Heavy metals in reindeer and their forage plants

O. Eriksson[1], A. Frank[2*], M. Nordkvist[2] and L.R. Petersson[2]

[1]Department of Animal Husbandry, Reindeer Section, Swedish University of Agricultural Sciences, Box 7024, S—750 07 Uppsala

[2]The National Veterinary Institute, (SVA), Box 7073, S—750 07 Uppsala, Sweden

*To whom correspondence should be addressed

Abstract: An attempt was made to assess the level of heavy metal transfer from forage plants to reindeer (*Rangifer tarandus L.)* in an area in northern Lapland affected from dust from an open pit copper mine.

Botanical analyses of rumen contents from reindeer provided information about the main plant species in the diet. Representative plant material was collected from sample plots within an 8 km radius from the central part of the mine and from a reference area situated about 200 km upwind of the mining site.

The following plant species were analysed: *Bryoria fremontii, Br. fuscescens, Cladina rangiferina, Equisetum fluviatile, Deschampsia flexuosa, Eriophorum vaginatum, Salix glauca, Salix phylicifolia, Betula nana,* and *Vaccinium myrtillus.*

The greatest difference between metal concentrations in the plants collected from dust contaminated area and from the reference area was found in lichens. Copper is the main metallic component of the ore and was found in higher concentrations in lichens coming from the area around the mine than in lichens from the reference area. Smaller differences were found in vascular plants. Dust particles, remaining on outer surfaces after snow smelt contributed to a limited extent to the metal contents. Species—specific accumulation of metals was observed in some plants. The uptake of lead and cadmium in some vascular plants was somewhat higher in the reference area compared with plants growing in the perifery of the mining center, probably due to the metal concentrations in the bedrock.

Organ material (liver and kidney) was collected from reindeer in both areas. No noticable effect on metal concentrations in the liver of the reindeer were found. Although the lead, cadmium and copper concentrations were higher in the organs collected from animals in the reference area than in those from the mining area, the levels were still below the concentrations regarded as harmful for the animals from toxicological point of view.

The material collected during this study would also lend itselfto research into the trace element nutrition of the reindeer.

Keywords: Reindeer forage, liver, kidneys, industrial emission, pollution, heavy metal accumulation

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Figure 1. Aitik, the reference area and Gällivare Forest Saami Community.

Introduction

Copper is extracted through open pit mining at Aitik, county of Norbotten, Sweden (Fig. 1.). Blasting causes emission of metal—containing dust (Rühling, 1978 & 1979, Göransson, 1983).

Applying for permission to increase production Boliden Mining Co. Ltd. was instructed by the National Franchise Board for Environment Protection to examine whether content of certain metals in and on reindeer forage plants and reindeer organ tissues exceeded current toxicological standards as prerequisites for a good state of health. This clam was caused by the fact that the mining area is situated within the summer range of Gällivare Forest Saami Community and that fears had been uttered by the Saami Community that the reindeer (and consequently the meat market) might be affected by heavy metals deposited with the dust.

The contents of copper and zinc in the moss *Pleurozium schreberi* and reindeer lichen (*Cladina spp.*) growing around the mine were analysed by Rühling (1978 & 1979). High copper concentrations (1600 mg/kg) were observed in the moss growing in the immediate vicinity of the mine, and concentrations over 100 mg/kg were found as far as at a three kilometre distance. The regional background level of 5 — 10 mg/kg was not reached until some ten kilometres from the mine, and elevated zinc contents were observed only in the immediate neighbourhood of the mine centre. Similar conditions but with lower metal concentrations (not more than 370 mg Cu/kg) were observed in reindeer lichen *(Cladina rangiferina)*.

The Aitik area is used by the Ratukka Group of the Gällivare Saami Community (SOU 1966). Direct movements between seasonal grazing areas are made only to a limited extent. The movements of the reindeer herds are described as "roving" or migration grazing (Planverket, 1974). Grazing of the area occurs mainly when there is no snow on the ground (July through September) but reindeer herds may be present in the area even at other times of the year (Erik Lindström, the County Government; Åke Nordvall, the Ratukka Group).

Aims

This study aims at

— clarifying the reindeer's choice of forage plants in the Aitik area during summer time,

— studying the content of metals in important reindeer forage plants, and

— studying the metal content in reindeer organs.

Areas for collection of biological materials

The mining site (lat. 67° 05' N, long. 20° 55' E) and the reference area (lat. 66° 15' N, long 18° 15' E) (cf. Fig. 1) are both within the Fennoscandian subprovince of the Boreal European-Westsibirian flora province (Sjörs, 1956). The vegetation is a mosaic of coniferous forests and poor northern fens (Domänverket, 1981).

Table 1. Sampled and analyzed forage plants

Species	Plant part	Sampling date			
		May	June	July	August
Bryoria fremontii (Tuck) Brodo & Hawksw.	all	+			
Br. fuscescens coll (Gyeln) Brodo & Hawksw.	all	+			
Cladina rangiferina L. Nyl.	top third	+	+		+
Stereocaulon paschale L. Hoffm.	top third		+		+
Equisetum fluviatile L.	stem			+	+
	rhizome		+		
Deschampsia flexuosa L.	above ground			+	
Eriophorum vaginatum L.	above ground	+		+	+
Salix glauca L.	buds, leaves		+		+
S. phylicifolia L.	buds, leaves		+		+
Betula nana L.	bark, buds, leaves			+	+
Vaccinium myrtillus L.	top 5 cm		+		+

The climate is continental. The humidity index of Martone is 32 - 36 during the growing season of 140 - 150 days above + 3°C.

Yearly precipitation is 400 - 450 mm, whereof 175 - 200 mm fall during the growing season and about 150 mm, 35 - 40% fall as snow. The latter stays for 200 - 220 days (Svenska sällskapet för Antropologi och Geografi, 1953 - 1971).

Winds from W - NW and from SE are dominating throughout the year (Fig. 4).

The reference area was considered free of deposition and man-made effects, but it is situated in the periphery of an ore province (Ores, industrial minerals, and rocks in Sweden. Map, SGU, ser. Ba No. 29, 1979).

Materials

Collecting has been carried out around Aitik and within a reference area (cf. Fig. 1 and Fig. 5). The test material consists of reindeer forage plants and reindeer organs.

a) Sampling of plants

To describe the distribution pattern of heavy metals within the Aitik area metal concentrations of some important reindeer forage plants were used. For chemical analysis the plants were collected at about the same time in both Aitik and the reference area.

At Aitik sampling plots were located at a distance of 1000, 2000, 4000, and 8000 m from the centre of the mine along NW - SE and NE - SW transects. The transects coincide with dominant wind directions (Fig. 4). In addition plots were chosen in all points of the compass, right outside the fence surrounding the mine.

