ANALYSIS OF THE ELEMENTAL COMPOSITION OF TISSUES AND FAECAL ASH IN A MOOSE (*ALCES ALCES*) EXPOSED TO TAILINGS AT THE ABANDONED COLOMAC GOLD MINE, NWT

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2005

Manuscript Report No.162

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ABSTRACT

A moose *Alces alces* jumped the fence bounding the tailings area of the Colomac mine site. The moose had been within the fenced tailings area for about 2 weeks. Concerns about possible contamination of the moose led to the moose being shot by a team comprised of a Tłi Cho elder and RWED personnel. We carried out a necropsy and sampled the moose tissue to determine the degree of contamination. This information would support other projects associated with exposure and ecological risk to Colomac wildlife from contaminants. Approximately 35 tissues, including gut contents and faecal material were collected and analyzed for metals by ICP/MS. The concentrations of individual elements varied markedly between individual tissues, and along the gut. Cyanide was below detection in most tissues but increased to about 5 $mg\cdot kg^{-1}$ in the omasum contents and caecum. Arsenic concentration was low in most tissues but the concentration was slightly higher in the tongue and faecal material. The higher levels of many elements in the hind gut and faecal material is probably due to the low rates of uptake in the gut, which results in increasing concentration as material moves through the digestive tract. Ash content of the gut contents was relatively high at lower ash temperatures, which may reflect the type of organic material in moose browse. Principal components analysis of the metal residues in the faecal ash fraction showed some similarity to Colomac tailings, while the pattern of metals in the gut contents resembled that of Paddle Lake caribou faecal material, probably due to high sodium content. When compared to Colomac caribou faecal pellets, the moose faecal pellets showed higher proportions of zinc, strontium and magnesium which could reflect the different metal content in insoluble material on moose browse. Blood and tissue levels of cyanide in this moose reflect oral exposure and uptake of environmental cyanide associated with the Colomac tailings pond, and highlight the potential environmental risk of acute cyanide toxicity. While the animal did not exhibit clinical signs consistent with cyanide toxicity prior to death or any histological evidence of tissue damage, blood levels were within the toxic range reported for domestic livestock.

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INTRODUCTION

In July 2004, a moose was discovered inside the fence used to isolate the extensive tailings storage area at the abandoned Colomac gold mine, Northwest Territories. The moose had scrambled over the fence and was not able to leave and was within the fenced area for about 2 weeks. The disposed tailings contain elevated levels of many inorganic contaminants, including cyanide and arsenic. The moose was exposed to these contaminants from: (1) dust from the dry tailings, (2) submerged tailings in Tailings Lake, (3) drinking the water; and (4) from aquatic macrophytes and browse on the site. Tłi Cho elders advised that the moose should be shot and removed from the area. Resources Wildlife and Economic Development (RWED) and Indian and Northern Affairs Canada used the opportunity to analyze the levels of contaminants in the tissues of the moose for evidence of exposure to the tailings to gather baseline information for risk analyses for ruminants exposed to contaminated sites.

This report summarizes the chemical analysis of the tissues of the moose. It also describes the analysis of gut contents and the ash content of faecal material and compares these to caribou faecal pellets which were collected by RWED in 2003, and analyzed using the same methodology (Macdonald and Gunn 2004).

METHODS

A Tłi Cho harvester shot the moose on 14 July and we undertook a necropsy. We collected tissues and intestinal content samples for toxicological analyses which were flown to Yellowknife and frozen within 6 hours. We also took and fixed (10% neutral buffered formalin) tissue samples for histopathological analyses by the Canadian Cooperative Wildlife Health Centre. Tłi Cho staff skinned and butchered the moose. The meat was flown to the RWED North Slave office to be held pending the toxicological analyses. The intestinal tract, and organs were examined and sampled and then disposed of in the bush away from the mine site.

Metal Analysis

Detailed methods of the chemical analysis of the tissues (Macdonald 2003) and faecal material (Macdonald and Gunn 2004) are reported elsewhere. In summary, individual tissues were analysed for cyanide and metals by EnviroTest Laboratories in Winnipeg, MB. Cyanide was analysed using a colourimetric method from the American Public Health Association (EnviroTest Method: A249.07). Metals in the tissues were analysed by digestion in nitric acid and hydrogen peroxide, followed by analysis by plasma mass spectrometer (U.S. Environmental Protection Agency Method 200.8, 3050B).

Faecal pellets were heated at 100 ^{o}C, then ashed at 450 ^{o}C for 8 h to remove all organic material. Dried faecal material (100 ^{o}C) was analysed for metal content by aqua regia digestion (concentrated HCl and nitric acid) using Actlabs Ultratrace 1 digestion and analysis process. The insoluble ash was then dried at 600 ^{o}C and reanalyzed for 53 metals.

Gross Necropsy and Histology

We undertook a complete necropsy examining all external and internal body systems, organs and tissues. We collected representative samples from a wide range of tissues and immediately preserved them in 10% neutral buffered formalin. Subsequently wildlife pathologists histologically examined the tissues at the Canadian Cooperative Wildlife Health Centre in Saskatoon, SK. Tissues examined histologically included skin, skeletal muscle, heart, trachea cranial & caudal lung lobes, tongue, oral cavity, hard palate, submandibular lymph node, retropharyngeal lymph node, parotid salivary gland, esophagus, rumen, reticulum, omasum, abomasums, jejunum, ileocecal lymph node, colon, liver, spleen, kidney and urinary bladder.

Statistics

Principal components analysis (PCA) was performed on the contaminant data with Sirius Version 6.0 (Pattern Recognition Systems AS, Bergen, Norway). Random numbers between zero and the detection levels were used for non-detectable values to maintain normal distributions. The concentration data reported for each digestion method were normalized to the total metals to remove the influence of concentration and standardized (autoscaled) prior to PCA.

RESULTS

The moose was a young adult male. There was no appreciable wear on the molariform (cheek) teeth which were fully erupted. The third incisor was broken and the other incisor teeth had horizontal cracks which is quite usual for moose. We found no external injuries, lesions or abnormalities (except a small healed tear in one ear). The moose had no visible backfat or cardiac fat and moderate amounts of kidney and mesenteric fat. All organs and tissue looked normal with no gross pathological signs. We found stripped willow leaves in the mouth. Tłı̨ Cho workers had seen the moose browsing on willow as well as drinking the water at the tailings lake.

Metals, cyanide and arsenic varied considerably over the tissues analyzed (Table 1). Although it is not possible to conduct statistical analysis on the single samples, concentrations varied by several orders of magnitude for some elements. Many elements, like silver, beryllium and bismuth remained below detection in all samples (Figure 1).

Cyanide concentrations reached a maximum in the caecum and gut contents, indicating that the moose could have been exposed to cyanide in its diet (Figure 2). There was not enough faecal sample available for the analysis of cyanide to determine if the elevated levels were also present in the final stages of the gut. Arsenic showed a similar pattern, with maximum levels in the gut (<0.05 to 4.29 $mg \cdot kg^{-1}$) and in the faeces. The highest concentrations of nickel were observed in the trachea, hard palate and skin samples. Titanium, which is used as a marker of plant material in the diet because of the very low uptake of titanium from the diet, showed an increasing concentration through the gut reaching a maximum level in the faecal pellet.

Table 1 Concentrations of cyanide, arsenic and metals in the tissues of the moose harvested at Colomac. All concentrations are in mg·kg^{-1} dry weight, except cyanide which is on a wet weight basis. NS – No Sample (tissue sample too small for separate cyanide analysis).

