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Influence of Season and Diet on Liver and Kidney Content of Essential Elements and Heavy Metals in Svalbard Reindeer

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ABSTRACT

Samples of liver (n = 78) and kidney (n = 60) from Svalbard reindeer (*Rangifer tarandus platyrhynchus* Vrolik) collected at four different seasons in Svalbard were analysed for their content of Cd, Pb, Cu, Zn, Mn, and Se. The study shows that when animals are exposed to large seasonal variations in both the quality and quantity of food, it is crucial to relate element concentrations to the physiological condition of the animal, e.g., to look at seasonal fluctuations in the total element content of the different organs.

Index Entries: Cadmium; copper; kidney; lead; liver; manganese; selenium; Svalbard reindeer; zinc.

INTRODUCTION

Earlier investigations have shown that the Svalbard reindeer is exposed to seasonal Fe overload *(1,2)*. During the winter season, the animals normally feed on Fe-rich mosses that are very poor sources of energy and protein. The liver in animals in late winter therefore has high

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concentrations of Fe due to storage from 1) catabolized blood and lean tissue, and 2) high uptake of food Fe.

In Svalbard, many of the most important reindeer forage plants have been shown to have a higher content of several minerals than similar plants in Norway *(3)*. The dietary shift from lichens as a major forage component during winter in Norway to mosses in Svalbard may also contribute to a change in mineral intake.

The efficiency of the absorption of several trace elements has been found to vary with season in the Svalbard reindeer *(4)*, and this will probably influence the mineral retention.

The aim of the present study was to determine the seasonal content of several trace elements in liver and kidney as a measure of mineral retention in the Svalbard reindeer.

MATERIALS AND METHODS

During the period April 1984 to April 1986, samples of liver and kidney from Svalbard reindeer (*R. t. platyrhynchus*) were collected at four different seasons from different locations in Svalbard (Table 1). In contrast to continental migratory reindeer/caribou, the Svalbard reindeer are restricted in their movements, and an exchange of animals between the four areas does not occur. A total of 78 animals were investigated; 36 females and 42 males. Total body wt (TBW), liver weight (LW), and kidney weight (KW) were measured. Age was determined from annuli in the cementum of the first incisor *(5)*.

Due to special climatic conditions at Isfjordflya in April, 1985, the content of rumen from animals in this area (coastal) consisted mainly of marine algae (*Laminaria* sp), i.e., the animals were not only going through their normal winter starvation, but also had a very different diet compared to inland animals that feed on mosses and woody plants during the winter.

Chemical Analyses

The elements Cd, Pb, Cu, Zn, and Mn were determined by flame atomic absorption after digestion in a mixture of nitric and perchloric acid *(6)*. The element Se was determined with a hydride generator system after the same digestion *(7)*. According to Reimers et al. *(8)*, the water content of the liver and kidney do not vary with season. All results are therefore given as μg/g wet wt. The detection limits were 0.1 mg/kg tissue for Cd, 1 mg/kg tissue for Pb, Cu, and Zn and 0.2 mg/kg tissue for Mn when starting with 3 g of sample, and 0.01 mg/kg tissue for Se when starting with 1 g sample. Standard reference Material 1577a bovine liver and MA-A 1 and 2 fish homogenate from National Bureau of Standards (Analytical Standards AB, Kungsbacka, Sweden) were used for control of the analytical method. The laboratory participates in interlab-

Table 1
Number of Svalbard Reindeer (*Rangifer tarandus platyrhynchus* Vrolik) and Different Locations in Svalbard Where Animals Were Collected During the Period April 1984 to April 1986 (n = 78)

	January	April[a]	July August	October
Gangdalen (inland)		8		
Adventdalen (inland)		9		4
Reindalen (inland)		4		
Isfjordflya (coastal)[b]	12	13	16	12

[a]Geographical variations in the same season; cf Figs. 3 and 5.
[b]Seasonal variations in the same location; cf Figs. 1–4.

oratory calibration studies organized nationally and also within the Scandinavian countries.