In mid-May, mid-June, mid-July, and mid-August 1982, plant samples were collected within all sampling plots. As shown in Fig. 3 and Table 1, stress was laid on plants of importance to reindeer during the sampling period. In July 1985 *Bryoria fuscescens* and *Br. fremontii* were once more sampled within both areas.

In August 1982, plant material equivalent to that of Aitik was collected at five locations within the reference area (Fig. 1).

Reindeer lichen from the June sampling at Aitik was used for determining wheter a metal accumulation in reindeer lichen occurred after the snow-melting period.

The plant material was classified, air dried, and packed for subsequent chemical analysis.

b) Sampling of rumen content for quantitative estimation of botanical composition.
During two periods (June 11 - 14 and August 12 - 19) five grazing reindeer, 10 animals totally, were shot in the Aitik area, and on one occasion (July 21) five reindeer were sampled during an ear-tagging session (Fig. 2).

From each animal about 2 litres of stirred rumen content was collected and preserved for quantitative botanical analysis.

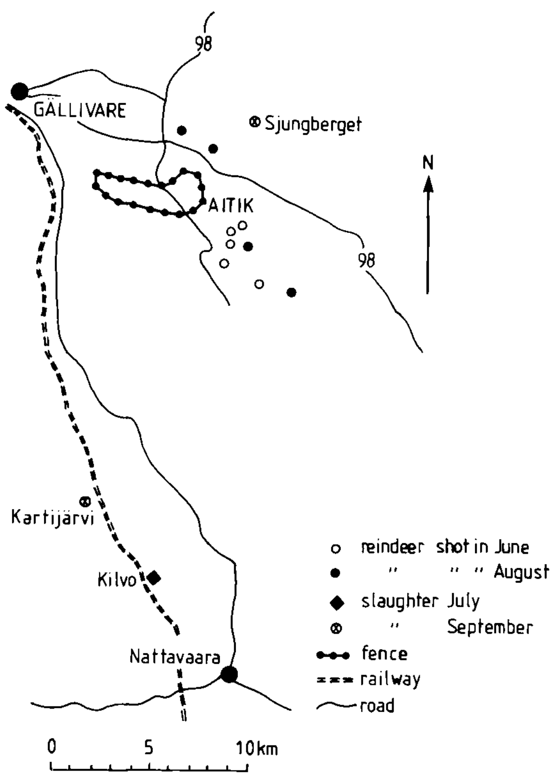

Figure 2. The sampling sites of reindeer around Aitik.

c) Sampling of organ material
Organ tissue samples were collected from the 15 reindeer which had also contributed rumen samples *(Aitik I)*.

Organ tissue samples were also collected from 29 reindeer *(Aitik II)* at routine slaughter in the autumn. Of these, 9 were slaughtered at Sjungberget, north of the mine, and 20 at Kartijärvi south of the mining area (cf. Fig. 2).

It should be pointed out that the degree of contact with the vicinity of the mine of the Aitik II reindeer has escaped determination. However, according to the local herdsmen most of the Ratukka-reindeer regularly utilize summer pastures round Aitik.

Reference samples from 20 reindeer were collected in connection with regular slaughter at Åberget (Fig. 1) in mid-December. A herd that had previously grazed within the reference area was then rounded up during its migration to the winter pastures.

The organ tissue samples consisted of liver and kidneys. The left metacarpal bone (for estimation of nutritional state) and the left mandibular bone (for age determination) were sampled as well. The Aitik material was examined at the SVA (the National Veterinary Institute), whereas corresponding investigations of the reference material was carried out at the slaughter site by members of the sampling staff.

The organ material was transferred to the SVA, where it was stored at -20° C until chemical analysis was performed.

Methods

a) Chemical analysis
Pretreatment of samples. - Combustion of *organ material* (5 g liver and kidney, respectively) was performed by automatic wet digestion. An oxidizing mixture (15 ml) of nitric/perchloric acids = 7:3 (vol.:vol.) was added to the samples in boro-silicate glass tubes, in an electrically heated block of aluminium. During the automatic wet digestion time and temperatures are controlled by a microprocessor (Autostep,

Digestor: Model 40, Tecator AB, Höganäs, Sweden) according to a standard ashing program (Frank 1976, 1983).

The air dried *plant samples* were cut to small pieces. One gram of each sample was wet digested according to the standard procedure.

Analysis. - The residue after wet ashing was evaporated to dryness and the dry residue dissolved in an ionic buffer solution for analysis using a direct current plasma-tomic emission spectrometer (SpectraSpan IIIA, Applied Research Laboratories Inc., Sunland, USA). The analysis comprised simultaneous determination of the concentration of i.a. lead, cadmium, copper, and zinc (Frank & Petersson, 1983).

Analytical results for plant material are given as mg/kg air dry weight, which means about 7 - 9 per cent water content; organ material results are given as mg/kg wet weight.

Mercury in the livers from the Aitik I and Aitik II materials was determined using neutron activation analyses (IVL, Institutet för vatten- och luftvårdsforskning, Stockholm, Sweden).

Statistical analysis were performed by using standard programs (Statgraphics) for i.a. calculation of linear regression.

b) Quantitative botanical analysis of rumen content

One litre of stirred rumen content was washed through a set of six sieves (mesh size ranging between 4000 - 125 μ m). Particles smaller than 125 μ m were discarded. The plant fragments were separated by aid of a grid and examined in a microscope.

The area frequency of plant groups was converted to frequency by weight using weight constants specific for plant groups and particle sizes (Eriksson et al., 1981).

Results and discussion

The summer diet of reindeer in the Aitik area

Figure 3 illustrates that dwarf shrubs contribute as much as 21 - 76 per cent to the summer diet of reindeer. In June *Vaccinium myrtillus* dominates, in July and August no species dominance was observed. The dwarf shrubs compartment then contains mainly *Vaccinium spp., Calluna vulgaris, Empetrum nigrum, Andromeda polifolia* and others.

Leaves from *Betula spp.* and *Salix spp.* were found in the rumens during the entire summer. In August there was a noticeable increase from 15 per cent by weight to 53 per cent. In June *Salix* leaves dominated, in July *Betula nana* and in August *Betula spp.*

Herbs occurred only in minor quantities (less than 1 per cent by weight).