Lab ID	Tissue	Cyanide	Antimony	Silver	Aluminum	Arsenic	Boron	Barium	Beryllium	Bismuth	Calcium	Cadmium	Cesium
Organs													
L193961-2	Liver	<1	<0.06	<1	13	0.2	1.7	0.34	<0.05	<0.02	253	3.11	0.21
L193961-3	Kidney	<1	<0.06	<1	9	0.13	1.9	0.63	<0.05	<0.02	486	51.8	0.63
L193961-4	Muscle	<1	<0.06	<1	19	0.06	1.4	0.15	<0.05	<0.02	287	0.02	0.22
L193961-5	Spleen	<1	<0.06	<1	20	0.09	1.6	2.52	<0.05	<0.02	331	0.46	0.16
L193961-6	Heart	<1	<0.06	<1	13	0.05	6.7	0.24	<0.05	<0.02	186	0.07	0.17
L193961-7	Tongue	1	<0.06	<1	247	1.37	4.1	2.42	<0.05	<0.02	1090	0.29	0.23
L193961-8	Bladder	<1	<0.06	<1	19	0.09	2.6	0.32	<0.05	<0.02	406	0.33	0.31
Respiratory System													
L193961-11	Trachea	NS	<0.06	<1	14	<0.05	1.6	1.22	<0.05	<0.02	1210	0.08	0.07
L193961-9	Lung - Cranial	2	0.07	<1	141	0.23	2.5	1.69	<0.05	0.03	845	0.39	0.14
L193961-10	Lung - Caudal	2	<0.06	<1	28	0.11	2.5	1.4	<0.05	<0.02	679	0.33	0.13
External Tissues													
L193961-1	Skin	<1	0.28	<1	112	0.36	3.9	1.68	<0.05	<0.02	912	0.25	0.05
L193961-12	Antler Velvet	NS	<0.09	<2	41	0.16	2.8	0.58	<0.08	<0.03	1830	0.05	0.08
L193961-13	Antler	<1	<0.06	<1	185	0.44	1.9	4.08	<0.05	<0.02	12200	0.02	0.09
Digestive System													
L193961-26	Soft Palate	<1	0.09	<1	33	0.06	1.2	0.24	<0.05	<0.02	337	0.04	0.04
L193961-27	Hard Palate	NS	<0.06	<1	167	0.53	2.2	1.93	<0.05	<0.02	931	2.17	0.07
L193961-15	Oesophagus	<1	<0.06	<1	16	0.1	1.9	0.5	<0.05	<0.02	471	0.06	0.19
L193961-16	Rumen	<1	<0.06	<1	43	0.22	7.8	57.3	<0.05	<0.02	10300	0.16	0.16
L193961-14	Reticulum	<1	<0.06	<1	57	0.21	4.7	7.72	<0.05	<0.02	3240	0.19	0.16
L193961-18	Omasum	1	<0.06	<1	217	0.95	15.9	24.1	<0.05	0.02	12000	0.61	0.19
L193961-20	Abomasum	<1	<0.06	<1	25	0.16	3.2	2.03	<0.05	<0.02	1370	0.77	0.24
L193961-21	Jejunum	NS	<0.06	<1	42	0.13	2.3	1.12	<0.05	<0.02	807	0.1	0.14
L193961-22	Duodenum	NS	<0.06	<1	92	0.24	2.6	8.83	<0.05	<0.02	2620	2.12	0.18
L193961-23	Ileum	1	<0.06	<1	161	0.7	5.9	9.85	<0.05	0.03	3310	0.53	0.18
L193961-24	Cecum	5	<0.06	<1	171	0.76	6.8	11.1	<0.05	0.03	4200	0.45	0.18
L193961-25	Colon	<1	<0.06	<1	89	0.24	1.2	1.08	<0.05	<0.02	439	0.06	0.03
Gut Contents													
L193961-17	Rumen contents	4	<0.06	<1	177	0.53	15.3	19.7	<0.05	0.02	9360	0.6	0.15
L193961-19	Omasum Content	6	<0.06	<1	446	1.23	18.6	23.1	<0.05	<0.02	13400	0.68	0.16
L193961-28	Faecal pellet	NS	<0.06	<1	452	4.29	21.9	39.6	<0.05	0.04	18800	2.81	0.4

Table 1 (cont'd) Concentrations of cyanide, arsenic and metals in the tissues of the moose harvested at Colomac. All concentrations are in mg·kg-1 dry weight, except cyanide which is on a wt weight basis. NS – No Sample (tissue sample too small for separate cyanide analysis).

Lab ID	Tissue	Cobalt	Chromium	Copper	Iron	Potassium	Phosphorus	Magnesium	Manganese	Molybdenum	Nickel	Lead	Rubidium
Organs													
L193961-2	Liver	0.51	<0.1	108	693	9340	9850	673	13.6	3.22	1	0.12	72.8
L193961-3	Kidney	0.57	0.2	30.6	171	12100	9730	789	12	1.48	4.9	0.57	69.8
L193961-4	Muscle	0.07	0.3	4.5	232	13600	6170	850	2	0.02	1.1	0.05	44
L193961-5	Spleen	0.21	0.3	11.1	3520	13300	7430	674	2.8	0.12	2.7	0.18	53.1
L193961-6	Heart	0.3	<0.1	12.8	255	11700	7120	1010	2.3	0.06	1.4	0.2	42.7
L193961-7	Tongue	0.24	2.9	18.4	1330	11200	5530	731	27.1	0.54	12	0.94	54.5
L193961-8	Bladder	0.11	0.8	5.1	130	16300	5460	649	2.1	0.04	2.7	0.14	83.4
Respiratory System													
L193961-11	Trachea	0.43	0.8	12.6	83	2460	1590	346	1.5	0.04	12.7	0.22	9.5
L193961-9	Lung - Cranial	0.3	2.6	8.7	1440	9950	7700	595	11.9	0.32	8.5	9.43	45.5
L193961-10	Lung - Caudal	0.34	0.4	7.1	783	9640	7630	556	2.8	0.29	1.9	0.17	46.2
External Tissues													
L193961-1	Skin	0.23	3.2	126	494	2910	1750	291	9.8	0.42	63.5	1.49	13.5
L193961-12	Antler Velvet	0.06	0.8	6.3	180	3080	2990	295	2.9	0.07	2.5	0.26	13.9
L193961-13	Antler	0.16	2.2	6.8	1040	8260	9530	845	18.6	0.13	9.4	0.29	32.8
Alimentary Canal													
L193961-26	Soft Palate	0.05	0.4	1.5	180	2040	1670	271	4.1	0.06	3	0.27	8.8
L193961-27	Hard Palate	0.34	9	8.8	617	3380	1730	295	10.1	0.18	14.9	0.53	19.4
L193961-15	Oesophagus	0.09	0.2	3.2	151	9890	4890	683	3.3	0.08	2.5	0.14	36.6
L193961-16	Rumen	0.54	0.2	7.2	279	11900	14900	3180	948	0.16	2.6	0.16	35.1
L193961-14	Reticulum	0.43	0.5	7.2	308	13800	9280	1400	177	0.15	3.2	0.11	45.9
L193961-18	Omasum	1.08	0.9	16.3	831	11800	15600	2790	379	0.56	3.2	0.39	33.5
L193961-20	Abomasum	0.22	0.1	4.5	197	16200	6980	759	18.7	0.11	0.6	0.08	55.4
L193961-21	Jejunum	0.19	0.3	3.4	212	7650	5690	872	30	0.13	0.9	0.06	32.7
L193961-22	Duodenum	0.22	1.9	7.1	748	13900	9200	733	101	0.16	1.6	0.4	56.4
L193961-23	Ileum	0.55	1.4	9.1	621	13700	7280	1380	125	0.37	1.9	0.36	50.5
L193961-24	Cecum	0.7	1.4	43.6	762	12200	5670	1610	154	0.48	3.7	0.33	46.6
L193961-25	Colon	0.09	0.5	1.3	440	2220	1180	165	9.1	0.05	0.7	0.29	9.8
Gut Contents													
L193961-17	Rumen contents	1	0.7	9.3	779	10800	12700	2240	207	0.65	3	0.41	25.6
L193961-19	Omasum Content	1.19	1.1	14.9	1570	10500	14600	2090	287	0.86	3.3	0.52	26
L193961-28	Faecal pellet	2.45	3.8	42.4	1920	3270	7280	3860	684	2.01	9.2	1.06	19.9

Table 1 (cont'd) Concentrations of cyanide, arsenic and metals in the tissues of the moose harvested at Colomac. All concentrations are in mg·kg-1 dry weight, except cyanide which is on a wt weight basis. NS – No Sample (tissue sample too small for separate cyanide analysis).

