Heavy metals and macroelements in the tundra of southern Spitsbergen: the effect of little auk *Alle alle* (L.) colonies

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Samples of two species of widely distributed mosses (*Sanionia uncinata* and *Hylocomium splendens*) were collected in the Ariekammen-Fugleberget catchment area (Hornsund, Spitsbergen) within and outside little auk *Alle alle* (L.) colonies. The concentrations of Cd, Pb, Ni, Zn, Cu, Mn, Fe, N, P, and S in the moss samples were found to be 1.5–2 times higher within than outside the colonies. Significant differences were found for Cd, Pb, Zn, Cu, and Fe, but not for Ni, Mn, N, P, and S. *Sanionia uncinata* accumulates up to 8 μg g^{-1} d. wt Cd, 14-Pb, 8-Ni, 47-Zn, 9-Cu, 90-Mn, and 1920 μg g^{-1} d. wt Fe, while *Hylocomium splendens* accumulates up to 4 μg g^{-1} d. wt Cd, 12-Pb, 3-Ni, 31-Zn, 5-Cu, 60-Mn, and 840 μg g^{-1} d. wt Fe. The colonies of seabirds contribute greatly to the supply of elements in the tundra ecosystems of southern Spitsbergen. The effect seems, however, to be limited to rather small areas.

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Introduction

The Arctic tundra consists mainly of mosses, lichens, and, to a lesser extent, vascular plants. The vegetation cover is compact in a several-kilometre-wide strip along the coast, while the vegetation further inland is more sparse (Billings 1973).

In Arctic regions, the activity of seabirds is one of the main factors that determines the diversity of vegetation and the degree of vegetation cover. In the Hornsund region little auk *Alle alle* occurs in large numbers while kittiwake *Rissa tridactyla*, black guillemot *Cepphus grille*, Brunnich's guillemot *Uria lomvia*, fulmar *Fulmarus glacialis*, glaucous gull *Larus hyperboreus*, and others are less dominating. Large amounts of nutrients are deposited through the faeces of birds. Constituents of the faeces are dissolved by precipitation and thawing waters, transported through tundra systems by temporary streams (Krzyszowska 1983), and partly washed out to sea. The remainder is utilized by the vegetation, which is always more abundant close to sites inhabited by birds than elsewhere (Eurola & Hakala 1977).

On the coastal cliffs close to the Polish Polar Station at Hornsund there are large colonies of little auks. The little auks feed mainly on Copepods (*Calanus sp.*) during the summer (Glutz von Blotzheim & Bauer 1982; Evans 1981) and on other small marine crustaceans and fish during the autumn (Lydersen et al. 1985, 1988). Marine animals in the Hornsund region contain fairly high concentrations of heavy metals (Protasowicki 1988). According to Godzik (unpubl. data), various species of marine animals (Amphipoda: *Gammarellus homari;* Decapoda: *Eualus gaimardi, Hyas araneus;* Echinodermata: *Heliometra glacialis;* Pisces: *Myxocephalus scorpius, Liparis liparis*) from the Hornsund area contain about 1.14–6.43 μg g^{-1} d. wt Cd, 2.2–43.5 Pb, 2.5–13.5 Ni, 49.7–185.3 Zn, 4.0–45.0 Cu, 3.5–22.1 Mn, and 56.8–514.0 μg g^{-1} d. wt Fe. It can be assumed that little auks feeding on these species deposit considerable amounts of the same elements in the tundra ecosystems through their faeces.

Because mosses absorb heavy metal ions, they are often used in the assessment of heavy metal pollution of the environment (Rühling & Tyler 1978, 1971; Pakarinen & Tolonen 1976; Grodzińska 1978). By using the common moss species *Sanionia uncinata* and *Hylocomium splendens*, this project has aimed at assessing the effect of colonies of little auk on the concentrations of heavy metals, sulphur, nitrogen, and phosphorus in the tundra ecosystem of southern Spitsbergen.

