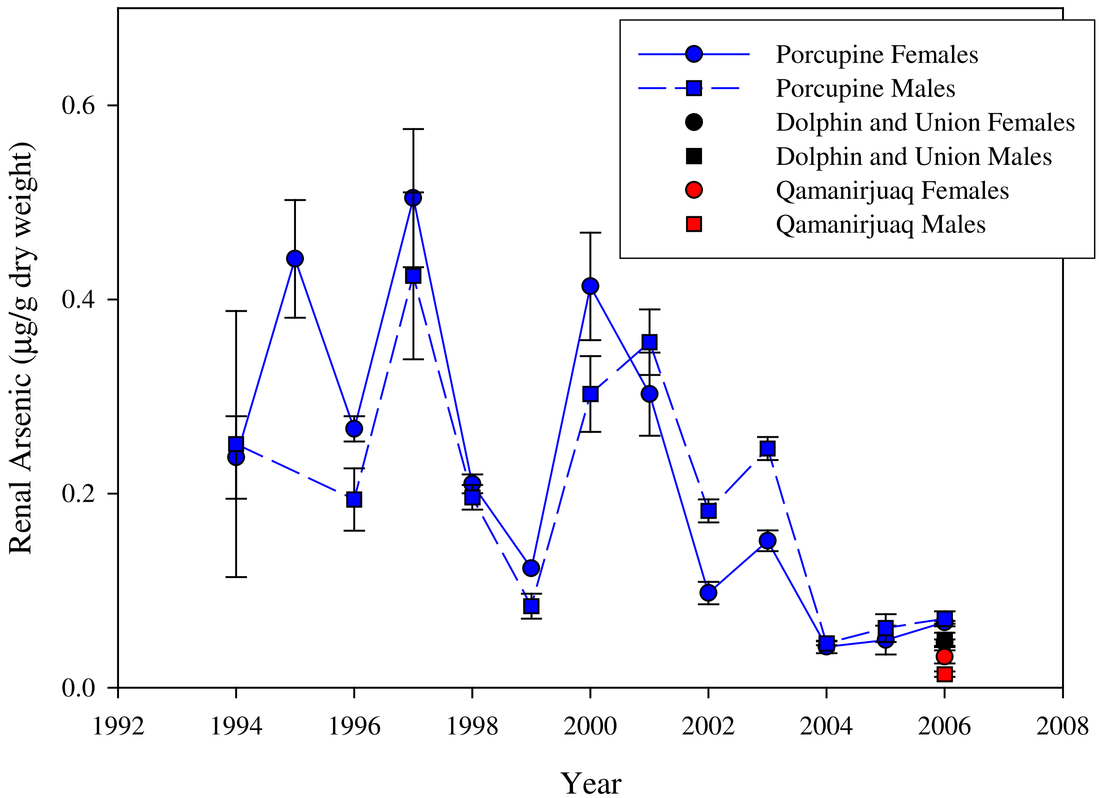

Figure 1. Renal arsenic concentrations relative to year of collection in three caribou herds from the Canadian Arctic.

Renal cadmium concentrations increased with age in all three herds ($p<0.001$ for all herds). Female Porcupine caribou had higher renal cadmium than males ($p<0.001$), but this difference was not seen in either of the other two herds (Figure 2). Spring collected Porcupine caribou had higher renal cadmium than fall-collected animals ($p=0.015$). Although renal cadmium was unaffected by year in the Porcupine herd, concentrations were higher in 1992 early spring than in 2006 early fall ($p=0.012$) in the Qamanirjuaq herd. It is not clear whether this difference is attributable to a decline over time or normal seasonal fluctuations. The effect of season was unable to be tested in the Dolphin and Union caribou, but there were no differences in renal cadmium concentrations between years of collection.

In the Porcupine herd, renal copper was higher in fall than in spring ($p<0.001$). While a similar difference was seen in the Qamanirjuaq herd, it was not statistically significant (and could also be attributable to changes over time)(Figure 3). Since the Dolphin and Union herd was only sampled in the fall, a seasonal difference in renal copper was unable to be tested for that herd. Renal copper levels were not affected by age, gender or year of collection in any of the herds.