Statistical Analyses

By use of a commercial statistical computer program (SAS®) the different sets of data were examined for significant differences ($p < 0.05$) by Wilcoxon's rank–sum test, and correlation analyses were done by t-test or Pearson product–moment correlation.

RESULTS

Age was determined in 44 of the animals (Table 2). Average TBW and LW from 76 animals and KW from 51 animals are given in Table 2. Due to the climatic conditions in Svalbard, the total body wt of the Svalbard reindeer may vary through the year with a factor of almost two. In the present investigation, the ratio between the average body wt in October and April is 1.8. The LW and KW showed even larger variations, the ratio between July/August and April being 2.8 and 2.2, respectively (Fig. 1).

Females and males showed the same tendencies in seasonal variations in TBW, LW, and KW and in element concentrations. The data from one location (see Table 1, Isfjordflya) are therefore presented for both sexes combined (Figs. 1–4).

The mean concentrations over the year and ranges of Cd, Pb, Cu, Zn, Mn, and Se in liver and kidney for all the animals collected are given in Table 3. When investigating all parameters determined, there were no differences between sexes, except for a slightly higher mean Cd concentration in kidneys from females compared to males. The difference was, however, not statistically significant.

Since both seasonal and geographical conditions may influence the concentrations of the elements, the differences related to these factors are reported below.

Table 2
Age, TBW, LW, and KW of Svalbard Reindeer
(*Rangifer tarandus platyrhynchus* Vrolik) at Different Regions and Seasons[a]

Season	*n*	Age, y	*n*	TBW, kg	LW, g	*n*	KW, g
Females							
Jan.	5	6.5 ± 4.5 (0.8–13)[b]	5	53.8 ± 7.9	424 ± 59	5	45.9 ± 8.4
Apr.	13	6.5 ± 2.3 (3–10)	16	39.0 ± 5.5	384 ± 49	6	44.5 ± 5.4
Jul./Aug.	–	—	5	52.4 ± 9.2	1134 ± 178	5	86.8 ± 9.1
Oct.	5	4.0 ± 2.3	10	68.3 ± 5.3	659 ± 110	6	55.6 ± 3.1
Males							
Jan.	7	5.6 ± 2.9 (2–8)*	7	68.4 ± 14.2	659 ± 221	7	67.1 ± 18.2
Apr.	6	4.4 ± 2.2 (2.5–7)	16	48.2 ± 8.8	561 ± 127	6	47.9 ± 12.2
Jul./Aug.	6	9.0 ± 1.7 (7–12)	11	76.2 ± 10.7	1434 ± 175	11	123.2 ± 17.3
Oct.	2	10,3	6	78.7 ± 5.6	900 ± 212	5	85.1 ± 19.0

[a]Values given are Mean ± SD. Age, $n = 44$; LW, $n = 76$; KW, $n = 51$.
[b]Range in parentheses.