Lab ID	Tissue	Selenium	Tellurium	Sodium	Tin	Strontium	Titanium	Thallium	Uranium	Vanadium	Zinc
Organs											
L193961-2	Liver	2.6	<0.08	2540	<1	0.2	0.74	<0.04	<0.006	<0.06	88.1
L193961-3	Kidney	3.9	<0.08	8260	<1	0.51	0.44	<0.04	<0.006	<0.06	128
L193961-4	Muscle	0.5	<0.08	1830	<1	0.2	0.79	<0.04	<0.006	<0.06	200
L193961-5	Spleen	1.1	<0.08	3870	<1	0.3	0.86	<0.04	<0.006	<0.06	104
L193961-6	Heart	1	<0.08	2870	<1	0.16	0.64	<0.04	<0.006	<0.06	81
L193961-7	Tongue	0.8	<0.08	4830	<1	1.88	9.4	<0.04	0.015	0.31	98.9
L193961-8	Bladder	0.7	<0.08	8510	<1	0.34	0.71	<0.04	<0.006	<0.06	125
L193961-11	Trachea	0.3	<0.08	8320	<1	0.96	0.6	<0.04	<0.006	<0.06	32
L193961-9	Lung - Cranial	0.7	<0.08	6930	<1	0.9	3.98	<0.04	0.007	0.24	67.9
L193961-10	Lung - Caudal	0.9	<0.08	5800	<1	0.55	0.9	<0.04	<0.006	<0.06	65.5
External Tissues											
L193961-1	Skin	0.3	<0.08	6790	3	2.43	4.87	<0.04	0.009	0.18	38.5
L193961-12	Antler Velvet	0.5	<0.1	5220	<2	1.13	1.48	<0.06	<0.009	<0.09	30.9
L193961-13	Antler	0.6	<0.08	7830	<1	6.57	5.92	<0.04	0.007	0.36	45.8
Digestive System											
L193961-26	Soft Palate	0.2	<0.08	4330	<1	0.29	0.9	<0.04	<0.006	<0.06	19.3
L193961-27	Hard Palate	0.4	<0.08	9210	<1	1.36	16.7	<0.04	0.007	0.42	26.2
L193961-15	Oesophagus	0.6	<0.08	4780	<1	0.4	1.94	<0.04	<0.006	<0.06	90.7
L193961-16	Rumen	0.5	<0.08	9900	<1	68.3	2.68	<0.04	<0.006	0.11	88.4
L193961-14	Reticulum	0.7	<0.08	9600	<1	12	2.17	<0.04	<0.006	0.16	110
L193961-18	Omasum	0.5	<0.08	11200	<1	26.6	20.4	<0.04	0.018	0.67	127
L193961-20	Abomasum	0.7	<0.08	8690	<1	1.62	1.8	<0.04	<0.006	<0.06	94.3
L193961-21	Jejunum	0.5	<0.08	5660	<1	2.02	2.1	<0.04	<0.006	0.1	60.8
L193961-22	Duodenum	0.8	<0.08	8510	<1	3.01	3.29	<0.04	<0.006	0.14	106
L193961-23	Ileum	0.6	<0.08	7320	<1	7.82	12.3	<0.04	0.012	0.4	111
L193961-24	Cecum	0.7	<0.08	8150	<1	10.5	14.2	<0.04	0.015	0.43	104
L193961-25	Colon	0.2	<0.08	1920	<1	0.64	5.66	<0.04	<0.006	0.13	19.2
Gut Contents											
L193961-17	Rumen contents	0.3	<0.08	15700	<1	17.8	8.9	<0.04	0.014	0.49	109
L193961-19	Omasum Content	0.3	<0.08	17800	<1	23.8	21.7	<0.04	0.026	2.31	113
L193961-28	Faecal pellet	0.4	<0.08	808	<1	42.1	32.9	<0.04	0.046	0.97	217

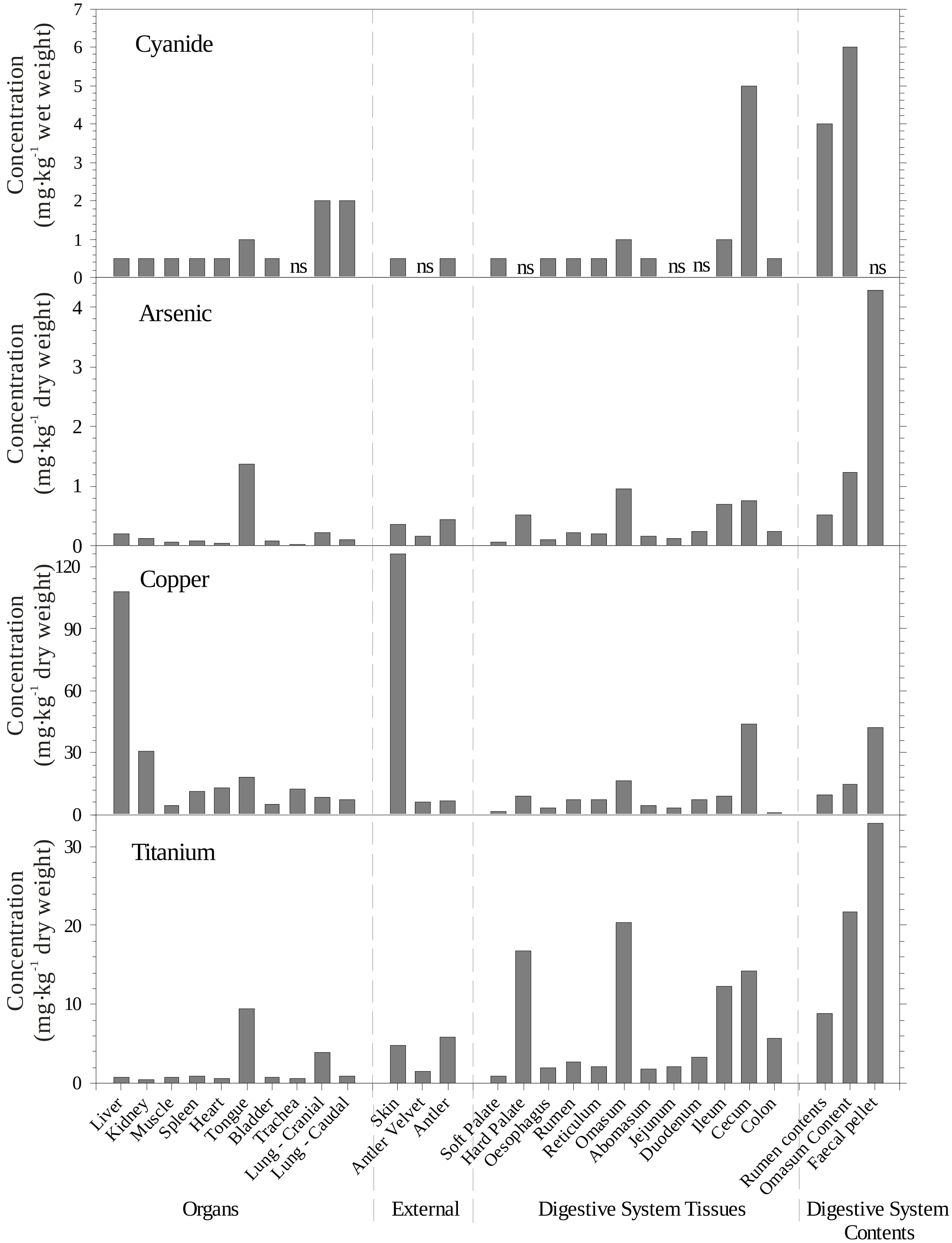

Figure 1 Concentration of four elements in internal and external tissues of the Colomac moose. ns – no sample; not enough sample for the cyanide analysis which was conducted separately from the metal analysis.