Graminoids quantitatively played a major role in June only, when 12 per cent by weight

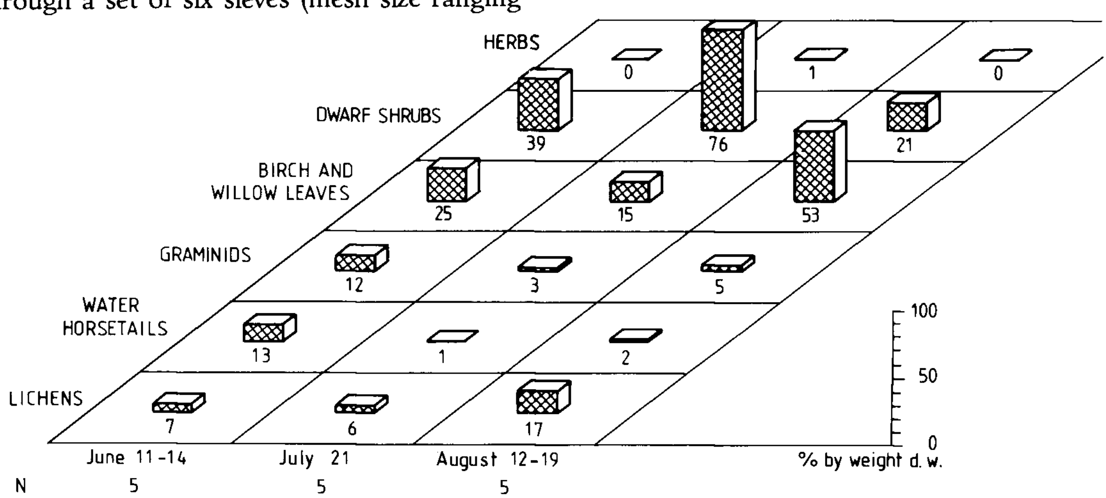

Figure 3. The forage selection of Aitik reindeer during summer. (Plant groups per cent by weight, d.w., + 80° C, 24 h.)

Table 2. Minimum and maximum values of copper and zinc concentrations in forage plants of reindeer in Aitik (n = 18) and the reference area (n = 5) in June, July, August 1982, and in July 1985. Values in mg per kg DM.

	month/82	Cu-Aitik	month/82	Cu-ref	Zn-Aitik	Zn-ref
Vaccinium myrtillus	8	6.5-16	8	6.7-14	21-47	19-42
Betula nana	6	7.5-52	8	2.3-3.8	109-282	128-206
Betula nana	7	4.1-25			91-232	
Salix glauca	8	3.0-25	8	5.1-7.4	39-410	151-567
S. phylici-	6	4.9-19	8	5.3-7.0	47-364	119-478
folia	8	2.7-12			8.8-230	
Deschampsia flexuosa	7	2.2-9.1	8	1.1-1.9	18-35	15-25
Eriophorum vaginatum	7	2.8-15	8	1.7-4.8	38-66	44-65
Equisetum fluviatile	7	2.2-17	8	0.95-3.0	32-72	39-97
Cladina	6	4.8-184			16-29	
rangiferina	8	3.9-170	8	1.0-1.6	13-30	15-22
	month/85		month/85			
Bryoria fremontii	7	4.9-54			32-61	
Br. spp.			7	2.0-2.2		30-32
Br. fusces-cens	7	6.8-132			49-86	

were registered. Among grasses *Deschampsia flexuosa* was common.

Equisetum fluviatile was frequent in June only, when it amounted to 13 per cent by weight. The high concentration of sodium (500 - 600 mg Na/kg D.M. and values even as high as 2530 mg/kg D.M. was determined in the reference area) should be of great importance to reindeer as a major sodium source. The sodium concentration in other vascular plants as well as in lichens were mainly between 100 and 200 mg/kg D.M.

Lichens occurred in the diet on all three sampling occasions. A marked increase was noted from 6 per cent in July to 17 per cent in August.

The plant species preference shown by the Aitik reindeer corresponded fairly well to the observations of Skuncke (1968) and Warenberg (1977) on domestic reindeer in Sweden, and those of Helle (1981) on wild Finnish forest reindeer *(Rangifer tarandus fennicus)*.

Plant material

Figure 5 shows the copper concentrations in *Cladina rangiferina* from the mining area.

The concentrations for copper, zinc, lead and cadmium are shown in Tables 2 and 3. They show the lowest and highest metal concentrations found in reindeer forage plants in the Aitik and the reference areas, respectively, as well as the date of sampling.

Considering the presence of gradients in the material from the Aitik area, which may be

Table 3. Minimum and maximum (lowest and highest) values of lead and cadmium concentrations in forage plants of reindeer in Aitik (n = 18) and the reference region (n = 5) in June, July, August 1982, and July 1985. Values in mg per kg DM.

	month/82	Pb-Aitik	month/82	Pb-ref	Cd-Aitik	Cd-ref
Vaccinium myrtillus	8	0.05-0.65	8	0.02-0.47	0.08-0.43	0.18-0.28
Betula nana	6	0.59-4.2	8	0.72-1.2	0.02-0.52	0.14-0.39
Betula nana	7	0.02-1.2			0.28-0.60	
Salix glauca	8	0.12-1.1	8	0.16-0.75	0.39-1.4	0.89-1.8
S. phylici-	6	0.02-0.34	8	0.47-0.74	0.28-1.3	0.80-2.0
folia	8	0.02-0.34			0.18-1.5	
Deschampsia flexuosa	7	0.21-1.0	8	0.29-0.73	0.02-0.24	≤0.02
Eriophorum vaginatum	7	0.02-0.72	8	0.47-1.2	0.02-0.22	≤0.02
Equisetum fluviatile	7	0.02-1.5	8	0.64-1.5	0.57-0.76	0.24-0.60
Cladina	6	2.7-6.7			0.10-0.30	
rangiferina	8	2.6-7.1	8	3.3-4.2	0.08-0.28	0.07-0.18
	month/85		month/85			
Bryoria fremontii	7	2.9-15			0.02-0.41	
Br. spp.			7	2.2-5.9		0.18-0.27
Br. fusces-cens	7	8.2-30			0.22-0.58	

more or less obvious, calculations of mean or median values have not been considered realistic.

Metals are transferred to and accumulated in lichens by airborn dust or dissolved in rain water (Monitor, 1987). According to Tuominen and Jaakola (1973), lichens also are able to take up and accumulate metals from the substratum via living or dead basal parts of thalli.

Metals are usually accumulated in lichens as ions adsorbed to cell walls (Monitor, 1987).

Zinc and cadmium, on the other hand, are carried within cells, and, - as far as it is known - are the only metals with distinctly harmful effects on lichens monitor, 1987).

Beyond accumulation of metal containing dust on outer surfaces (leaves etc.) metals are accumulated also by root uptake in *Betula nana*, *Salix spp.*, *Deschampsia flexuosa*, *Eriophorum vaginatum*, *Equisetum fluviatile* and *Vaccinium myrtillus*.

Copper: The highest copper concentrations found in *Cladina rangiferina* and *Bryoria spp.* from the reference area are low (1.6, and 2.2 mg Cu/kg) compared to the copper concentrations in *Cladina rangiferina*, *Bryoria fuscescens* and *Br. fremontii* from Aitik with the highest values of 170, 132 and 54 mg/kg, respectively (cf. Table 2).