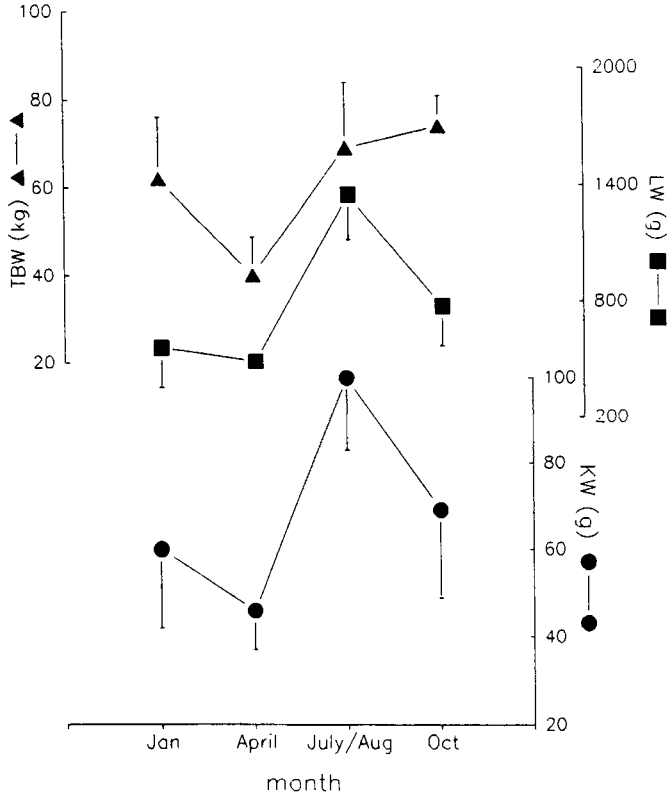

Fig. 1. Seasonal variations in TBW, LW, and KW (both sexes combined) of Svalbard reindeer from Isfjordflya (coastal area).

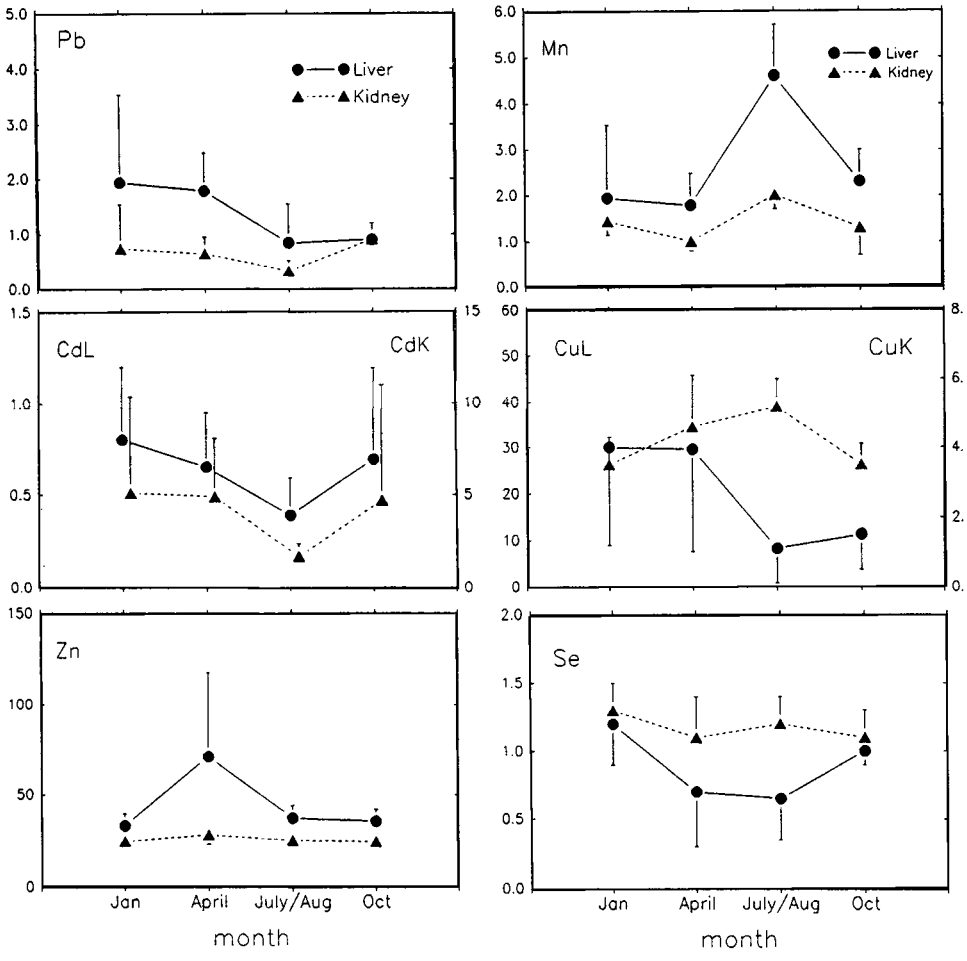

Fig. 2. Seasonal variations in hepatic and renal trace elements concentrations (µg/g wet wt) in both sexes combined of Svalbard reindeer from Isfjordflya (coastal area).