Fractions of ash (450 ^{o}C) in the moose gut contents and faecal material (Table 2) ranged from 0.13 in the rumen contents to 0.19, or 19% of dried material, in the omasal material. These levels are similar to the higher levels of ash content in the caribou faecal pellets from the previous study (Figure 2). The ash content levels in the moose samples declined substantially at 600 ^{o}C ashing temperatures to about 0.06 (6%) of dried material in the omasum and faecal pellets, which is in the middle of the range relative to the caribou faecal pellets. The magnitude of the decline in fraction ash found in the moose samples was not observed in the caribou pellets and could be due to the different character of the organic matter in moose browse relative to lichen.

The insoluble ash of the gut contents and faecal material were analysed for 54 metals (including gold) in the aqua regia digestion and for 53 metals in the four-acid digestion method (Table 3). Many of the elements were below the detection limits of the methods because of the small sizes of the ash samples analysed (Table 4, 5). PCA was conducted on the full suite of 54 metals in the rumen, omasum and faecal samples (with replicates) with the caribou faecal samples from Colomac and the tailings samples. The objective of the analysis was to determine how similar the relative amount of each metal was to the tailings samples and the four caribou faecal samples with high ash contents from the previous study.

All moose samples and their replicates were situated very close to each other in the scatter plots, indicating good consistency in the metal analysis (Figure 3). The rumen and omasum samples were situated very close to the samples of caribou faecal pellets from Paddle Lake, due to high proportions of sodium. The moose faecal samples were modeled with the Spruce Lake caribou faecal samples with elevated ash. This portion of Figure 3 has been expanded in Figure 4 to show the similarity between the moose faecal samples and the Spruce Lake caribou on principle component (PC) 1, which accounted for 73.2% of the variability. Although many of the elements that are modeling the distribution of samples are below detection limits in the faecal tissues, major modeling elements include aluminum, manganese, iron, lead, and molybdenum. The distribution of the metals is similar in the caribou and moose faecal pellet samples

PCA was also run on the Colomac caribou and moose samples without the samples of tailings (Figure 5). In this analysis, the first component only accounted for 41.4% of the variability. The moose faecal samples were separated from the Spruce Lake caribou faecal samples on the second component, due to higher proportions of zinc, strontium, cadmium and magnesium in the moose samples. The Spruce Lake caribou samples are modeled by higher proportions of aluminum, lead, chromium and several minor elements. As in the previous analysis, the moose gut samples group with the Paddle Lake caribou samples due to high proportions of sodium. The analysis suggests that the metal distribution in the moose faecal pellets is similar to the caribou faecal pellets in some respects, however there are also differences in the levels of some major elements which are unique to each group.

Table 2 Ash content of replicate samples of rumen and omasum contents and faecal material. Samples were dried at 100 ^oC and ashed at 450 and 600 ^oC.

Sample Name	Sample Weight	Ashed Sample Weight	Sample Weight	Dried Sample Weight (@ 100C)	Ashed Sample Weight (@ 450C)	Fraction Ash (@ 450)	Ashed Sample Weight (@ 600C)	Fraction Ash (@ 600C)
Rumen Contents (1)	2.1010	0.0376	2.1362	0.3332	0.0421	0.126	0.0068	0.020
Rumen Contents (2)	2.2033	0.0393	2.1647	0.3528	0.0443	0.126	0.0082	0.023
Average	**2.15**	**0.038**	**2.150**	**0.343**	**0.043**	**0.126**	**0.008**	**0.022**
Standard Deviation	**0.07**	**0.001**	**0.020**	**0.014**	**0.002**	**0.001**	**0.001**	**0.002**
Omasum Contents (1)	2.0886	0.0520	1.9824	0.3154	0.0618	0.196	0.0198	0.063
Omasum Contents (2)	2.0503	0.0507	2.1645	0.3090	0.0547	0.177	0.0157	0.051
Average	**2.07**	**0.051**	**2.073**	**0.312**	**0.058**	**0.186**	**0.018**	**0.057**
Standard Deviation	**0.03**	**0.001**	**0.129**	**0.005**	**0.005**	**0.013**	**0.003**	**0.008**
Faecal Pellets (1)	1.9808	0.0905	2.0824	0.6060	0.1047	0.173	0.0344	0.057
Faecal Pellets (2)	2.0306	0.1120	2.0967	0.5880	0.1007	0.171	0.0398	0.068
Average	**2.01**	**0.101**	**2.090**	**0.597**	**0.103**	**0.172**	**0.037**	**0.062**
Standard Deviation	**0.04**	**0.015**	**0.010**	**0.013**	**0.003**	**0.001**	**0.004**	**0.008**

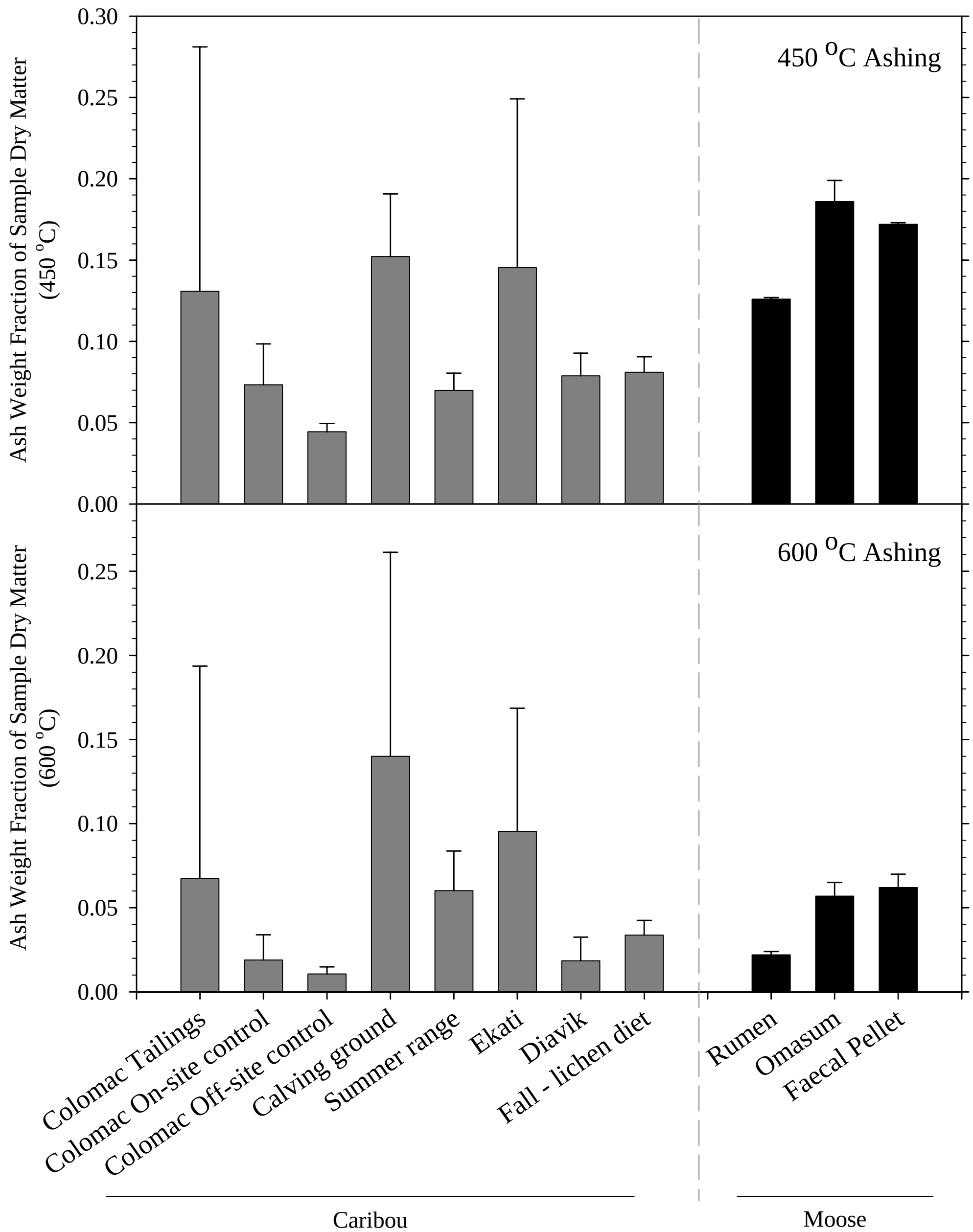

Figure 2 Ash weight as a fraction f sample dry weight for caribou faecal pellets and moose gut contents and faecal pellets.