Within a circle round the mine with a radius of about 8 kilometres the dust downfall has caused conspicuously elevated contents of copper in *Cladina rangiferina* and *Bryoria spp.* as compared to the reference area (cf. Fig. 4 and Table 2). The latter concentrations are in agreement with the values registered by Holm

Table 4. Heavy metals in reindeer lichen (*Cladina* sp.) from the Rogen area (1961-1975) µg/g dry weight (Holm 1981).

Fe	Zn	Mn	Pb	Cu	Ni	Cd
160 ± 20	18 ± 2	10 ± 3	9 ± 3	1.8 ± 3	0.70 ± 0.10	0.10 ± 0.02

(1981) in *Cladina* sp. at Rogen, county of Jämtland (cf. Table 4).

The mining company, within its own measuring program, is continuosly monitoring the dust downfall and its copper concentration at 9 measuring stations around Aitik (Göransson, 1983).

For these 9 downfall measuring stations the copper concentration of *Cladina rangiferina* was estimated by weighting measuring values from three adjacent plant sampling plots. Weights were inversely proportional to the square of the distance from the mine centre. A stepwise regression analysis between measuring values for copper in *Cl. rangiferina* and 24 monthly mean values was carried out. The downfall for the year 1982-1983 was proportional to the copper concentration of *Cl. rangiferina* (r^2 = 0.91) (cf. Fig. 6). How much of the downfall from the time before measuring that had contributed to the copper content of *Cl. rangiferina* is, however, not known.

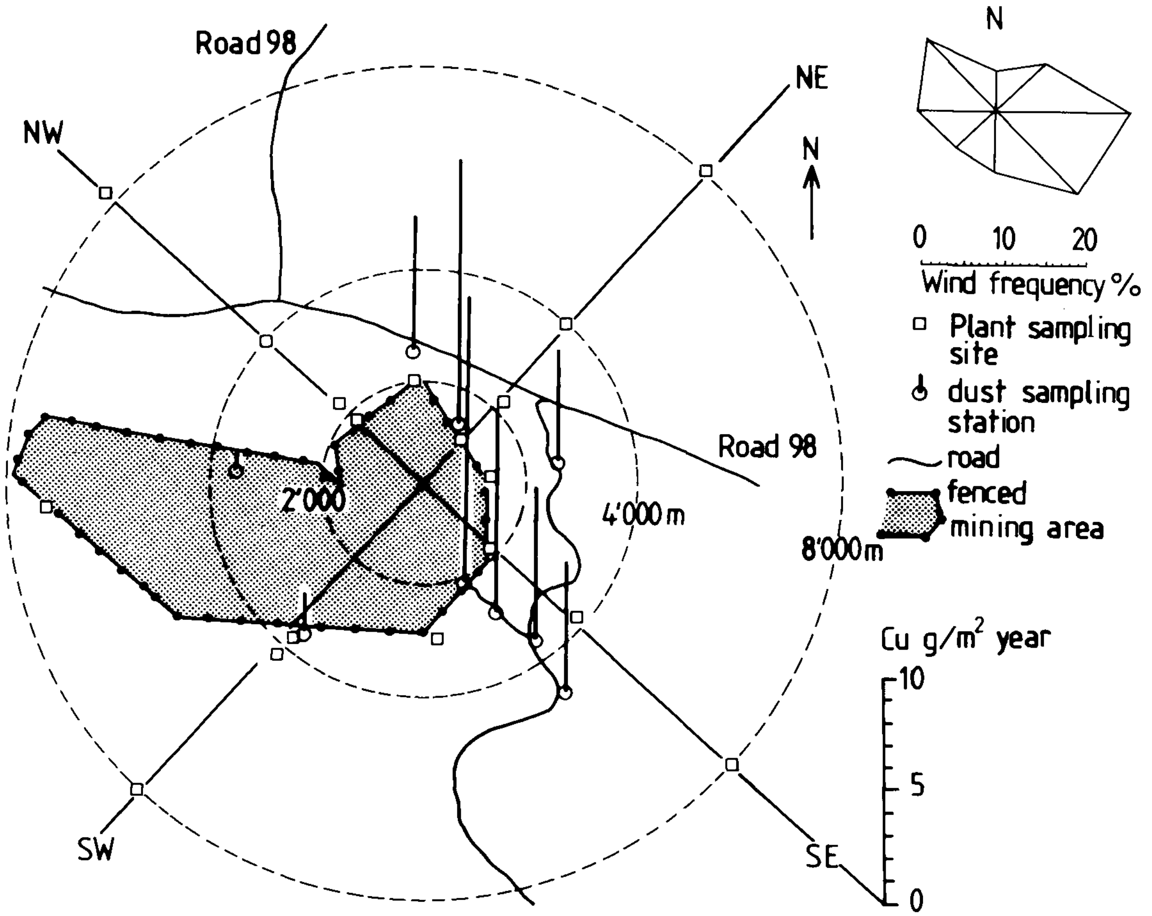

Figure 4. Fallout of dust-carried copper around Aitik, 1982 - 1983. (Wind frequency registered at Gällivare airport, close to the plant sampling site: NW 8'000 m.)