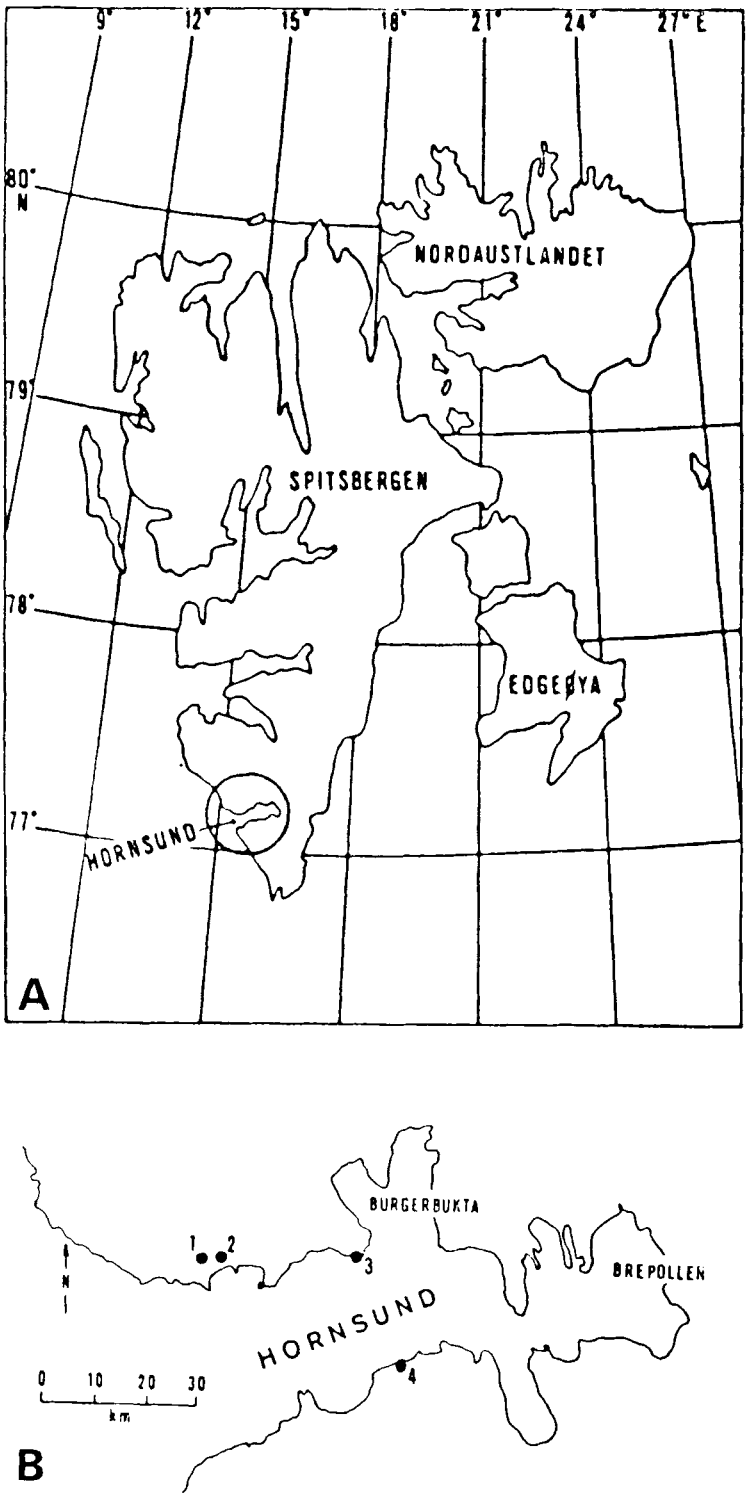

Fig. 1. Location of Hornsund (A) and sites of moss sampling in the Hornsund area (B). 1 = Ariekammen; 2 = Fugleberget; 3 = Gnålberget; 4 = Rasstupet.