Seasonal Differences

For the samples collected at Isfjordflya, the liver and kidney concentrations of Cd, Pb, Cu, Zn, Mn, and Se are plotted against month of collection (Fig. 2). However, the large seasonal variations in LW and KW (Fig. 1) contribute to the differences in the concentrations. Variations in total hepatic and renal content of the different trace metals in the animals collected at Isfjordfly are therefore shown in Figs. 3 and 4.

Geographical Differences

The liver concentration of some elements in samples collected in April vary considerably with different regions (Fig. 5). For instance, samples from Isfjordflya (coastal area), where the animals fed on marine

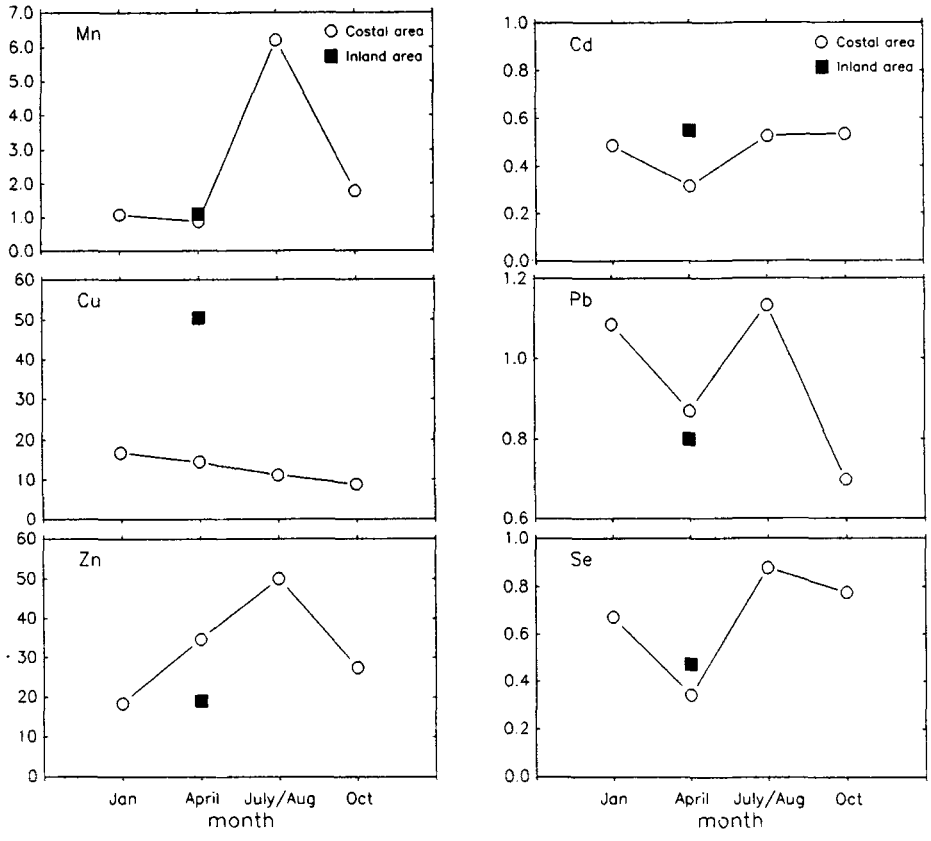

Fig. 3. Seasonal variations in total hepatic content (mg) of trace elements in both sexes combined of Svalbard reindeer collected at the coastal area. The hepatic content in animals from the inland areas in April is also shown.

algae (in 1985), demonstrate significantly lower hepatic Cu concentration than those from the three inland areas, i.e., Gangdalen ($p < 0.001$), Adventdalen ($p < 0.01$), and Reindalen ($p < 0.001$), where the animals fed on mosses and woody plants. The hepatic Zn concentration in samples from Isfjordflya was significantly higher than those from Adventdalen ($p < 0.05$), whereas the corresponding renal level was significantly higher than those from both Adventdalen ($p < 0.01$) and Reindalen ($p < 0.01$). Also, in October, the animals from Isfjordflya had a lower liver Cu than those from Adventdalen ($p < 0.001$). The total liver content of trace elements of the inland animals in April are shown in Fig. 3.