Table 3 List of elements analysed in the aqua regia (Ultra Trace 1) and four-acid (Ultra Trace 4) digestion of gut contents and faecal material.

Symbol	Element	Symbol	Element
Ag	Silver	Mn	Manganese
Al	Aluminum	Mo	Molybdenum
As	Arsenic	Na	Sodium
Au	Gold	Nb	Niobium
B	Boron	Nd	Neodymium
Ba	Barium	Ni	Nickel
Be	Beryllium	Pb	Lead
Bi	Bismuth	Pr	Praseodymium
Ca	Calcium	Rb	Rubidium
Cd	Cadmium	Re	Rhenium
Ce	Cerium	Sb	Antimony
Co	Cobalt	Sc	Scandium
Cr	Chromium	Se	Selenium
Cs	Cesium	Sm	Samarium
Cu	Copper	Sn	Tin
Dy	Dysprosium	Sr	Strontium
Er	Erbium	Ta	Tantalum
Eu	Europium	Tb	Terbium
Fe	Iron	Te	Tellurium
Ga	Gallium	Th	Thorium
Gd	Gadolium	Tl	Thallium
Ge	Germanium	Tm	Thulium
Hf	Hafnium	U	Uranium
Ho	Holmium	V	Vanadium
In	Indium	W	Tungsten
K	Potassium	Y	Yttrium
La	Lanthanum	Yb	Ytterbium
Li	Lithium	Zn	Zinc
Lu	Lutetium	Zr	Zirconium
Mg	Magnesium		

Table 4 Metal content of gut content and faecal material. Concentration is in $mg \cdot kg^{-1}$, except for gold (Au) which is in $\mu g \cdot kg^{-1}$ and major ions, which are expressed as percentages. Europium and terbium were below detection (<0.1 $mg \cdot kg^{-1}$) in all samples and hence the results are not shown.

Aqua Regia Digestion (Ultra Trace 1)																		
Sample	**Li**	**Be**	**B**	**Na%**	**Mg%**	**Al%**	**K%**	**Ca%**	**Sc**	**V**	**Cr**	**Mn**	**Fe%**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**
Rumen Content	0.6	<0.1	<1	0.144	0.04	<0.01	0.13	0.16	<0.1	<1	<0.5	37	0.02	0.2	0.4	1.93	19.8	0.02	<0.1
Rumen Content (Replicate)	0.9	<0.1	<1	0.127	0.04	<0.01	0.13	0.15	<0.1	<1	<0.5	35	0.02	0.2	0.4	1.91	19.5	0.03	<0.1
Omasum Contents	<0.5	<0.1	<1	0.145	0.05	0.01	0.13	0.22	<0.1	1	<0.5	59	0.03	0.2	0.5	2.67	21.0	0.04	<0.1
Omasum Contents (Replicate)	1.0	<0.1	<1	0.129	0.04	0.01	0.13	0.24	<0.1	2	0.6	55	0.03	0.2	0.5	2.60	22.7	0.05	<0.1
Faecal Pellets	<0.5	<0.1	<1	0.011	0.14	0.03	0.09	0.69	<0.1	1	0.9	232	0.12	0.8	2.2	14.4	82.7	0.25	<0.1
Faecal Pellets (Replicate)	<0.5	<0.1	<1	0.011	0.14	0.03	0.08	0.69	<0.1	1	1.0	233	0.16	0.8	2.2	13.8	81.7	0.32	<0.1

Aqua Regia Digestion (Ultra Trace 1)																		
Sample	**Se**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	**Te**	**Cs**	**Ba**	**La**	**Ce**	**Pr**	**Nd**
Rumen Content	<0.1	3.1	2.9	0.03	<0.1	<0.1	0.09	0.005	<0.1	<0.02	<0.05	<0.02	<0.02	<0.1	3.1	<0.5	0.14	<0.1	0.09
Rumen Content (Replicate)	<0.1	3.0	2.7	0.03	<0.1	<0.1	0.07	0.011	<0.1	<0.02	<0.05	<0.02	<0.02	<0.1	2.8	<0.5	0.11	<0.1	0.08
Omasum Contents	<0.1	3.9	4.1	0.06	<0.1	<0.1	0.11	0.029	<0.1	<0.02	<0.05	<0.02	<0.02	<0.1	4.3	<0.5	0.25	<0.1	0.16
Omasum Contents (Replicate)	<0.1	3.0	3.8	0.05	<0.1	<0.1	0.10	0.018	<0.1	<0.02	<0.05	<0.02	<0.02	<0.1	4.2	<0.5	0.27	<0.1	0.16
Faecal Pellets	<0.1	4.6	14.5	0.25	0.2	<0.1	0.67	0.277	0.4	<0.02	<0.05	<0.02	<0.02	0.1	13.7	0.6	1.07	0.2	0.69
Faecal Pellets (Replicate)	<0.1	4.9	14.5	0.34	0.2	<0.1	0.66	0.307	0.4	<0.02	<0.05	<0.02	<0.02	0.1	14.2	0.9	1.40	0.2	1.01

Table 4 (cont'd) Metal content of gut content and faecal material. Concentration is in $mg \cdot kg^{-1}$, except for gold (Au) which is in $\mu g \cdot kg^{-1}$ and major ions, which are expressed as percentages. Europium and terbium were below detection (<0.1 $mg \cdot kg^{-1}$) in all samples and hence the results are not shown.

Aqua Regia Digestion (Ultra Trace 1)																		
Sample	**Sm**	**Gd**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Hf**	**Ta**	**W**	**Re**	**Au (ppb)**	**Tl**	**Pb**	**Bi**	**Th**	**U**
Rumen Content	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.1	<0.001	26.8	<0.02	0.05	<0.02	<0.1	<0.1
Rumen Content (Replicate)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.1	<0.001	30.4	<0.02	0.06	<0.02	<0.1	<0.1
Omasum Contents	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	0.1	<0.001	133	<0.02	0.08	<0.02	<0.1	<0.1
Omasum Contents (Replicate)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	0.1	<0.001	48.6	<0.02	0.08	<0.02	<0.1	<0.1
Faecal Pellets	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	0.8	<0.001	280	<0.02	0.32	0.02	0.1	<0.1
Faecal Pellets (Replicate)	0.2	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	1.2	<0.001	383	<0.02	0.44	<0.02	0.1	<0.1

Table 5 Metal concentrations in gut contents and faecal material from the four-acid digestion. Concentration is in $mg \cdot kg^{-1}$, except for major ions, which are expressed as percentages.