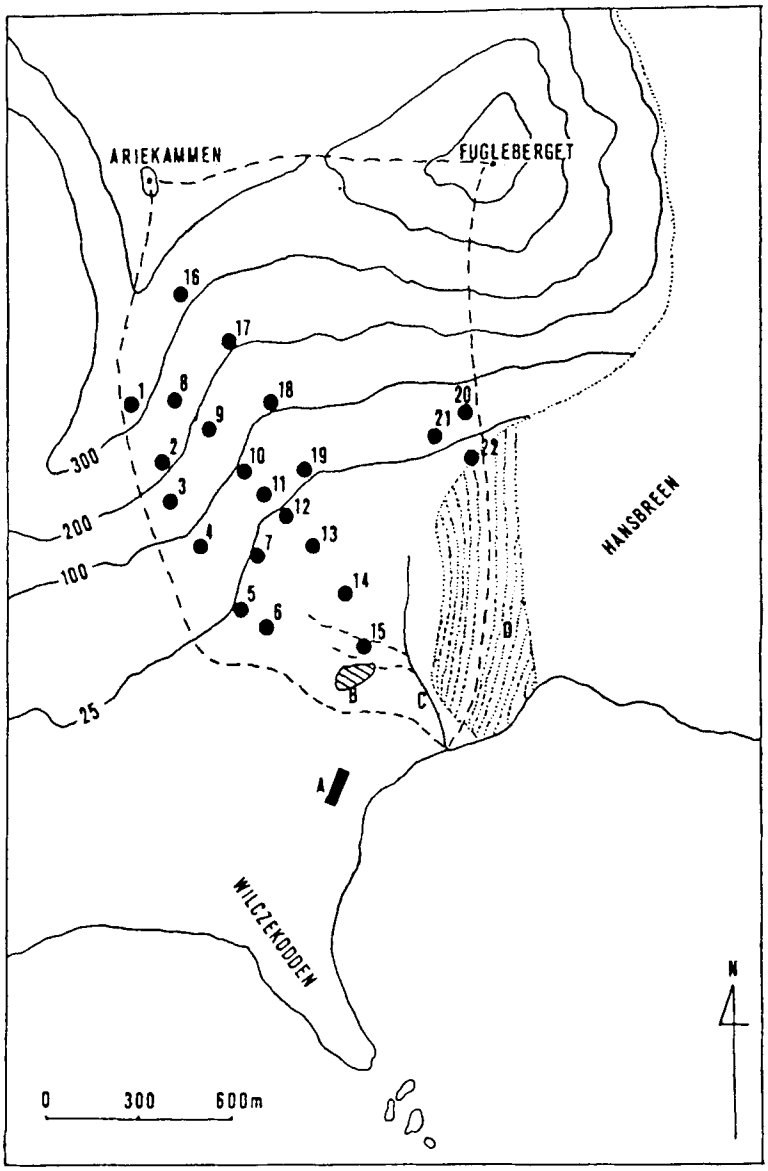

Fig. 2. Sites of moss sampling in Ariekammen-Fugleberget watershed. A = Polish Polar Station; B = Water pool; C = Fuglebekken river; D = Hans Glacier moraine. Broken lines indicate boundaries of the watershed area.

Study area

The studies were carried out on a fragment of tundra vegetation in the Fuglebekken river catchment area close to the Polish Polar Station at Hornsund in the southwestern part of Spitsbergen (76°59'N, 15°33' E) (Fig. 1A). The catchment area comprises the southern and southeastern slopes of the Ariekammen (511 m a.s.l.) and Fugleberget (569 m a.s.l.) mountains and the flat terrain in the southern part of the catchment (Fig. 2). In the western part of the catchment area, on the slopes of Ariekammen, there is a colony of about 50 thousand pairs of little auks. A mosaic pattern of rock rubble divides the colony into rather autonomic subcolonies. The density of

breeding pairs is usually one pair per 1.5–2.0 m^2 (Stepniewicz 1980). In the eastern part of the catchment area (slopes of Fugleberget) little auks occur less frequently, accompanied by small colonies of kittiwakes. The flat part of the study area is a feeding ground for the pink-footed goose *Anser brachyrhynchus*.

The vegetation of the Ariekammen-Fugleberget catchment area is variable. The western part (southern slope of Ariekamman) is "fertilized" by birds and supports abundant ornithocoprophilous plant communities, a condition lacking in the eastern part (Dubiel & Olech in press).

Materials and methods

Sanionia uncinata (Hedw.) Loeske and *Hylcomium splendens* (Hedw.) B. S. G. are the most widespread moss species occurring in both the "fertilized" and "nonfertilized" parts of the catchment area. Samples of these mosses were collected in June 1986 within the Ariekammen-Fugleberget catchment area (Fig. 2) and at several other sites in the Hornsund fiord (Fig. 1B; Table 1). Samples were taken in the western part of the catchment area, along three transects leading from points elevated about 300 m a.s.l. on the slopes of Ariekammen towards the flat coastal terrace about 10 m a.s.l. (19 samples, locations 1–19), in the eastern part of the catchment area at the foot of Fugleberget (3 samples, locations 20–22), close to Gnålberget (1 sample, location 23), and on Rasstupet (2 samples, locations 24–25).