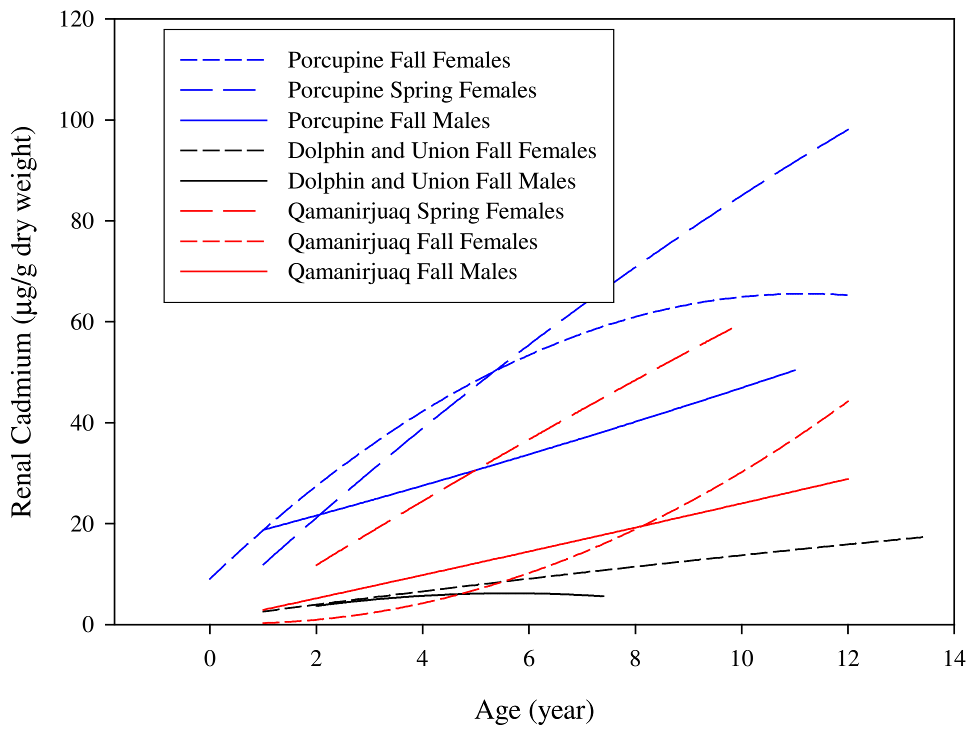

Figure 2. Renal cadmium concentrations relative to age in three caribou herds from the Canadian Arctic.

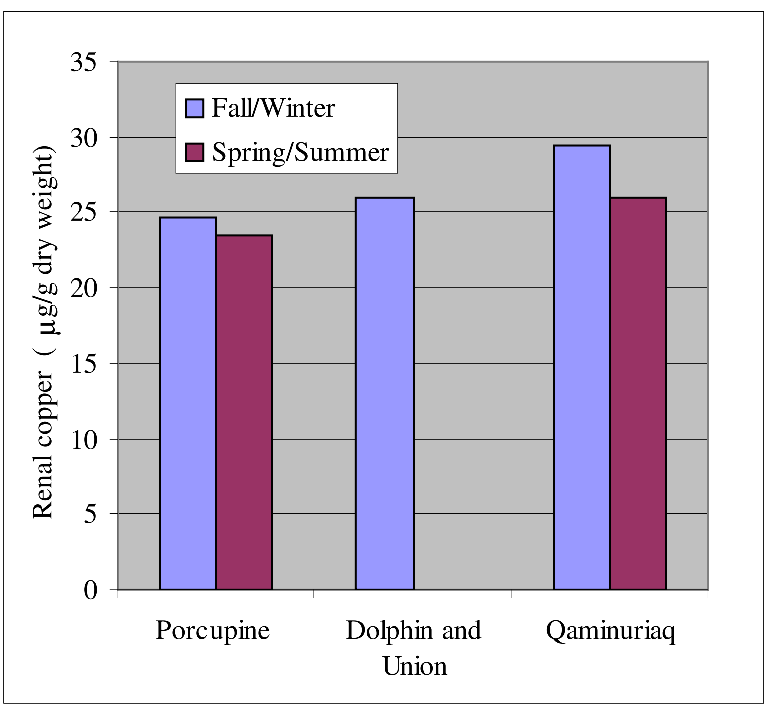

Figure 3. Renal copper concentrations in three caribou herds from the Canadian Arctic.

Lead was higher in spring than in fall ($p<0.001$) in the Porcupine caribou herd and in the Qamanirjuaq herd ($p=0.024$), although the difference for the Qamanirjuaq herd could be attributable to a seasonal difference or an increase over time. The effect of season was unable to be tested on the Dolphin and Union herd. Female Porcupine caribou had higher renal lead than males ($p<0.001$), but no gender differences were seen in the other herds. Renal lead was unaffected by age of the caribou in all three herds. Renal lead declined over time in the Porcupine caribou herd, but only in fall-collected females. Although it appears as if lead levels are increasing in male Porcupine caribou (Figure 4), the large variation around the mean renders the trend not statistically significant.