Four Acid Digestion (Ultra Trace 4)																			
Sample	**Li**	**Be**	**B**	**Na (%)**	**Mg (%)**	**Al (%)**	**K (%)**	**Ca (%)**	**V**	**Cr**	**Mn**	**Fe (%)**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	**As**
Rumen Content	<0.5	<0.1	<1	0.003	<0.01	<0.01	<0.01	<0.01	<1	<0.5	<1	<0.01	<0.1	<0.5	<0.2	0.8	<0.1	<0.1	<0.1
Rumen Content (Replicate)	<0.5	<0.1	<1	0.005	<0.01	<0.01	<0.01	<0.01	<1	<0.5	1	<0.01	<0.1	<0.5	<0.2	2.0	<0.1	<0.1	<0.1
Omasum Contents	<0.5	<0.1	<1	0.009	<0.01	0.03	0.01	<0.01	<1	<0.5	2	<0.01	<0.1	<0.5	<0.2	2.9	<0.1	<0.1	<0.1
Omasum Contents (Replicate)	0.6	<0.1	<1	0.009	<0.01	0.03	<0.01	0.01	<1	<0.5	3	<0.01	<0.1	<0.5	0.3	2.0	<0.1	<0.1	<0.1
Faecal Pellets	<0.5	<0.1	<1	0.019	<0.01	0.05	0.01	<0.01	<1	<0.5	3	0.01	<0.1	<0.5	1.1	0.9	0.1	<0.1	<0.1
Faecal Pellets (Replicate)	<0.5	<0.1	<1	0.022	<0.01	0.06	0.01	0.02	<1	<0.5	6	0.04	<0.1	<0.5	1.6	0.9	0.2	<0.1	<0.1

Four Acid Digestion (Ultra Trace 4)																			
Sample	**Se**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	**Te**	**Cs**	**Ba**	**La**	**Ce**	**Pr**	**Nd**
Rumen Content	<0.1	<0.2	0.2	<0.1	<1	<0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	<1	<0.1	<0.1	<0.1	<0.1
Rumen Content (Replicate)	<0.1	<0.2	<0.2	<0.1	<1	<0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	<1	<0.1	<0.1	<0.1	<0.1
Omasum Contents	<0.1	0.3	1.6	<0.1	<1	<0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	4	<0.1	0.1	<0.1	<0.1
Omasum Contents (Replicate)	<0.1	0.2	1.2	<0.1	<1	<0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	2	<0.1	0.1	<0.1	<0.1
Faecal Pellets	<0.1	0.3	1.4	0.1	2	0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	3	0.2	0.3	<0.1	0.2
Faecal Pellets (Replicate)	<0.1	0.3	1.7	0.1	2	<0.1	<0.1	<0.05	<0.1	<0.1	<1	<0.1	<0.1	<0.05	4	0.2	0.3	<0.1	0.2

Table 5 (cont'd) Metal concentrations in gut contents and faecal material from the four-acid digestion. Concentration is in mg·kg^{-1}, except for major ions, which are expressed as percentages.

Four Acid Digestion (Ultra Trace 4)																			
Sample	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Hf**	**Ta**	**W**	**Re**	**Tl**	**Pb**	**Bi**	**Th**	**U**
Rumen Content	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1
Rumen Content (Replicate)	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1
Omasum Contents	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1
Omasum Contents (Replicate)	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1
Faecal Pellets	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1
Faecal Pellets (Replicate)	<0.1	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.001	<0.05	<0.5	<0.02	<0.1	<0.1

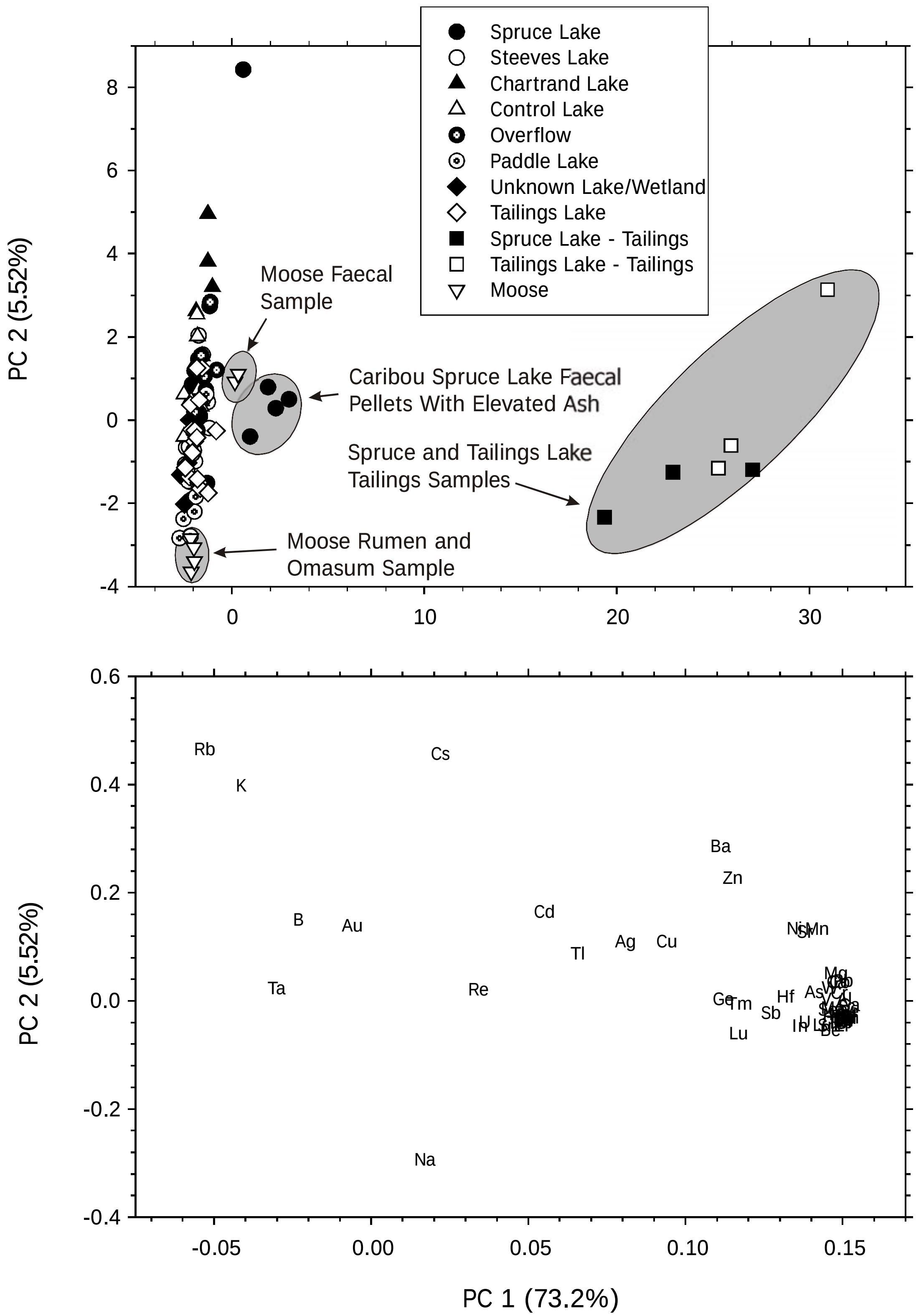

Figure 3 PCA of the caribou faecal pellets from Colomac and the moose gut and faecal contents. The analysis is designed to show the similarity in the relative proportion of metals between the sets of samples and solid tailings from Spruce and Tailings lakes at Colomac. The metals grouping the samples (i.e. loadings) are in the lower figure.