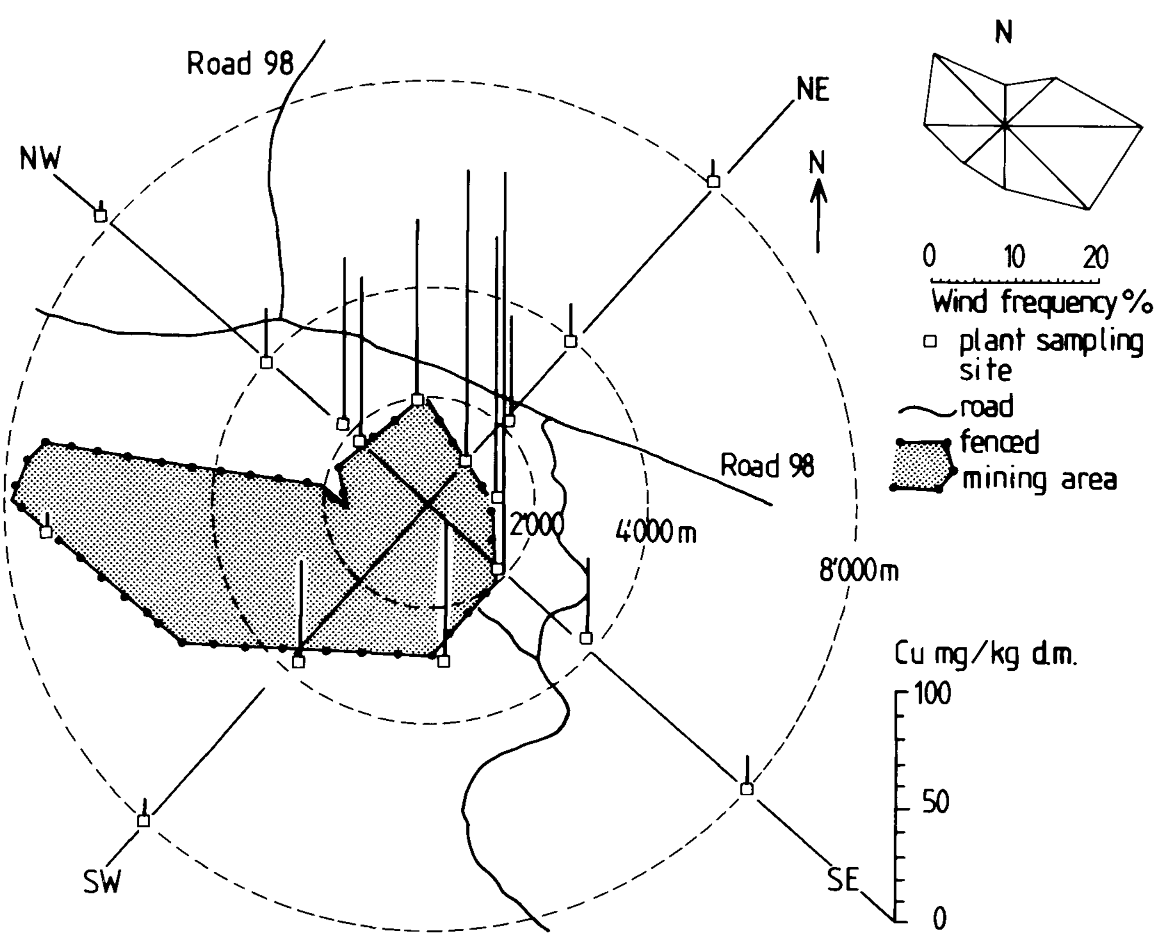

Fig. 5. Copper concentrations in *Cladina rangiferina* growing in the Aitik-area.

Figures 4 and 5 show the influence of dominating winds on downfall and copper concentration in *Cl. rangiferina* in the Aitik area. As expected, most of the copper in the lichens of the investigated area originates from the emission caused by the mining activities.

The highest concentrations of copper in *Cl. rangiferina* and *Bryoria spp.* have been established E and SE of the mine centre in dominating wind directions, show in Fig. 5, which together make 30 per cent of the relative wind frequency (SMHI, 1982). The highest values measured in *Cladina rangiferina* were 184 and 170 mg/kg (cf. Table 2 and Fig. 5), values which are much lower than the highest concentration (370 mg/kg) reported by Rühling (1979). The lowest value reported by Rühling (8 mg/kg) was in a distance of 12 kms West of the mining centre and is higher than the lowests in our survey (3.9 and 4.8 mg/kg).

Metal containing dust accumulates in snow during the winter. After the snow-melting period release and subsequent uptake of metals was negligible in *Cl. rangiferina* as shown by its copper concentrations in June and August. According to Table 2 minimum and maximum values were only insignificantly higher in the June material.

The highest *copper* contents of the reference area in *Salix glauca* and *S. phylicifolia* are 7.4 and 7.0 mg Cu/kg, respectively, whereas the corresponding plants from Aitik contained 25, 19 (June) and 12 mg Cu/kg (August), respectively, as shown in Table 2.

The copper concentrations in *Salix glauca* and *S. phylicifolia* of the reference area are of the same level and are about three times higher than those in *Cladina rangiferina,* indicating copper uptake from the ground of vascular plants. Compared to the lichens the differences in copper concentration between the *Salix spp.* of the reference and the Aitik area are not as great.

The differences in copper concentration in *Betula nana* between the reference area (2.3 - 3.8 mg/kg) and Aitik are conspicuous. The highest concentration of 52 (June) and 25 (July) mg/kg were found near the centre of the mining area.

Of the grass species examined, *Deschampsia flexuosa* from the reference area has low copper concentrations (1.1 - 1.9 mg/kg). The highest value from the mining area is 9 mg/kg.

Larger variations in concentration are shown by *Eriophorum vaginatum* (cf. Table 2). The copper concentration from the reference area is 1.7-4.8 mg/kg and the highest level from Aitik was 15 mg/kg.

A similar pattern is shown in *Equisetum fluviatile* with lower copper values from the reference area than from the Aitik area (2.2 — 17 mg/kg).

The range between minimum and maximum copper values is much larger in Aitik than in the reference area and varies with different plant species. The range is very wide for lichens but much more narrow for other plants.

In the reference area there is a tendency for the copper concentrations of the reindeer forage plants to be low. The only exception was shown by *Vaccinium myrtillus* with a slightly higher concentration of 14 mg/kg. This value is of the same magnitude as the highest concentration in Aitik (16 mg/kg) and is explained by the high degree of soil mineralization in the reference area.

Zinc: Zinc concentrations in *Cladina rangiferina* from Aitik (13 — 30 mg/kg) do not differ remarkably from those of the reference area (15 — 22 mg/kg, cf. Table 2) but they are about 2 — 3 times higher in *Bryoria spp.* from Aitik (61 and 86 mg/kg, respectively, as the maximum values), than from the reference area with zinc concentrations of 32 mg/kg as the highest values. In *Cladina rangiferina* from Aitik concentrations of 25 — 56 mg/kg were found by Rühling (1979) close to the values found in our investigation.

The zinc concentrations of the vascular plants are of the same magnitude in both areas. It is possible that there is a certain species specific accumulation of zinc in *Salix glauca* and *S. phylicifolia.* In the reference area on the border of the ore province zinc concentrations are higher (567 and 478 mg/kg, respectively) than in Aitik, when comparing the highest concentrations (410, 364, 230 mg/kg).

Differences in *Vaccinium myrtillus, Betula nana, Graminidae,* and *Equisetum fluviatile* are negligible as shown in Table 2.

Lead: A study of the highest lead values found does not give any indication for a general tendency for lead accumulation. If, however, separate lead concentrations are studied in detail a less uniform picture emerges.

The lead concentration in *Cladina rangiferina* from the reference area was 3.3 - 4.2 mg/kg as shown in Table 3. In Aitik, where the highest concentrations were 7.1 and 6.7 mg/kg, respectively, 11 of 17 measuring plots yielded lead concentrations exceeding the highest ones from the reference area.

For *Bryoria spp.* higher lead concentrations can be recorded for *Bryoria fuscescens* than for *Br. fremontii.* In the latter species the lead concentrations exceeded the highest value of 5.9 mg/kg from the reference area at 7 measuring plots only, whereby the highest value round the mine was 15 mg/kg. In *Br. fuscescens* all values were higher (8.2 - 30 mg/kg) than the highest ones of the reference area (cf. Table 3).