The mean concentrations over the year (Table 3) were used to study possible correlations.

Correlations

Correlations between the concentrations in liver and kidney were for Cd ($r = 0.78$, $n = 60$, $p < 0.001$), Mn ($r = 0.70$, $n = 57$, $p < 0.001$), Zn ($r =$

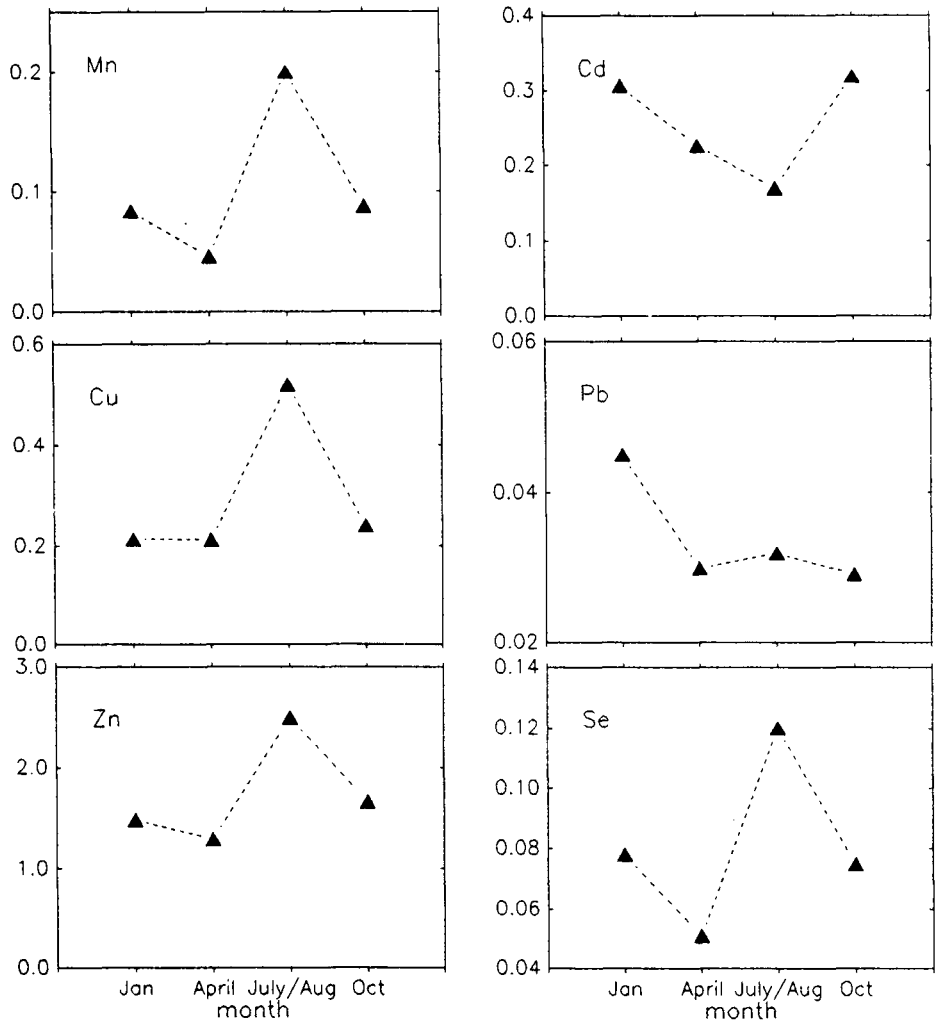

Fig. 4. Seasonal variations in total renal content (mg) of trace elements in both sexes combined of Svalbard reindeer collected at the coastal area.

0.47, $n = 60$, $p < 0.001$), and for Se ($r = 0.53$, $n = 47$, $p < 0.001$). The correlation of Se and Cd in liver was $r = 0.41$, $n = 76$, $p < 0.001$. For Cd and Zn concentrations in kidney, the correlation was $r = 0.43$, $n = 60$, $p < 0.01$.