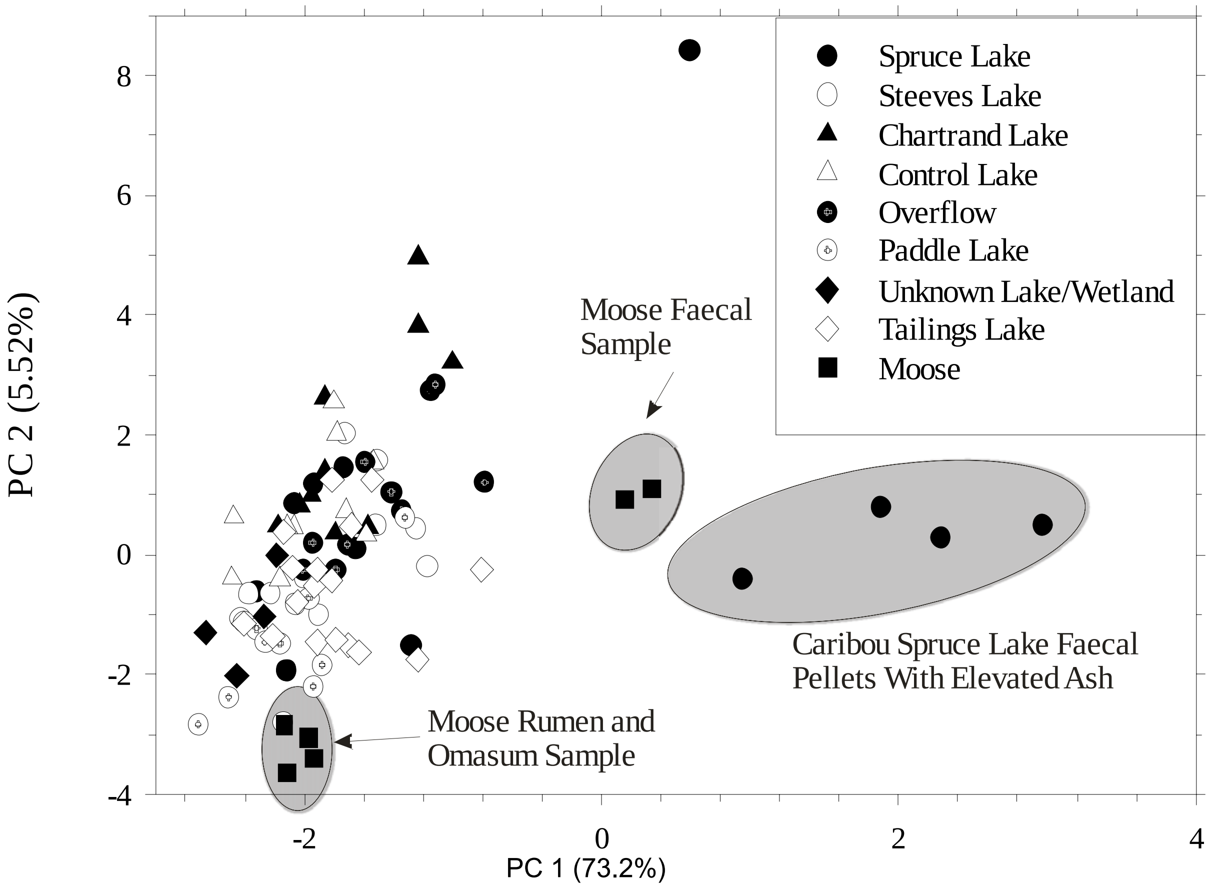

Figure 4 Re-plotting of Figure 3, but with the X-axis expanded to remove the tailings samples. The figure shows the similarity between the two moose faecal samples and the caribou faecal samples collected at Spruce Lake which had significantly elevated ash content. The moose rumen and omasum samples show a similarity in metal patterns to Paddle Lake caribou faecal samples.

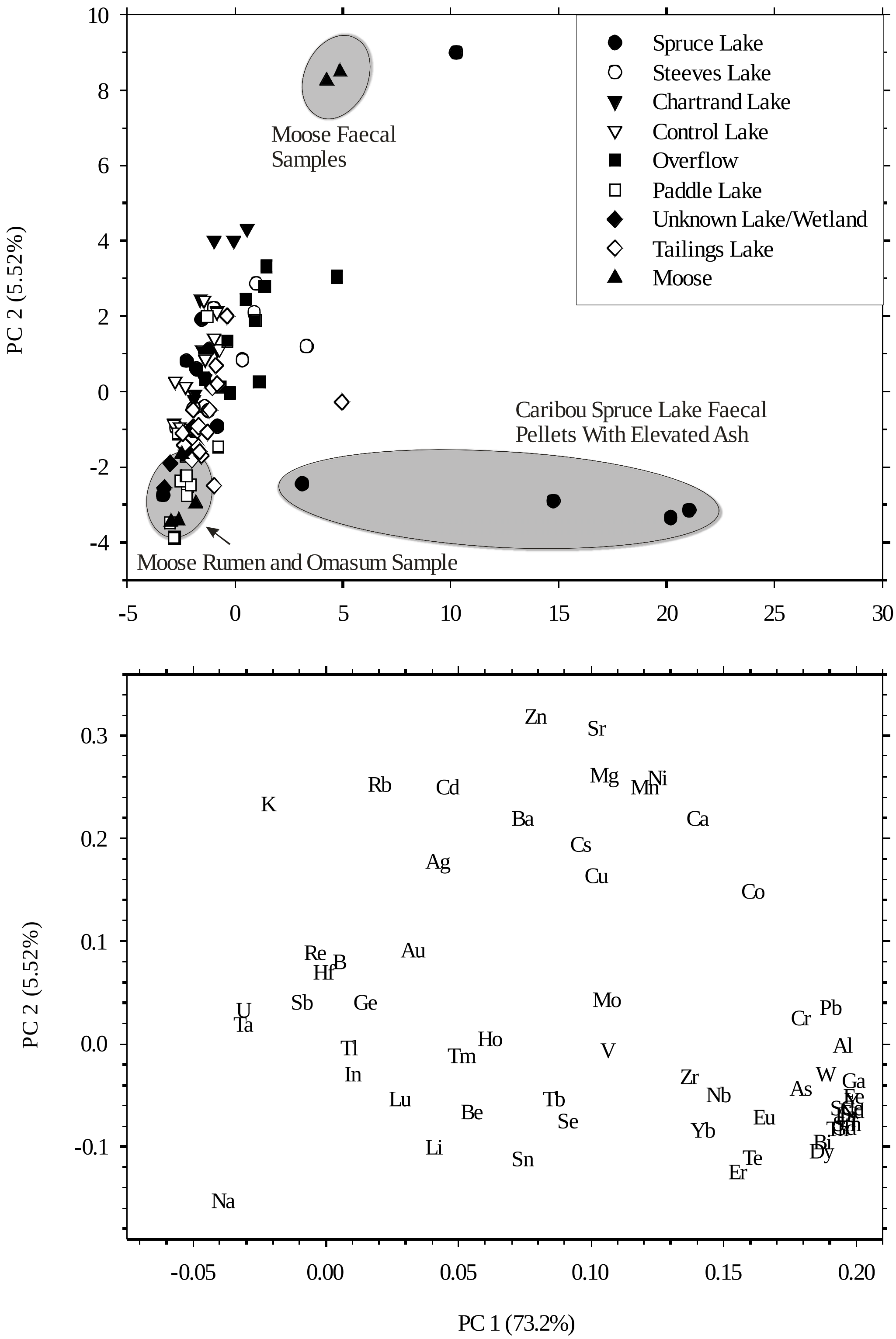

Figure 5 PCA of the Colomac caribou and moose samples without the tailings samples. Patterns are based on the relative proportion of the metal concentrations, after standardizing. The moose faecal samples show higher proportion of Zn, Sr and Cd than most caribou faecal pellets, while the gut content samples show a similarity to Paddle Lake caribou faecal samples with a high proportion of Na.

Pathology Results

On gross necropsy, there were no visible changes or abnormalities in any body system or tissues. On histological examination, there were no significant lesions in any of the submitted tissues. Pigmentation due to course brown granules (likely hemosiderin or melanin) were noted in the medulla of the ileocecal, retropharyngeal and submandibular lymph nodes; this pigmentation is an incidental finding and not considered significant.

The tissue and blood levels of cyanide (Table 6) are consistent with oral ingestion of cyanide in the diet or through consumption of liquid tailings. Given the tissue levels of cyanide and metals, the moose meat was destroyed.

Table 6. Concentrations of cyanide, arsenic and metals in the whole blood, serum and plasma of the moose harvested at Colomac. All concentrations are in ppm, except cyanide and nitrite which are in umol/l. Interpretation of levels is based on cattle reference data given lack of reference data specifically for moose.