There is, however, a different picture to be seen when studying the lead uptake by vascular plants. In the latter the lowest lead values of the plants from the reference area are often higher than those from, e.g. *Beula nana, Salix glauca,* *S. phylicifolia*, *Deschampsia flexuosa*, *Eriophorum vaginatum*, and *Equisetum fluviatile* from Aitik. Thus, there are indications that the soils of the reference area are richer in minerals than those of Aitik, the latter mainly carrying cupreous minerals.

The higher lead concentration of the Aitik-lichens compared to those of the reference areas, may be explained both by anthropogenic sources in the ares, such as automobile transports etc. and by the lead concentration of the dust, the latter explanation finding support in the efficiency of *Bryoria fuscescens* in dust enrichment.

The results indicate that a certain deposition of lead occurs in the neighbourhood of the mine, but the mineralization and the lead uptake is larger in the vascular plants of the reference area than in those of Aitik.

Cadmium: In *Cladina rangiferina* of the reference area the highest cadmium concentration was 0.18 mg/kg. In Aitik 0.28 and 0.30 mg/kg were found to be the highest values. Differences are greater in the efficiently dust filtering *Bryoria spp.* In *Br. fremontii* and *Br. fuscescens* 0.41 and 0.58 mg Cd mg/kg, respectively, were observed as the highest concentrations in Aitik, whereas the cadmium concentration of the reference area did not exceed 0.27 mg/kg. Thus, cadmium levels increased towards the mining centre, probably as a result of increased dust downfall.

In similarity to lead it can be noted as a remarkable observation, that the lowest cadmium concentrations in *Salix glauca* and *S.phylicifolia* were higher in plants from the reference area (0.89 and 0.80 mg/kg, respectively) than in those from Aitik (0.39, 0.28, and 0.18 mg/kg). This phenomenon can be interpreted, partly as an indication of species specificity, partly as an expression for the higher degree of mineralization of the soils of the reference area.

The cadmium uptake of the other vascular plants was largely of the same magnitude in the two areas examined, possibly somewhat larger in the reference area.

Even for cadmium the same phenomenon as for lead can be observed, namely that the downfall at the mine implies a certain cadmium burden, but the greater mineralization in the soils of the reference area seems to bring about an increased cadmium uptake by vascular plants.

A constant characteristic of the metal concentrations (copper, zinc, lead, and cadmium) in sampled *Bryoria fuscescens* and *Br. fremontii* from Aitik was that the former had 138-282 per cent higher metal concentrations than the latter. *Br. fuscescens* was collected on Norway spruce *(Picea abies)* whereas *Br. fremontii* was collected on Scots pine *(Pinus sylvestris)*. One

Table 5. Regional means ($\bar{X}$), medians ($\tilde{X}$) and ranges (min - max) of lead, copper, zink and mercury in liver and kidney of reindeer (mg per kg wet weight)

Region	N	Lead			Copper			Zink			Mercury		
LIVER		$\bar{X}$	$\tilde{X}$	min-max	$\bar{X}$	$\tilde{X}$	min-max	$\bar{X}$	$\tilde{X}$	min-max	$\bar{X}$	$\tilde{X}$	min-max
Aitik I	15	0.27	0.13	0 -0.99	21	16	3.1-65	31	29	24-46	0.07	0.004	0.02-0.19
Aitik II	29	0.26	0.25	0.14-0.44	26	19	3.3-131	27	25	15-51	0.05	0.004	0.02-0.11
Ref.	20	0.81	0.75	0.40-1.66	29	21	7.7-72	32	31	24-45			
KIDNEY													
Aitik I	15	0.19	0.17	0.10-0.44	5.4	5.3	4.2-6.7	23	24	19-29	not measured		
Aitik II	29	0.28	0.26	0.13-0.48	5.0	4.8	3.4-7.4	23	24	20-28	"		
Ref.	20	0.42	0.44	0.22-0.70	4.0	4.0	3.1-4.8	24	25	19-29	"		

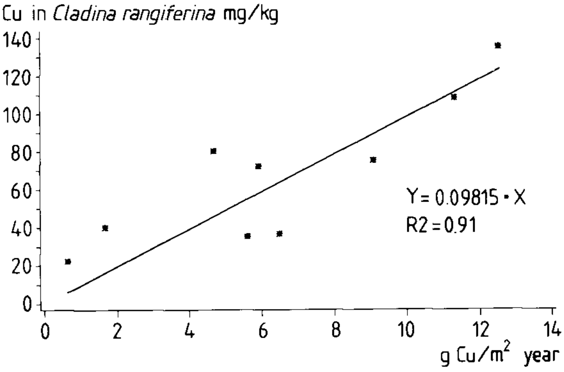

Figure 6. Dry deposition of copper at nine monitoring stations compared to copper concentrations in *Cladina rangiferina* (weighted mean values).

might suggest that the canopy of Norway spruce funnels wet downfall towards the parts of the tree where arboreal lichens grow more efficiently than does the canopy of Scots pine.

Organ material

Results of analysis of reindeer organs from Aitik I and II and from the reference area are shown in Table 5 and are further illustrated by Figures 7 & 8. There was a wide range in several elements, and therefore both mean and median values are given.

Copper: Mean values (medians within brackets) for copper concentrations from Aitik I, Aitik II, and the reference area are 21 (16), 26 (19), and 29 (21) mg Cu/kg, respectively. Range was considerable and largely of the same magnitude in all groups, excepting the highest copper concentration in liver of 131 mg/kg, which was found in the group from Aitik II. The value is considered moderately elevated. In a material from Norway higher concentrations were observed, 3.8 per cent of the reindeer examined having copper levels of more than 150 mg/kg liver (Frøslie *et al.* 1987).

The copper concentrations in liver varied considerably, an observation which coincides with earlier data on copper in the livers of wild ruminants (Bonniwell 1986). The concentrations found in the present material were in several instances critically low, seen from the nutritional point of view. As upper limit 10 mg Cu/kg wet weight is regarded for copper deficiency in domestic ruminants, especially in sheep. Serious deficiency in considered at levels lower than 3 - 5 mg/kg (Blood *et al.* 1989, Frøslie *et al.* 1987, Schwan *et al.* 1987).

If the same criteria are applied to reindeer, copper levels are inadequate in 27 percent of the Aitik I, in 31 per cent of the Aitik II, but in 5 per cent only of the reference material. No serious deficiency was found in our material, whereas in the Norwegian investigation 43 per cent of the material was reported to be deficient *(Frøslie et al.* 1987). The copper supply of the reindeer in the present investigation seems to be better than that in the Norwegian one.