Some of the *Sanionia uncinata* samples were collected within bird colonies: little auk colonies on Ariekammen (locations 2–4, 9–11, 18), colonies on Fugleberget (location 20–21), within geese-feeding ground (location 14), and within a colony of kittiwake on Rasstupet (location 25). The remaining samples were collected outside bird colonies or feeding grounds.

Five samples of *Hylocomium splendens* were collected within little auk colonies, on Ariekammen (locations 9–11, 18) and Fugleberget (location 20). The remaining samples were collected either above or below the colonies.

Moss samples were air-dried and then oven-dried at 105°C to constant weight. The samples were slowly digested in a 4:1 mixture of spectral

Table 1. Number of samples and localities of moss collection in the Hornsund region (a = within bird colonies; b = outside bird colonies)

Species		*Sanionia uncinata*	*Hylocomium spendens*
Locality			
Ariekammen	a	8 samples locations: 2, 3, 4, 9, 10, 11, 14,18	4 samples locations: 9, 10, 11, 18
	b	11 samples locations: 1, 5, 6, 7, 8, 12, 13, 15, 16, 17, 19	7 samples locations: 1, 5, 8, 12, 16, 17, 19
Fugleberget	a	2 samples locations: 20, 21	1 sample location: 20
	b	1 sample location: 22	—
Rasstupet	a	1 sample location: 24	—
	b	1 sample location: 25	—
Gnålodden	a	—	—
	b	1 sample location: 23	—

pure nitric and perchloric acids on a hot plate for 3 days until all organic matter was oxidized. The solution was then evaporated to 1 ml and diluted with distilled water to 50 ml. Blanks were run for each series of samples. The paper bags in which the plants had been stored were treated in the same way as the moss samples. The concentrations of Cd, Pb, Ni, Zn, Cu, Mn, and Fe were determined with an atomic absorption spectrophotometer (Varian-Techtron model A-1000). The measurements were repeated on a Hitachi 180–80 spectrophotometer. Sulphur was determiend by a nephelometric method, nitrogen by Kjeldahl method, and phosphorus by a vanado-molybdate method (Nowosielski 1968).

The concentrations were determined collec-

Table 2. Heavy metal, phosphorus, sulphur (μg g^{-1} d.wt), and nitrogen (%) concentrations in *Sanionia uncinata* collected in the Hornsund area (localities within bird colonies have been given in frames).

Locality		No	Cd	Pb	Ni	Zn	Cu	Mn	Fe	P	S	N
Ariekammen	transect I	1	1.58	6.3	1.8	18.3	3.8	25.3	407.1	1880	1206	1.16
		2	3.84	10.9	1.9	31.1	5.0	35.4	428.3	2860	1729	2.09
		3	6.33	12.9	2.8	42.2	6.8	37.6	575.4	2980	1895	2.37
		4	7.96	12.0	2.6	46.9	8.0	34.7	530.6	3200	1856	2.34
		5	3.07	4.3	1.7	17.9	2.9	48.5	509.6	1900	1297	1.31
		6	1.05	5.8	2.5	13.1	2.9	29.8	122.6	1680	996	0.94
		7	2.27	5.3	2.6	23.1	6.5	55.2	291.4	2800	1680	1.97
	transect II	8	2.41	11.1	2.6	22.4	3.7	38.3	289.6	1700	1264	0.94
		9	1.97	13.7	8.1	37.4	6.8	90.2	839.7	2390	1143	1.66
		10	2.12	13.7	2.7	22.4	4.2	42.7	866.9	1670	1023	1.24
		11	4.48	12.2	1.9	33.9	5.4	29.1	486.3	2880	1886	2.07
		12	4.47	8.5	1.8	37.6	5.2	38.5	174.7	3240	1649	2.20
		13	1.32	4.3	1.7	21.7	4.3	36.6	220.5	2630	1522	1.69
		14	1.13	10.4	5.3	21.6	8.4	71.4	1354.5	2800	1361	1.59
		15	0.81	11.7	4.6	13.6	3.7	41.3	1058.4	2650	1058	1.03
	transect III	16	1.82	8.8	2.2	14.2	2.6	21.5	184.3	1370	1127	1.12
		17	1.64	9.0	2.7	12.9	5.0	36.5	794.7	1670	1303	1.24
		18	1.66	10.8	5.6	22.0	8.7	88.0	331.4	1970	1071	0.89
		19	1.56	6.3	1.7	17.3	3.8	17.0	301.4	1960	1311	1.14
Fugleberget		20	1.87	9.5	5.4	17.6	10.0	72.7	1362.3	2900	1262	1.87
		21	1.08	9.7	6.0	18.2	8.3	106.1	1919.7	2160	1303	1.37
		22	1.56	10.6	2.6	13.1	2.8	32.8	425.5	1460	1273	1.19
Gnålodden		23	1.25	7.4	2.6	15.1	2.9	10.7	253.0	1630	1208	0.68
Rasstupet		24	3.15	12.7	2.1	16.2	2.6	14.5	212.2	2320	1744	1.37
		25	1.62	7.9	2.1	12.3	1.2	12.6	59.7	1570	1120	0.91