Lab ID	Tissue	Analysis	Deficient	Marginal	Normal	High Normal	Toxic	Units
D0426179	Blood	Cyanide					45	umol/l
		Lead			0.00			ppm
D0426179	Serum	Arsenic			0.005			ppm
		Copper		0.52				ppm
		Iron			2.54			ppm
		Magnesium				26.7		ppm
		Manganese		0.011				ppm
		Molybdenum			0.16			ppm
		Selenium		0.042				ppm
		Zinc			0.94			ppm
D0426179	Plasma	Nitrite			0.00			umol/l

DISCUSSION

The tissue cyanide concentrations in the moose that had spent about 2 weeks exposed to the tailings reached a maximum in the caecum and gut contents, indicating that the moose was likely exposed to cyanide in its diet. Blood cyanide levels were very high (45 umol/l), and would be considered to be in the "toxic" range based on cattle reference data (species-specific sensitivity data not available for moose or other wild ungulates). While this suggests the possibility of acute toxicity occurring through exposure to environmental cyanide associated with the tailings, there was no evidence of clinical signs or pathological changes associated with cyanide toxicity in this case. We could not find published information on cyanide toxicity levels for moose but this case highlights the risk of acute cyanide toxicity associated with exposure to tailings, and the need to mitigate this risk effectively.

In Canada, more than 90% of mined gold is extracted from ores through a cyanidation process, using sodium cyanide (NaCN) to extract gold from the ore. Tailings ponds associated with this process can contain alkaline water with high concentrations of potential toxic NaCN, free cyanide, and metal cyanide complexes than can be accessible and pose a hazard to wildlife. Many chemical forms of cyanide are present in the environment, but only free cyanide presents a primary toxic form. Cyanide seldom remains biologically available in soils because it is either complexed by trace metals, metabolized by various microorganisms, or lost through volatilization (Towill et al. 1978; Marrs and

Ballantyne 1987). The greatest source of cyanide exposure to ruminants is through cyanogenic plants, but exposure to anthropogenic sources of free cyanide in tailings ponds is also a significant concern. Gold and silver mines are considered the most widespread sources on anthropogenic cyanides in critical wildlife habitat (Hill and Henry 1996). Some cyanides are extremely toxic for terrestrial animals exposed to ore-leaching solutions (Clark and Hothem 1991; Eisler 1991; Henny et al. 1994). Between 1980 and 1989, 519 mammals including mule deer were found dead at cyanide-extraction, gold-mine tailing and heap leach ponds in California, Nevada and Arizona (Clark and Hothem 1991).

Cyanide does not bioaccumulate in animals because low doses are rapidly metabolized and high doses are lethal. Cyanide does not biomagnify in food webs, and has not been shown to pose important chronic hazards to terrestrial wildlife. Therefore, acute toxicity is the principal hazard to wildlife; exposed individuals either succumb or recover, and carcasses of poisoned animals do not pose a significant risk of secondary poisoning to scavengers.

Cyanides are readily absorbed through inhalation, ingestion, or skin contact, and are readily distributed throughout the body via blood. Cyanide is a potent and rapid asphyxiant, that induces tissue anoxia through inactivation of cytochrome oxidase, causing cytotoxic hypoxia in the presence of normal hemoglobin oxygenation (Eisler et al. 1999). Signs of acute cyanide poisoning usually occur within 10 minutes of exposure. Signs include excitability, muscle tremors and incoordination, salivation, lacrimation, defecation, urination, labored breathing and convulsions leading to death. Reported acute oral LD50 values for mammals range from 4.1 to 28.0 mg HCN/kg body weight. Livestock mortalities have been reported near a cyanide disposal site where the animals had been drinking surface run-off water containing 365 mg HCN per litre (USEPA 1980). However, more research is required to establish threshold limit values for cyanide (Eisler et al. 1999).

Despite the high lethality of large single exposures, repeated sublethal doses, especially in the diet, are tolerated by many species for extended period, perhaps indefinitely (Eisler 1991). At sub-lethal doses, cyanide reacts with thiosulfate in the presence of rhodanese to produce the comparatively nontoxic thicyanate, most of which is excreted in the urine. Rapid detoxification enables animals to ingest sub-lethal doses of cyanide over extended periods without harm. Cyanide is not carcinogenic or mutagenic.

The fence surrounding the tailings at Colomac mine was designed to exclude barren-ground caribou. The fence is chainlink and 2.4 m in height. Once the tailings are reclaimed, the fence will be removed and in the mean time, the Tłi Cho Logistics staff monitor wildlife presence in the area. The height of 2.4 m is a relatively standard recommendation for deer (and caribou) but frightened deer can clear a 2.4 m fence (Katona et al. 2000). Although moose occur in the Colomac area, they are not numerous and we would expect that it is unlikely another moose would jump the fence into the tailings area. However, if a moose is found within the tailings area and cannot be removed within 5-7 days, it should be shot and sampled similar to above. Although 2.4 m is a recommended fence height to exclude moose, its effectiveness could be increased by using a highly visible 'ribbon' (mylar material) to extend the height about 30 cm.

ACKNOWLEDGEMENTS

We thank the staff from Tłi Cho Logistics for their hospitality at Colomac mine. We especially appreciate how George Lafferty, Jaymes Dircks, and Leon Zoe provided endless help and patiently answered many questions and requests for information. Eddie Camille and George Lafferty collected the moose and with Leon Ekendia skinned it and helped us with the sampling. Barry Franklin helped package and dispose of the carcass and Murry Ellis kept us safe. Octavio Melo (Indian and Northern Affairs Canada) has been supportive of wildlife monitoring and funded the sample analyses.

LITERATURE CITED

Clark, D.R. Jr., and R.L.Hothem. 1991. Mammal mortality at Arizona, California, and Nevada gold mines using cyanide extraction. Calif Fish Fame 77:61-69.

Eisler, R. 1991. Cyanide hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Dept. Interior, Fish Wildl. Serv. Boil. Rep 85:1-23.

Eisler, R., D.R. Clark, S.N. Wiemeyer and C.J. Henny. 1999. Sodium cyanide hazards to fish and other wildlife from gold mining operations. In: Azcue, J..M. (ed). Environmental impacts of mining activities: emphasis on mitigation and remedial measures. Springer-Verlag, Berlin. Pp. 55-67

Henny, C.J., R.J. Hallock and E.F. Hill. 1994. Cyanide and migratory birds at gold mines in Nevada, USA. Ecotoxicology 3:45-58.

Hill, E.F. and P.F.P. Henry. 1996. Cyanide. In: Fairbrother, A., L.N. Locke and L.N. Hoff (eds). Non-infectious diseases of wildlife, second edition. Iowa Sate Uni Press, Ames. Pp. 99-107.

Katona, G. Z., R. A. Davis and G. F. Searing. 2000. Evaluation of the efficacy of various deer exclusion devices and deterrent techniques for use at airports. Unpublished report by LGL LIMITED
environmental research associates, for Aerodrome Safety Branch, Transport Canada, Ottawa, Ontario K1A 0N8 (available at http://www.tc.gc.ca/civilaviation/Aerodrome/WildlifeControl/Deer/menu.htm

Macdonald, C.R. 2003. Summary report on the analysis of soil and plant samples collected at the Colomac mine site in September 2002. Indian and Northern Affairs Canada, Yellowknife, NT.

MacDonald, C. and A. Gunn. 2004. Analysis of the ash weight and elemental composition in caribou (*Rangifer tarandus*) faecal pellets collected at Colomac and other sites in the NWT. Northwest Territories Department of Resources, Wildlife and Economic Development, Manuscript Report 159, 51 pp.

Marrs, T.C. and B. Ballantyne. 1997. Clinical and experimental toxicology of cyanides: an overview. In: Ballantyne, B., and T.C. Marrs (eds). Clinical and experimental toxicology of cyanides. Wright, Bristol, pp. 473-499.

Towill, L.E., J.S. Drury, B.L. Whitfield, E.B. Lewis, E.L. Galyan and A.S. Hammons. 1978. Reviews of the environmental effects of pollutants: V. Cyanid. US Environ Prot Agen Rep 600/3-79-009, pp 1-129.

US Environmental Protection Agency (USEPA). 1980. Ambient water quality criteria for cyanides. US environ Prot Agen Rp 440/5-80-037. Pp. 1-72.