The correlation between TBW of the animals and LW was found to be $r = 0.68$, $n = 69$, $p < 0.001$. For Cu there was a negative correlation between hepatic concentration and LW ($r = -0.49$, $n = 70$, $p < 0.001$), whereas for Mn, there was a positive correlation with LW ($r = 0.68$, $n = 54$, $p < 0.001$).

Concentrations of Cd in both liver and kidney increased with increasing age, $r = 0.59$ ($n = 44$, $p < 0.001$) and $r = 0.76$ ($n = 38$, $p < 0.001$) (Fig. 6), respectively. However, when comparing males and females, there

Table 3
Concentration of Cd, Pb, Cu, Zn, Mn, and Se in Liver and Kidney from Svalbard Reindeer (*Rangifer tarandus platyrhynchus*)[a]

	Cd	Pb	Cu	Zn	Mn	Se
Liver						
n	78	78	78	78	74	76
Mean ± SD	0.73 ± 0.51	1.3 ± 1.0	43 ± 48	44 ± 25	2.6 ± 1.2	0.87 ± 0.35
Range	(0.2–2.4)	(<0.5–6.1)	(3.2–260)**	(15–140)†	(1.2–6.5)	(0.30–1.83)
Kidney						
n	60	57	57	60	57	47
Mean ± SD	4.3 ± 4.4	0.8 ± 2.0	4.2 ± 1.2	25 ± 4.6	1.3 ± 0.5	1.18 ± 0.22
Range	(0.5–23)	(<0.5–15)††	(2.2–7.6)	(15–38)	(0.4–2.5)	(0.76–1.70)

[a]Values given are Mean ± SD and range (μg/g wet wt). All values from summer and winter seasons included.

**Seven values >100 μg/g.

†Five values >100 μg/g.

††One value >3.0 μg/g.