Table 3. Mean concentrations of heavy metals, phosphorus, sulphur (μg g^{-1} d.wt) and nitrogen (%) in *Sanionia uncinata* collected within the little auk colony on the slope of Ariekammen (I), outside the little auk colony on the slope of Ariekammen (II), in small bird colonies at the foot of Fugleberget and Rasstupet (III), outside small bird colonies on Fugleberget, Gnålodden and Rasstupet (IV).

Locality		Cd	Pb	Ni	Zn	Cu	Mn	Fe	P	S	N
I	$\bar{x}$	4.05	12.3	3.7	33.7	6.4	51.1	579.8	2564	1515	1.81
(2, 3, 4, 9, 10, 11)	SD	2.398	1.20	2.33	9.41	1.63	26.28	202.41	569.7	412.7	0.568
II	$\bar{x}$	2.00	6.2	2.4	19.3	4.0	35.1	436.8	2136	1310	1.34
(1, 5, 6, 7, 8, 12, 13, 15)	SD	1.039	3.10	0.85	9.41	1.16	11.29	402.70	591.9	224.8	0.425
III	$\bar{x}$	1.81	10.58	4.7	18.4	7.3	66.2	1212.2	2545	1418	1.55
(20, 21, 24)	SD	0.965	1.47	1.76	2.29	3.25	38.01	717.25	360.5	221.4	0.237
IV	$\bar{x}$	1.48	8.6	2.4	13.7	2.3	18.7	246.1	1553	1202	0.93
(22, 23, 25)	SD	0.198	1.72	0.29	1.25	0.95	12.25	183.00	86.2	79.2	0.255

tively for the green and brown parts of the mosses. Only three samples of *Sanionia uncinata* were subjected to separate analysis of the green and brown parts. Differences in heavy metal concentrations were assessed by a Kruskall-Wallis and Student t-test. The heavy metal index (S_j) was calculated according to a procedure suggested by Grodzińska (1978) from the formula

$$S_j = \sum_{i=1}^{i=j} \frac{x_{ij} - \bar{x}_i}{\bar{x}_i}$$

where x_{ij} is the content of i-heavy metal in j-location; $\bar{x}_i$ – mean content of i-heavy metal in all locations; in this case j equals 7 (Cd, Pb, Ni, Zn, Mn, Fe).

Results

The chemical composition of the samples of *Sanionia uncinata* collected across the Ariekammen slopes varies considerably (Table 2). Cadmium and manganese show the widest ranges, and lead, copper, sulphur and phosphorus showed the narrowest ranges.

The variation is particularly high in the concentrations of heavy metals and macroelements found along transects I and II; variation along transect III is much smaller. Along transect I, the concentration of cadmium increases sixfold in locations approaching the centre of a colony; that of lead, zinc and nitrogen increases twofold; and the remaining elements increase about 1.5 times. The highest concentrations were found at locations 3, 4 and 9 where the nests of birds were most densely arranged. Among locations situated within the colonies, the lowest concentrations of elements were found in moss from location 18 which has few nests of little auks (Table 2).