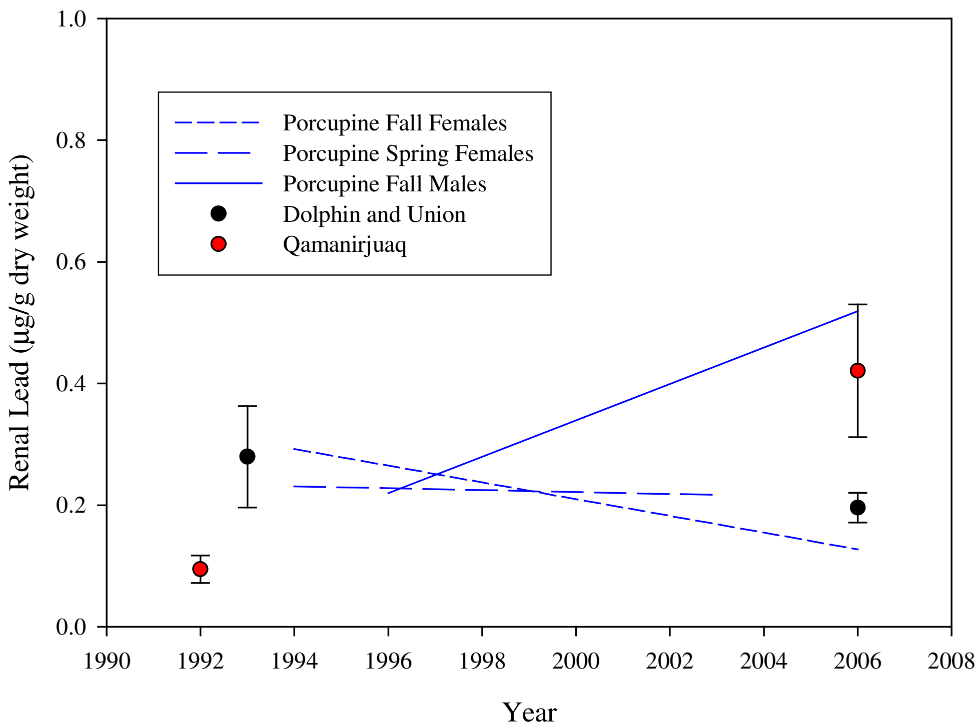

Figure 4. Renal lead concentrations relative to year of collection in three caribou herds from the Canadian Arctic.

Renal mercury was higher in spring than in fall in the Porcupine caribou herd ($p<0.001$) and in the Qamanirjuaq herd ($p=0.012$), although the difference for the Qamanirjuaq herd could be attributable to a seasonal difference or an increase over time. The effect of season was unable to be tested on the Dolphin and Union herd. Female Porcupine caribou had higher renal mercury than males (Figure 5), but no gender differences were seen in the other herds. Total renal mercury increased with age in all three caribou herds, but in the Porcupine herd it increased with age in females ($p=0.024$) and decreased with age in males ($p=0.006$) (Figure 6). There was no difference in mercury concentrations between 1993 and 2006 in the Dolphin and Union caribou herd, while renal mercury

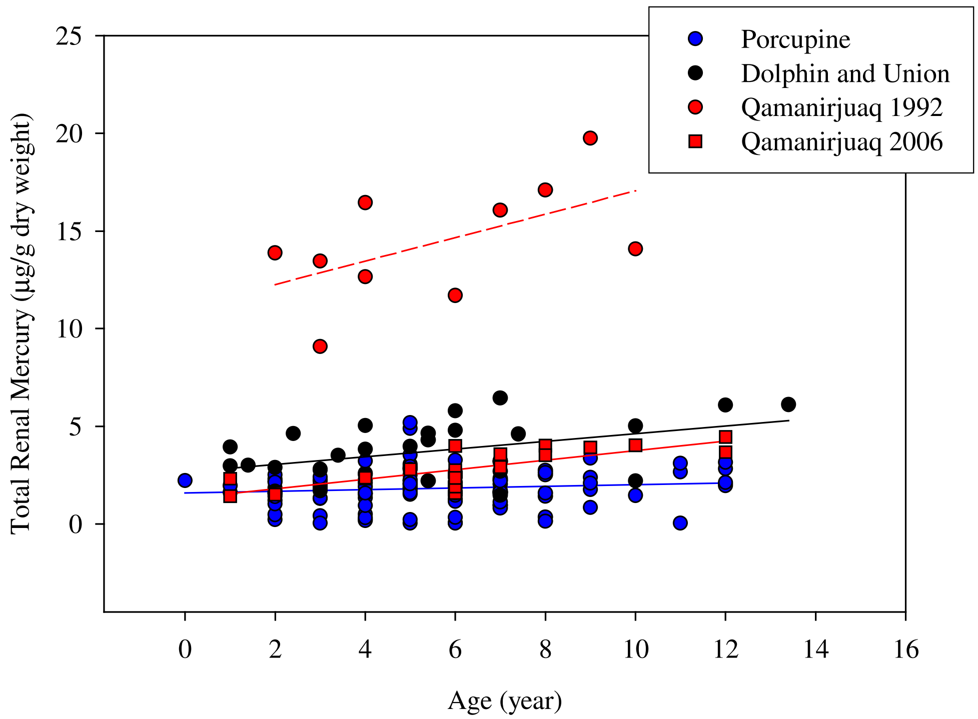

Figure 5. Total renal mercury concentrations relative to age in three caribou herds from the Canadian Arctic.