The renal copper levels are within normal values in all groups. The mean concentrations (medians within brackets) were 5.4 (5.3), 5.0 (4.8), and 4.0 (4.0) mg Cu/kg for Aitik I, Aitik II, and the reference area, respectively. It was interesting to note that the copper concentration in the livers was lowest in Aitik I and highest in the reference reindeer, where as in the kidneys the case was reversed. This fact is true both for mean values and medians (cf. Fig. 7).

The following thoughts may contribute to a possible explanation. The two grazing areas in question have different geo-chemical backgrounds. Different elements may interact in reindeer organs. Higher intake of copper, but also of molybdenum and tungsten, in the reference area, can be thought to influence copper metabolism and the excretion of copper in pastures otherwise rich in copper. High levels of tungsten were found in some vascular plants from the reference area as illustrated by *Equisetum fluviatile* (5.8 - 50 mg W/kg, *Betula nana* (2.8 - 4.0 mg W/kg) and *Salix phylicifolia* (4.2 - 5.0 mg W/kg). Both molybdenum and tungsten are known to influence the copper metabolism of ruminants, especially that of sheep (Blood et al. 1989). The copper state of the reindeer in the reference area is the highest, although neither high nor low extremes are present, and it is possible that this fact is due to interaction with molybdenum and/or tungsten.

Zinc: The range in zinc concentration in liver has not been found to be as wide as that for copper. Only in Aitik II there are reindeer, at a rate of 21 per cent, with zinc levels lower than 20 mg/kg. The median values (27 - 31 mg Zn/kg) are of the same magnitude as that found in the investigation in Norway (28 - 48 mg/kg), but the range in the latter material is much wider. The highest zinc value in the Swedish material was 51 mg/kg compared to 120 mg/kg in the material from Norway (Frøslie *et al.* 1987).

The *zinc* levels in kidney are largely the same in three groups.

Lead: The mean (and median) value in livers is 0.27 (0.13) in Aitik I, 0.27 (0.25) in Aitik II, and 0.81 (0.75) mg/kg in the reference group. Corresponding values for kidney are 0.19 (0.17), 0.28 (0.26), and 0.42 (0.44) mg/kg (cf. Table 5). The result is a clear indication and it is shown in Fig. 7, that the reindeer in Aitik I are the least lead burdened, and those of the reference area the most heavily burdened. The higher lead burden and the better rate in copper supply might be explained by the higher rate of mineralization of the soil of the reference area.

The lead burden of reindeer in Norway showed a wide regional variation (Froslie *et al.* 1984). Mean values from 0.19 (Hattfjelldal, mid Norway) to 1.08 mg/kg (Dovre, south Norway, with maximum value of 1.8 mg Pb/kg) were obtained, whereas in our investigation the highest value observed was 1.66 mg/kg.

Mercury: Analysis have been made in livers from Aitik I and Aitik II only. The median value was low in both groups. The exposure to mercury is considered to be low. The highest mercury concentrations observed (0.19 and 0.11 mg/kg, respectively) are comparable to the highest values observed in Norway (0.24, Dovre, south Norway, and 0.18, Karasjok and 0.10 mg Hg/kg, Sortland, north Norway, Frøslie *et al.* 1984).

Table 6. Cadmium concentrations in liver and kidney from the reindeer in Aitik I, Aitik II and the reference area. Means $\overline{X}$, standaerd deviations (S.D.), and ranges (min - max), mg Cd per kg wet weight.

		LIVER			KIDNEY		
Age, years	N	$\overline{X}$	S.D.	min-max	$\overline{X}$	S.D.	min-max
AITIK I							
1 - 2	6	0.15	0.07	0.05-0.25	0.45	0.25	0.22-0.93
3 - 4	6	0.15	0.05	0.09-0.21	1.33	1.58	0.29-4.42
5 - 8	3	0.31	0.08	0.22-0.38	2.99	2.18	0.67-4.99
AITIK II							
2.5	3	0.17	0.07	0.09-0.23	0.71	0.45	0.31-1.19
3 - 4.5	20	0.22	0.07	0.14-0.42	1.29	0.74	0.50-3.42
5 - 8	6	0.44	0.33	0.21-1.09	3.94	3.06	1.23-8.47
REFERENCE							
1.5 - 2.5	7	0.44	0.15	0.22-0.62	1.44	0.62	0.49-2.22
4.5	2	0.70	0.04	0.68-0.73	4.38	0.54	4.00-4.77
5.5 - 7.5	11	1.00	0.39	0.58-1.89	10.2	6.28	2.52-19.0

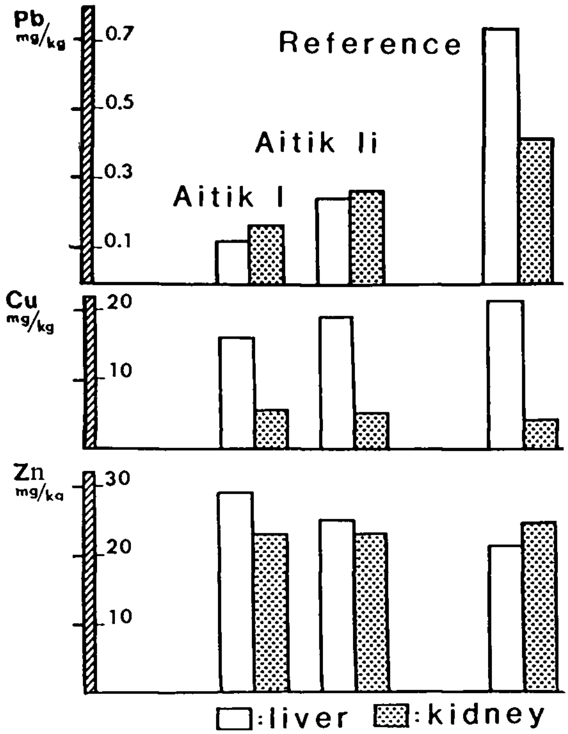

Figure 7. Lead, copper, and zinc concentrations in the liver and kidney of the reindeer from Aitik I, Aitik II and reference areas.

Cadmium: With a view to the fact that cadmium accumulation in liver and kidney is age dependent the groups have been treated according to age for the preliminary study. The result of the statistical treatment (cf. Table 6) illustrates this fact when cadmium levels in liver and kidney are concerned.

A heavier cadmium burden of the reindeer of the reference area than of those from Aitik is statistically significant in both liver and kidney for both age groups (P 0.01 for kidney in the younger age group; in the other age groups P is <0.001).