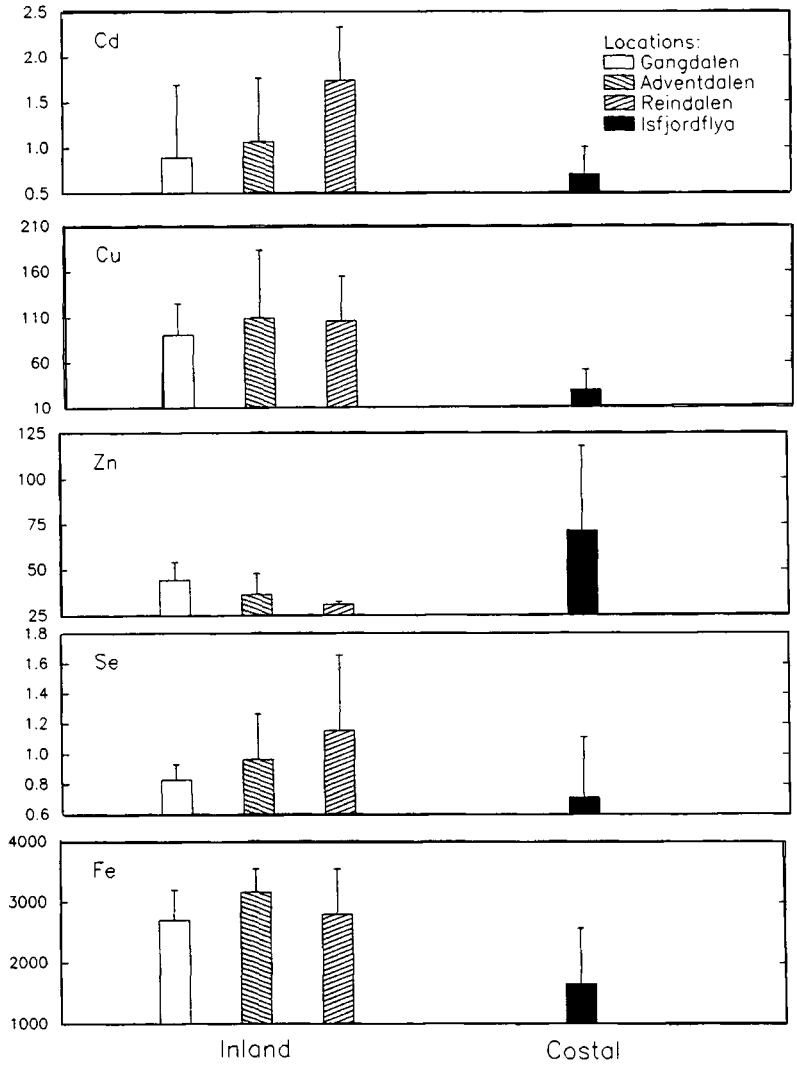

Fig. 5. Hepatic concentrations (μg/g wet wt) of some trace elements in both sexes combined of Svalbard reindeer collected in April in inland and coastal areas (Fe values from Borch-Iohnsen and Nilssen *(1)*).

was a higher accumulation rate in females. The relation between Cd concentration (y) and age (x) is described by the following equations:

male liver: $y = 0.03x + 0.36$ ($r = 0.50$, $n = 21$, $p < 0.05$)
female liver: $y = 0.18x - 0.09$ ($r = 0.81$, $n = 23$, $p < 0.001$)
male kidney: $y = 0.44x + 0.94$ ($r = 0.78$, $n = 15$, $p < 0.001$)
female kidney: $y = 0.38x - 2.27$ ($r = 0.84$, $n = 23$, $p < 0.001$)

The regression coefficients in both liver ($p < 0.001$) and kidney ($p < 0.01$) were statistically different.

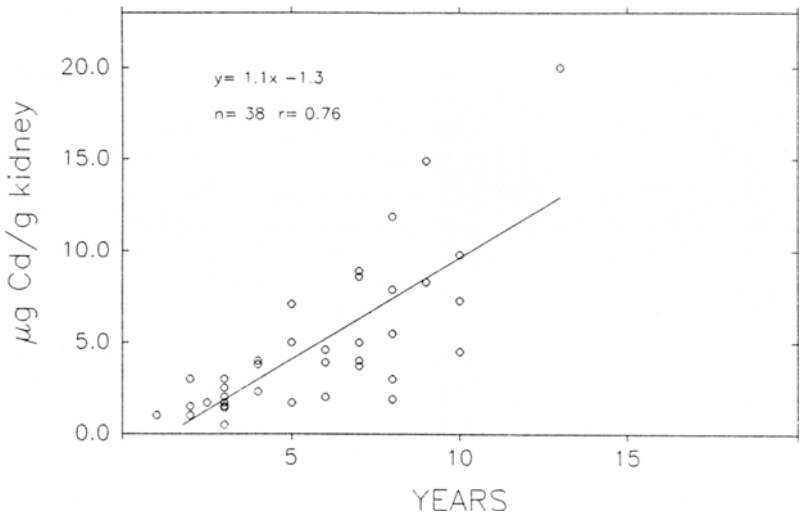

Fig. 6. Concentration of Cd in kidney from Svalbard reindeer as a function of age.

DISCUSSION

We have shown that the total content of trace minerals in liver and kidney from coastal animals at different seasons show a sixfold increase in hepatic Mn, a 2.5-fold increase in hepatic Zn and Se in the summer compared to the winter; whereas the hepatic Cu, Cd, and Pb show small differences over the year. The renal content of Mn, Cu, Zn, and Se in July/August is 4, 2.4, 2, and 2.5 times higher than in April, respectively. As expected, the Cd and Pb contents did not vary with the seasons.

With respect to the liver content of trace elements in inland animals in late winter, it is especially noteworthy that the Cu content in these animals is more than twice and the Zn content is about half the coastal value. Dietary differences probably caused these results.

The concentration of Cu, Mn, Zn, Co, and Mo in the reindeer forage plants do not vary with season, whereas the Fe concentration is much higher in winter than in summer forage *(3)*. Analyses of the rumen content from winter animals feeding on mosses have shown a very high Fe concentration, i.e., 1300 mg Fe/kg, whereas rumen content from animals left to feed on marine algae had an Fe concentration of 175 mg/kg, which is comparable to the level in summer animals *(2–4)*. Mosses as forage resulted in significantly higher hepatic Fe concentration (2900 µg/g) than marine algae (1650 µg/g) *(1)*.