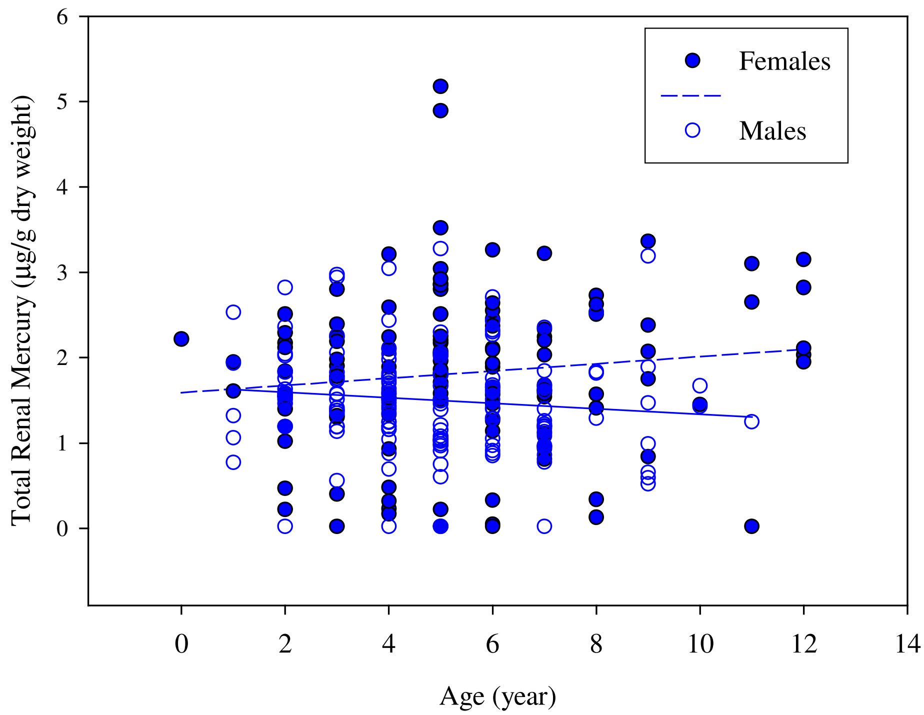

Figure 6.Total renal mercury concentrations relative to age in the Porcupine caribou herd.

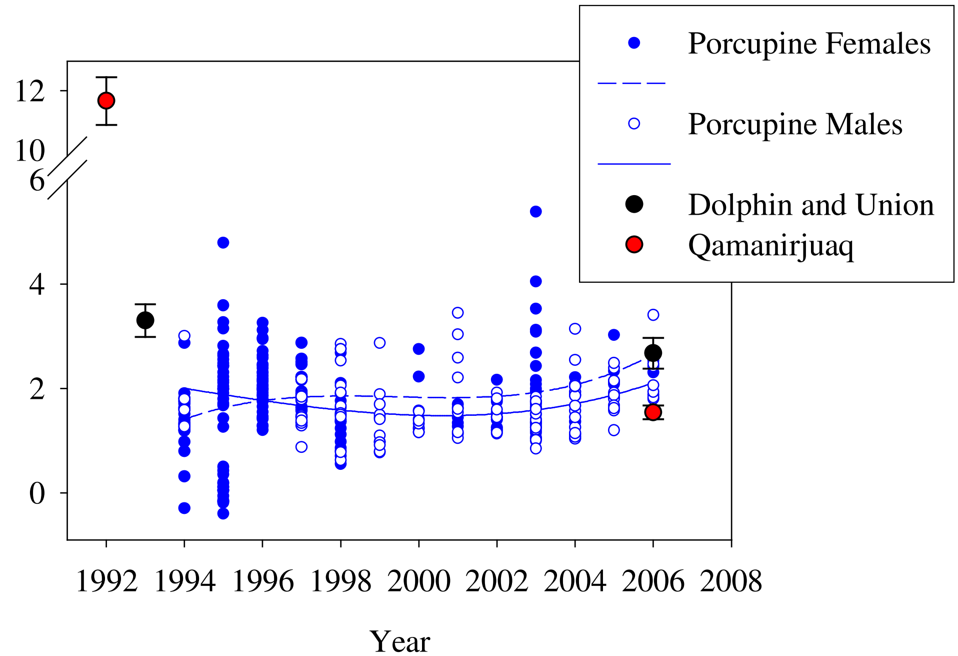

Figure 7. Total rrenal mercury concentrations relative to year of collection in three caribou herds from the Canadian Arctic.

levels in Qamanirjuaq caribou collected in late spring, 1992 were markedly higher than the concentrations found in animals from the same herd collected in early fall of 2006. From these data, it is unclear whether there has been a decline in mercury concentrations in this herd or whether this is normal seasonal variation (as demonstrated by the Porcupine herd). Renal mercury increased over time in the Porcupine caribou, for both males and females (Figure 7).

Renal selenium was higher in females from the Porcupine herd (p=0.015), but not in either of the other two herds. Renal selenium was also higher in spring-collected animals from the Porcupine herd than fall-collected animals (p=0.029). Since selenium was not measured in 1992 for the Qamanirjuaq herd or in 1993 for the Dolphin and Union herd, the effect of season and year cannot be tested for these herds. Renal selenium was not affected by age in any of the herds but increased over time (p=0.03) in the Porcupine caribou herd (Figure 8).