When samples of the same species of moss were collected on the Ariekammen slopes outside the colonies of little auks (localities 1, 5, 6, 7, 8, 12, 13, 15), the average concentrations of cadmium, lead and zinc were less than half those found within the colonies, concentrations of copper and manganese were about one-third, and of nickel and iron about one-fourth as much (Table 3).

Samples of the moss *S. uncinata* collected at locations with few birds (localities 20, 21, 24) contained less than half the amount of the concentrations of cadmium and zinc found within colonies on the Ariekammen slopes and similar concentrations of the remaining elements (Table 3). Lower concentrations of heavy metals and macroelements were found in the samples of *S. uncinata* collected about 100–300 metres below the small groupings of nests (Table 3).

The differences in concentrations of Cd, Pb, Zn, Cu, and Fe in the mosses collected within and outside colonies were statistically significant ($P < 0.05$).

The total index (S_j) of heavy metal concentrations in the mosses allows the separation of the site locations into low content locations (index values ranging from −0.45 to 0.0) and high content locations (index values ranging from 0.0 to 0.64). The first group comprises the locations outside the bird colonies; the latter comprises those within the colonies (Fig. 3).

The moss *Hylocomium splendens* is a weaker heavy metal accumulator than *Sanionia uncinata*.

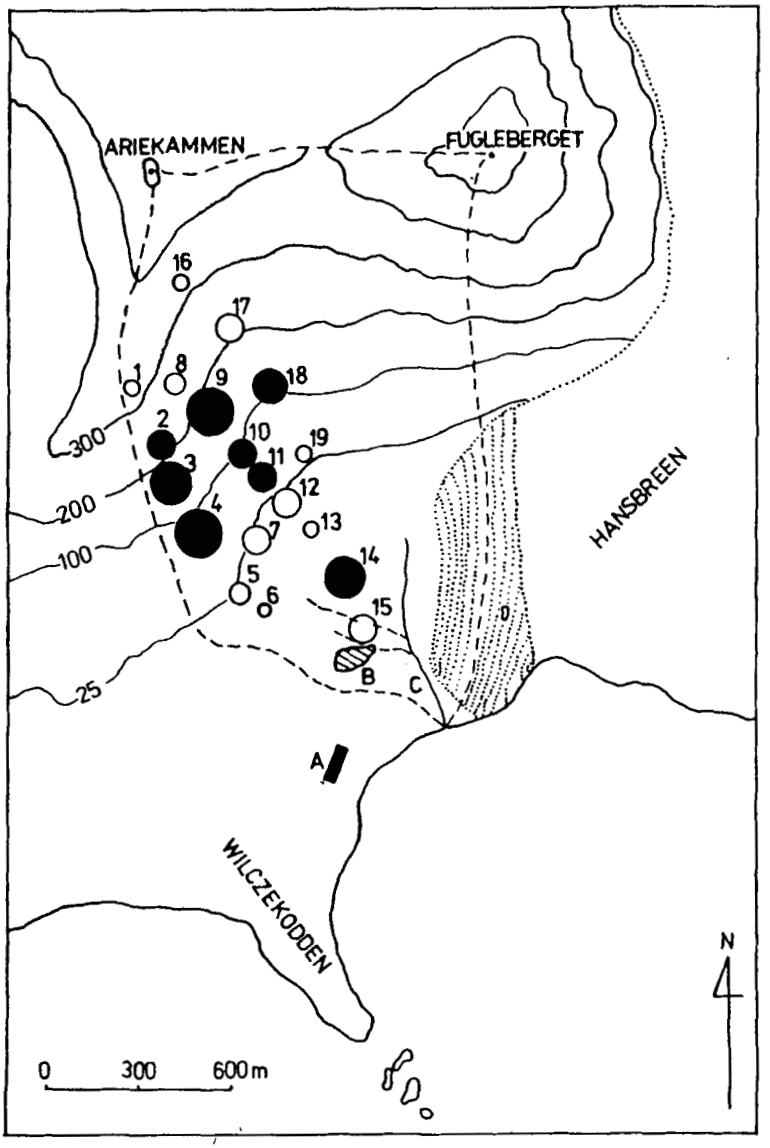

Fig. 3. Index of heavy metal contents of the moss *Sanionia uncinata* collected on the slope of Mt. Ariekammen. Solid circle (●) = localities within the *Alle alle* colony (index value: 0.0–0.64) and in the feeding ground of *Anser brachyrhynchus* (locality 14, index value: 0.44). Open circle (○) = localities outside the *Alle ale* colony (index value: −0.45–0.0). Other explanations as in Fig. 2.