As mentioned above the accumulation of cadmium in liver and kidneys is age dependent. Therefore, one can not express the cadmium burden of an animal species without considering the age of the individual. The longer an animal has lived in a certain environment, the higher the cadmium levels in the organs become. Cadmium accumulates in the liver, but mainly in the kidneys. The correlation between cadmium concentration and age can be approximately define in the form of a linear regression and be expressed by the equation: $Y = A \cdot X + B$, where Y is the cadmium concentration of the organ and X is the age of the animal. A and B are constants, A (slope of the regression line) is characteristic for a certain region and/or population, and should be used together with B, the intercept of the regression line.

The constants A and B calculated for age dependent cadmium accumulation in kidney and liver for the three groups are shown in Table 7.

Table 7. Calculated values of A (slope) and B (intercept) of regression lines expressing the cadmium burden of populations as a function of Cd-concentration in the respective organ (kidney resp. liver) and the age of the animal. All values in mg Cd per kg wet weight.

Population	Kidney		Liver	
	A	B	A	B
Aitik I	0.54	-0.52	0.031	0.077
Aitik II	0.90	-1.79	0.055	0.044
Reference	1.93	-2.71	0.112	0.239

Figure 8 illustrates the relation between age and cadmium accumulation in kidney in the groups examined from Aitik I, Aitik II, and the reference area. Where the slope is the largest the same goes for the cadmium burden. The latter is largest in the reference area, as is the uptake of copper and lead, the explanation being the high degree of soil mineralization of the reference area.

Similar calculations were reported in an investigation of Norwegian wild as well as domestic reindeer (Froslie et al. 1986). The regression coefficients (slopes) represent three regions in Norway with values of 1.8 in the South, 1.5 in the middle, and 0.25 in the

North. In comparison with the values from Norway, the ones from Sweden calculated from nearby areas, seem to reveal a higher degree of local variations. However, comparison of slopes gives only a rough idea of not fully comparable relative values.

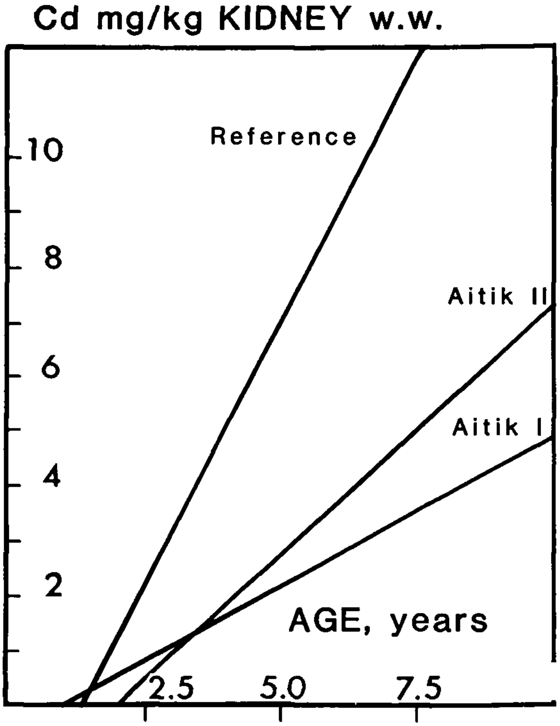

Figure 8. Age related cadmium accumulation in the kidney of reindeer from Aitik I, Aitik II and reference areas.

The intercepts, shown in Fig. 8 and the values given in Table 7, but not given in the Norwegian investigation, show a great variation from positive to negative values depending on individual variations in the investigated groups. As the regression line in total expresses the relationship between age and cadmium concentration of the kidney, neither A nor B must be neglected. Consequently, only the slopes do not give the true values, on the other hand taken together with the intercept result in unrealistic values.

The material has been treated also according to another statistical model, which is less prone to objection and allows comparison of the cadmium burdens of different regions. A quotient is formed by dividing the cadmium concentration of the respective organ with the estimated age of the animal. From these quotients mean and median values are calculated as shown in Table 8. No weighting for age distribution has been made, as the size of the population is limited and the age distribution is different in the three groups.

Table 8. Means $\bar{X}$, $\bar{Z}$ and medians ($\tilde{X}$, $\tilde{Z}$) of the quotients of Cd-concentration in the organs (kidney resp. liver) and the age of animals expressing the cadmium burden of the investigated populations. All values in mg Cd per kg wet weight.

Population	Kidney		Liver	
	$\bar{X}$	$\tilde{X}$	$\bar{Z}$	$\tilde{Z}$
Aitik I	0.285	0.234	0.051	0.069
Aitik II	0.369	0.311	0.056	0.067
Reference	1.297	1.053	0.157	0.196

In comparison to the values calculated as in Table 8 the calculation as in Table 7 yields more correct values, negative intercepts according to the first calculation mode are unlikely to occur. Age determination by way of visual estimation and not by closer examination of cut sections of the teeth means a somewhat uncertain procedure. Medians are preferable means and show the average yearly cadmium uptake in the respective organ in the actual population and the respective region in question.

The calculation illustrate the same feature, namely, that the cadmium burdens like the uptake of other trace elements by animals and vascular plants were heaviest in the reference area.

Summary

Activities at the open pit copper mine at Aitik, county of Norrbotten, causes fallout of con-

siderable amounts of metal-containing dust in the neighbourhood of the mining area. Mapping of metal contamination was made round the mine and within a reference area by analysing important reindeer forage plants as well as liver and kidneys from reindeer.

The highest metal contents were demonstrated in lichens, which accumulate *i.a.* metals by airborne deposition and with precipitation. Elevated concentrations of copper could be registered within an area with the mine as its centre and with the radius of 8 kilometers. Outside that range background levels were generally obtained. For zinc, lead, and cadmium higher values than normal background levels were not found other than in close vicinity of the mine. Dominating winds contributed to an increased contamination NE - SE of the mine.

Near the centre of the mining area copper concentration even of the vascular plants was higher, probably due to the metal-containing dust. A clear trend towards elevated metal concentration in the vascular plants of the reference area could also be registered, even though no notable presence of airborne dust could be observed. This phenomenon is thought to be due to the fact that the reference area is situated on the border to an ore province. The finding even of a species specific metal accumulation has been made during the study.

Analysis of reindeer organs revealed largely the same offering of metals as did the analysis of the forage plant material. Copper, lead, and cadmium levels were higher in the reindeer of the reference area than in those of the mining area. In comparison with the animals from the reference area the differences in metal concentrations were smaller between reindeer from Aitik I and Aitik II. The latter, though, presented signs of the stronger influence of metals, which in turn, may be due to the possibility that they may have been grazing in other - unknown - areas with a heavy metal burden, or to the fact that they were slaughtered in September and had consequently the time to consume considerable amount of lichens after slaughtering of the Aitik I reindeer had occured.

Reindeer migrate and utilize widely spread pastures. A local source of metal emission, consisting in the present investigation of copper mainly, does not seem to imply any health hazard worth mentioning.

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