Renal zinc concentrations were unaffected by gender in all three caribou herds. Renal zinc levels were higher in spring-collected animals from the Porcupine herd (p<0.001), but the same trend was not seen in the Qamanirjuaq herd. Renal zinc increased with age in the Porcupine and Qamanirjuaq herds (p<0.001) but not in the Dolphin and Union herd (Figure 9). Renal zinc did not change over time in any of the herds measured.

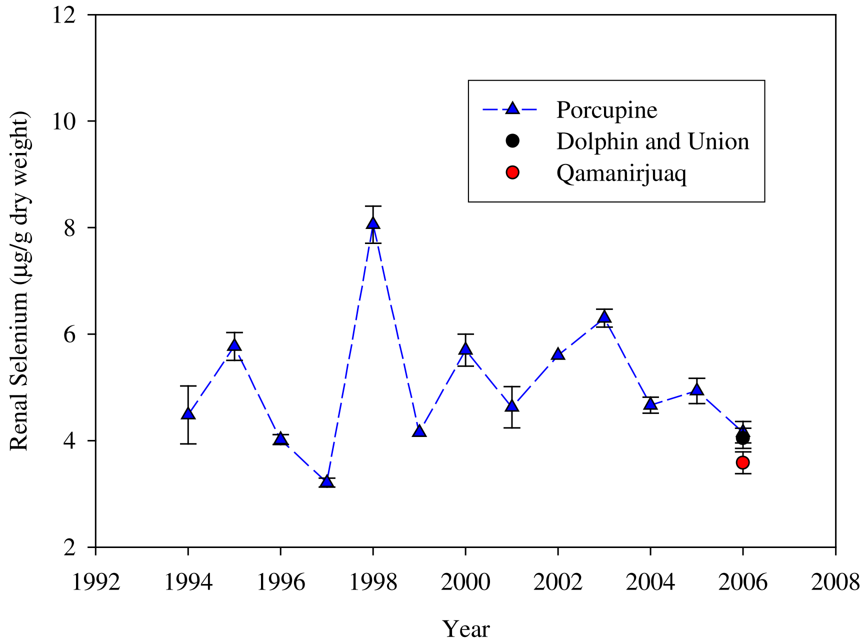

Figure 8. Renal selenium concentrations relative to year of collection in three caribou herds (fall-collected females only) from the Canadian Arctic.

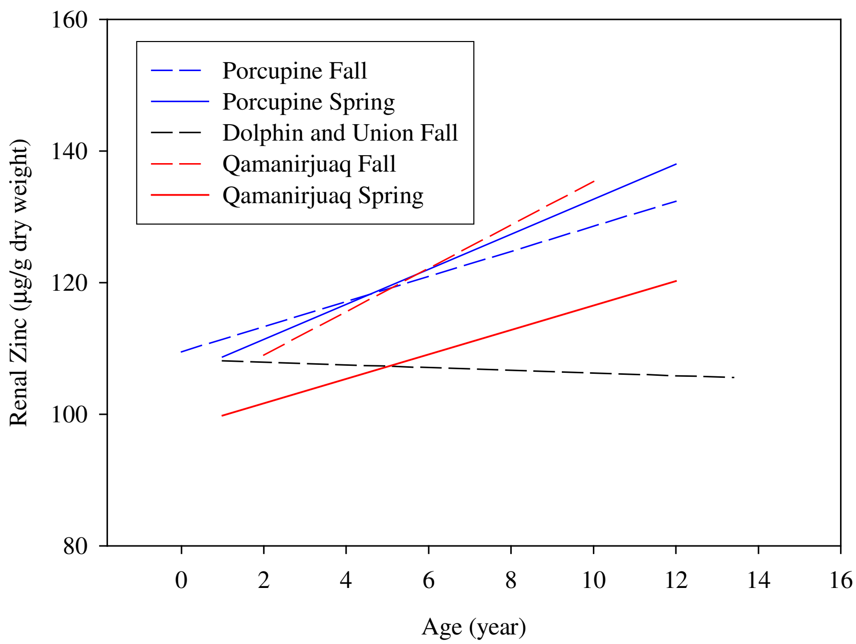

Figure 9. Renal zinc concentrations relative to age in three caribou herds from the Canadian Arctic.