The absorption of dietary Zn has been shown to be reduced by high Fe intake *(9)*. Accordingly, one cause for the high hepatic Zn concentration in the April coastal animals may have been that lower dietary Fe has improved the Zn bioavailability. In addition, the Zn content of the algae

may have been higher than the Zn content of the normal winter forage plants, but this was not measured.

The low hepatic Cu content in April in the animals from the coastal area compared to the inland values is probably the result of a lower Cu intake and maybe also of a reduced Cu absorption caused by excess Zn *(10)*.

According to Staaland *(4)*, the efficiency of mineral absorption in the Svalbard reindeer shows seasonal variations. The absorption rate, based on measurements of mineral concentration differences along the gastrointestinal tract, of Fe and Co is significantly higher during winter than during summer, whereas the opposite is true for Zn and Mo. With Cu and Mn, there were no seasonal differences. The size of the dietary volume will, however, determine the absolute amount absorbed. The retention of a mineral measured as, e.g., hepatic and renal content, may express differences in amount absorbed in the different seasons. Thus, if both the concentration of Mn in forage plants and the rate of absorption are the same through the different seasons *(3,4)*, the high hepatic and renal Mn content during summer may be the result of an increased dietary intake, i.e., volume.

When ranges of trace element concentrations are compared between Svalbard reindeer and reindeer in Norway (Table 4), it can be seen that upper range values for hepatic Pb, Cu (also high in Northern Norway), Zn, and Mn, and renal Cd are considerably higher in Svalbard reindeer. As has been discussed above, such comparisons are difficult to interpret, however, since the concentrations in liver and kidney may be the result of several factors, e.g., season, diet, bioavailability of elements, and interactions between different elements.

Pollution by long-distance transport of some fairly volatile trace elements such as Cd, Pb, and Se from industrial sources provides a rather insignificant source of heavy metal supply to Northern Norway *(11)*, and this may also be the case for Svalbard. It is, therefore, suggested that the high levels of Cd and Pb in some of the Svalbard animals may have originated from natural sources.

The regression coefficient for the relation between Cd levels in kidney and age of Svalbard reindeer (b = 1.1) is comparable to that of figures for reindeer from the Norwegian mainland: Southern Norway, area 1, b = 1.8; Southern Norway, area 2, b = 1.5; and Northern Norway, b = 0.25 *(12)*. Thus, it seems possible that the intake of Cd in Svalbard reindeer is almost as high as that in reindeer from the southern part of Norway. Local geological conditions seem to be the most reasonable explanation of the present results (Ottesen, personal communication).

To conclude, this investigation shows that when animals are exposed to large seasonal variations in both quality and quantity of the food, it is crucial to relate element concentrations to the physiological condition of the animal, e.g., to look at seasonal fluctuations in the total element content of the different organs.

Table 4
Element Concentrations in Liver and Kidney from Svalbard Reindeer *(Rangifer tarandus platyrhynchus)* and Reindeer in Norway *(R. tarandus tarandus)*[a]

	Svalbard		Norway[b]	Northern Norway[c]	
	Liver	Kidney	Liver	Liver	Kidney
Cd	0.2–2.4	0.5–23	0.2–1.6	0.1–1.4	0.3–8.7
Pb	<0.5–6.1	<0.6–15	0.07–1.8	<0.5–1.4	<0.5–0.6
Cu	3.2–260	2.2–7.6	5–88	5.6–200	—
Zn	15–140	15–38	20–55	20–62	—
Mn	1.2–6.5	0.4–2.5	—	1.9–3.2	—
Se	0.3–1.8	0.76–1.7	0.21–1.2	—	—

[a]Values given are μg/g. All values from summer and winter seasons included.
[b]Whole country (from Fröslie et al. *(12)*).
[c]From Fröslie et al. *(13)*.

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