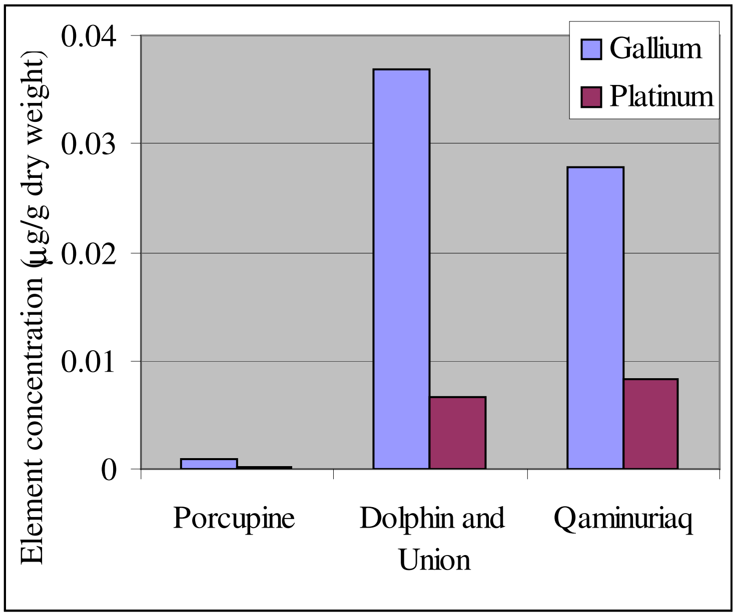

Figure 10. Renal gallium and platinum concentrations in three caribou herds from the Canadian Arctic.

Renal gallium and platinum were notably higher in the Qamanirjuaq and Dolphin and Union caribou kidneys than in kidneys from the Porcupine caribou (Figure 10). It is unclear what 'normal' levels of platinum and gallium are for caribou. Renal thallium tended to be more variable in kidneys from the Qamanirjuaq herd than from other herds.

Discussion

Female Porcupine caribou had higher levels of arsenic, cadmium, lead, mercury and selenium than males. No gender differences were seen in either of the other two herds except for higher arsenic in female Qamanirjuaq caribou than males. This is likely due to the much higher sample size in the Porcupine herd. Differences may exist between genders in the other two herds as well, but the sample size may not be large enough to show it. It is interesting that female caribou have higher concentrations of all the toxic elements measured while the elements necessary in trace amounts (copper and zinc) show no gender differences. The exception to this is selenium, which is known to be related to mercury physiologically. One possible explanation for the higher levels of toxic elements in female caribou is the smaller body size of the females, and the energetic cost of parturition and lactation. This means that they must eat proportionally more than males (in relation to their body size), thus ingesting proportionally more of these toxic elements. In contrast to the homeostatically controlled essential nutrients, these toxic elements tend to build up in the body if more is ingested than the body can eliminate. This gender difference was also seen in Yukon mink (*Mustela vison*) where smaller female mink had higher concentrations of total and methyl mercury than larger male mink (Gamberg et al. 2005).

Concentrations of renal cadmium, lead, mercury, selenium and zinc were higher in spring-collected animals than those taken in the fall, while the opposite was true for copper. This is likely because the winter diet of barren-ground caribou consists mostly of lichens, which are efficient at absorbing elements from the atmosphere. In the summer, the diet switches to more grasses and sedges, which generally have lower concentrations of these elements. In addition, fast growing herbaceous vegetation tends to have lower levels of many of these elements (Puls 1994). Higher cadmium levels in the 1992 spring samples from the Qamanirjuaq caribou as compared to the 2006 fall samples are likely a seasonal effect rather than a decline over time. It is not clear why concentrations of copper were higher in the fall than spring. A current Northern Contaminant Program project is measuring element concentrations in caribou forage and will allow more in-depth understanding of these differences.

Renal cadmium, mercury and zinc concentrations increased with age in most caribou. The relationship between cadmium concentration and age is well-known and has been documented in the literature for both moose and caribou (Gamberg and Scheuhammer, 1994; Glooschenko et al., 1994)). Interestingly, both male and female caribou have similar cadmium concentrations when they are young, but females accumulate cadmium at a greater rate (Figure 2), likely related to their higher requirement for food relative to body weight as previously discussed. The same is true for mercury, although mercury actually decreases with age in male Porcupine caribou (Figures 5 and 6). This suggests that over their lifetimes, males ingest less mercury than they are able to eliminate from their bodies, while females eat more than they can eliminate. One possible explanation for this is the difference in ranges between genders in the spring. In early spring, female Porcupine caribou travel to the north coast of the Yukon where they give birth and nurse their calves. The males stay farther south during this period and only join the females just before they begin their journey back south. The females may be ingesting more mercury through their food than the males during this time. Steffen et al. (2008) has described mercury depletion events in the arctic atmosphere at polar sunrise. A chemical reaction, mediated by a build-up of bromine on sea ice and initiated by sunlight, causes gaseous mercury to become particulate and be deposited out of the air onto the sea ice and neighbouring land. This may cause higher levels of mercury in terrestrial vegetation in the area of the arctic coast. A current Northern Contaminants Program project is studying this theory to see if it might explain differences in mercury burdens between genders in the Porcupine caribou.

Renal cadmium, copper and zinc were stable over time in all herds with the exception of the Qamanirjuaq herd having higher renal cadmium in the spring of 1992 than in the fall of 2006. As previously discussed, this is likely a seasonal difference rather than a change over time. This suggests that these elements are being taken up from naturally occurring sources and not subject to changes due to anthropogenic input.

Arsenic and lead declined over time in the Porcupine caribou and possibly in the Qamanirjuaq herd (but this could also be a seasonal effect). This is likely reflective of the declining atmospheric emissions of both arsenic and lead in North America and

Europe reported by Pacyna et al. (2001, 2007) since the early 1990's. The reduction of use of unleaded gasoline has likely contributed to this decline.

Renal mercury increased over time in both male and female Porcupine caribou while the higher concentrations in the 1992 spring-collected Qamanirjuaq caribou relative to the 2006 fall-collected animals are likely a seasonal difference rather than a temporal trend. Renal selenium also increased over time in the Porcupine herd. Although there was not a statistically significant correlation between selenium and mercury in this study, the interaction between the two elements is well-documented. Selenium is believed to have a protective effect against mercury toxicity by forming mercuric selenide, a relatively insoluble compound that reduces the bioavailability of the mercury (Ikemoto et al. 2004).

Temporal trends of Hg over the past 20–30 years in various arctic biota are inconsistent (Braune et al. 2005). Some animal populations exhibited significant increases in mercury whereas others did not, perhaps suggesting different pathways of exposure for different species and different locations. Long-term measurements of atmospheric mercury suggest that concentrations increased from the late 1970s to a peak in the 1980s, decreased to a minimum around 1996 and have been nearly constant since that time (Slemr et al. 2003). However, Lindberg et al. (2007) contends that a reduction in anthropogenic input of mercury to the atmosphere will not necessarily result in a linear reduction in mercury deposition, particularly at remote locations like the arctic. In addition, the warming of the climate may have dramatic effects on the availability of mercury to biota, particularly in the arctic where the timing and extent of sea ice and its coverage is changing quickly (Stroeve et al 2005). Finally, coal and fossil fuel combustion in Asia, a major source of global mercury, is expected to increase up to 350% between 1990 and 2020 (van Aardenne et al. 1999). With these uncertainties, and the temporal trend we see in the Porcupine caribou, it is essential to continue monitoring arctic caribou to keep track of potential changes in the mercury status of this important northern species.

Those elements that are required in trace amounts for the normal functioning of the animal (copper, selenium and zinc) were found in adequate concentrations in all three caribou herds and there is no evidence that they reached toxic levels in any of the animals measured. The toxic elements (arsenic, cadmium, lead and mercury) were found in measurable amounts, but never higher than is considered 'normal to high' for domestic cattle (Puls 1994). None of these elements currently approach levels that would be expected to cause toxic effects in the caribou.

Conclusions

Overall, the Dolphin and Union, Porcupine and Qamanirjuaq caribou herds have low levels of contaminants and there is no immediate cause for concern. However, renal mercury concentrations are increasing over time in at least one herd, and given the global concern about potentially increasing levels of mercury in the arctic environment, and declining caribou populations, it is considered essential to continue to monitor this important northern species so that we are aware of changes in contaminant burdens as they occur.

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Appendix 1. Renal element concentrations (µg/g dry weight) in three Canadian caribou herds collected in the fall of 2006.

Herd	Dolphin and Union	Qamanirjuaq	Porcupine
N	20	21	14
Age	5.4+ 3.0	6.3+ 3.0	5.2+ 2.0
Moisture (%)	78.1+ 1.5	78.5+ 3.2	78.8+ 1.9
Aluminum	0.9+ 0.6	0.5+ 0.2	2.4+ 4.3
Antimony	0.0+ 0.0	0.0+ 0.0	0.1+ 0.2
Arsenic	0.0+ 0.0	0.0+ 0.0	0.1+ 0.0
Barium	1.0+ 0.7	1.2+ 0.3	2.9+ 1.3
Beryllium	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Bismuth	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Cadmium	7.7+ 6.3	15.6+ 10.7	39.2+ 20.7
Cesium	0.1+ 0.2	1.2+ 0.8	1.4+ 1.1
Chromium	0.4+ 0.3	0.1+ 0.0	0.2+ 0.1
Cobalt	0.3+ 0.1	0.2+ 0.0	0.4+ 0.1
Copper	25.3+ 4.9	26.0+ 1.8	24.9+ 2.9
Gallium	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Iron	197.9+ 56.9	176.2+ 87.5	174.9+ 68.2
Lanthanum	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Lead	0.2+ 0.1	0.4+ 0.5	0.2+ 0.3
Lithium	0.1+ 0.1	0.1+ 0.0	0.3+ 0.3
Manganese	8.4+ 1.9	7.7+ 0.8	7.3+ 1.7
Mercury	3.6+ 1.5	2.8+ 1.0	2.2+ 0.9
Molybdenum	1.2+ 0.3	0.7+ 0.2	1.2+ 0.4
Nickel	0.1+ 0.4	0.1+ 0.2	0.2+ 0.1
Platinum	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Potassium	12911.0+ 2091.6	11676.2+ 1207.0	13027.0+ 830.4
Rubidium	21.8+ 17.0	85.7+ 32.6	45.9+ 19.7
Selenium	3.9+ 0.8	3.6+ 0.5	4.7+ 0.7
Silver	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Strontium	0.2+ 0.1	0.5+ 0.1	0.6+ 0.2
Thallium	0.0+ 0.0	0.2+ 0.2	0.0+ 0.0
Tin	0.2+ 0.2	0.3+ 0.1	0.5+ 0.2
Uranium	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Vanadium	0.0+ 0.0	0.0+ 0.0	0.0+ 0.0
Zinc	106.5+ 17.1	109.6+ 12.8	129.8+ 12.6

Appendix 2. Toxicological information on selected elements

Although **arsenic** is generally considered a non-essential element, it has been identified as an essential trace element for domestic goats (Puls 1994). It can be absorbed by ingestion, inhalation and permeation of skin or mucous membranes and accumulates in the liver, kidney, spleen, muscle, skin and hair. Toxic effects include respiratory cancer, peripheral nervous system disorders and dermatitis (Jaworski 1980). Toxicity depends on the concentration and form, trivalent arsenic (arsenite) being 5 to 10 times more toxic than pentavalent (arsenate). Elemental arsenic is non-toxic. Since the use of arsenic in herbicides, insecticides, fungicides and rodenticides has been largely discontinued, the main sources of arsenic to the environment are mine tailings, smelter waste and natural mineralizations (Jaworski 1980).

Cadmium is a toxic element that accumulates in animals over time (and therefore with age), primarily in the kidneys and liver. Chronic exposure may lead to anemia, enteropathy, renal damage, osteoporosis and osteomalacia. Long-range transport distributes cadmium widely over the environment, and natural mineralizations may serve as point sources. Lichens absorb cadmium directly from the air, eventually passing it on to caribou that feed on the lichen. Plants differ in their ability to absorb cadmium from soil and water, some species accumulating relatively high concentrations if they grow in cadmium-rich soil. Cadmium accumulates in long-lived herbivores, generally not in high enough levels to impair their health. Industrial uses of cadmium include production of cadmium-plated metal, nickel-cadmium batteries, pigments and plastic stabilizers, mining and refining of copper, lead and zinc (Jaworski 1980).

Copper is an essential element. Since it is homeostatically controlled, excess copper is excreted in the urine, and toxicity is rare under normal conditions. Toxic effects may occur, however, and can include dermatitis, anemia, gastric ulcers, renal damage and hemolysis (Aaseth and Norseth 1986). Copper deficiency has been noted in Alaskan moose with faulty hoof keratinization and reduced reproductive rates (Flynn et al. 1977). Industrial uses include production of electrical equipment and alloys, plating, plumbing, heating, and uses in mining and smelting.

Lead is a toxic element that is stored for the long term in bone tissue, and in the short-term, in liver and kidney. Toxic signs include anemia, anorexia, fatigue and blindness. Common sources of lead include mining, smelting and refining of lead and other ores, burning petroleum fuels containing lead additives, burning coal and oil and use in shotgun pellets. Lead may also be found in paint (even ‘lead-free paint may contain up to 1% lead), waste engine oil, lead batteries, putty, roofing tiles, linoleum, solder and golf balls. Some pipe joint or thread compounds (used on drilling sites) can contain up to 40% lead powder (Puls 1994)

Mercury is a toxic element that accumulates in brain and kidney tissue, affects neurological functions and may cause gastrointestinal disturbance, reduction of food intake, poor growth, renal damage or death. Prenatal exposure may lead to cerebral palsy (Berlin, 1986). Inorganic mercury may be transformed to methylmercury (a more toxic form of mercury) by natural microbial action in lakes. This process may be promoted by excess sulphides from atmospheric deposition or nutrification of lakes. Aquatic life is generally more sensitive to methylmercury than terrestrial species. Environmental sources of mercury include mining, milling and smelting of mercury-containing ores, chlor-alkali plants, coal-burning plants, municipal wastewater treatment plants, pulp and paper mills and fungicides. Natural mercury occurs as volcanic gases, natural mineralizations and evaporation from oceans (World Health Organization, 1989).

Selenium is an essential element, which interacts with vitamin E to ensure optimum functioning of the immune and reproductive systems. Because some geographical areas are naturally low in selenium, deficiencies are possible, causing white muscle disease, reduced growth and reproductive rates, and reduced immune response. Signs of toxicity may include emaciation, lameness, cracked or deformed hooves and loss of hair. It has been thought that excess selenium also caused ‘blind staggers’, but this may be due to other compounds in the selenium-accumulating plants (*Astralagus* sp.) responsible for this disease (Puls 1994). Industrial uses of selenium include electronics, photography, glass production, fungicides, insecticides and pigments in plastics, paints, enamels, inks and rubber.

Zinc is an essential, homeostatically controlled element, and is an important component of many proteins and enzymes. Zinc deficiency may result in reduced conception rate, reduced feed intake and growth rate, and thickening and shortening of bones. Toxic effects include anemia, poor bone mineralization, arthritis, general osteochondrosis and lameness (Sileo and Beyer 1985). Zinc is released into the environment through mining, smelting and residential and industrial effluents and is used industrially in electroplating, the combustion of fossil fuels, petroleum by-products and solid wastes.

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