H. splendens accumulated only about half the amount of Cd, Ni, Zn and Mn, and about two-third the amount of the remaining elements as did *S. uncinata*. Similar to *S. uncinata*, samples of *H. splendens* collected within colonies contained higher heavy metal concentrations than those from outside bird-inhabited sites (Table 4).

The concentrations of heavy metals in the younger, green parts of *S. uncinata* mosses were always lower than those in the older brown parts (Fig. 4). The greatest differences occurred in Ni and Mn concentrations. The brown parts contained 3 to 12 times more Ni and Mn than the green parts. The concentration of cadmium was 1.5 to 2 times higher, lead 2–3 times, zinc 3–5 times, and copper 3–7 times more than in the green parts (Fig. 4). The differences were statistically significant ($P < 0.05$). Phosphorus and

Table 4. Heavy metals, phosphorus, sulphur (μg g^{-1} d.wt) and nitrogen (%) concentrations of the moss *Hylocomium splendens* collected in the Hornsund area (localities within bird colonies have given in frames).

Locality	No	Cd	Pb	Ni	Zn	Cu	Mn	Fe	P	S	N
Ariekammen	1	0.96	3.8	0.7	13.2	2.0	17.7	173.1	1590	827	1.15
	5	0.83	3.5	1.0	13.1	2.5	21.3	204.9	1680	938	1.01
	8	1.00	12.0	1.6	11.1	2.7	16.1	388.7	1720	869	1.37
	9	1.06	8.6	1.9	12.7	3.7	13.0	193.0	1500	890	0.94
	10	1.09	11.3	2.3	10.5	3.9	16.3	473.1	1300	692	0.86
	11	4.23	7.0	1.7	31.5	4.4	28.4	316.2	2860	1639	1.92
	12	0.95	5.2	0.5	10.4	2.3	10.4	259.2	1340	605	0.81
	16	1.40	6.1	0.9	9.9	2.2	11.5	245.1	1630	1049	1.05
	17	1.10	6.8	2.2	10.0	2.8	32.4	562.1	1290	1087	0.67
	18	1.30	7.5	2.8	18.8	4.1	57.6	840.2	1380	811	0.60
	19	0.93	5.9	1.7	11.5	4.6	13.4	142.1	1420	929	0.69
bird colony	$\bar{x}$	1.92	8.6	2.2	18.4	4.0	28.83	455.6	1760	1008	1.08
	SD	1.544	1.92	0.49	9.43	0.30	20.29	280.84	737.9	428.5	0.58
outside bird colony	$\bar{x}$	1.002	6.2	1.3	11.3	2.7	17.5	282.2	1524	901	0.96
	SD	0.184	2.83	0.62	1.38	0.87	7.55	146.68	172.1	159.7	0.256
Fugleberget	20	1.78	8.0	2.2	12.6	3.4	11.7	664.6	2040	1173	1.08

sulphur were accumulated most efficiently in the brown parts, while nitrogen in the green parts (Fig. 4).

Discussion

The group nesting of seabirds in the Far North regions is a major factor in influencing the variability and abundance of plant associations. In the sites fertilized by bird faeces, specific ornithocoprophilous associations have developed (Eurola & Hakala 1977; Dubiel & Olech in press).

The presence of a great colony (comprising more than 50 thousand pairs) of little auks on the slope of the Ariekammen mountains has caused vegetation to thrive much better than elsewhere in the catchment area.

The little auks remain in their breeding colonies from mid-June to mid-August before later migrating south. In this period, egg-laying, incubation, and feeding of the young take place. Adult and young birds consume about 280 metric tonnes of marine food during this period. About a third of this amount is voided as faeces deposited mainly within the colonies (Klekowski & Opaliński 1984).

Previous studies have shown that the concentrations of nitrogen (as nitrates) and phosphorus in surface waters were high within the colonies but decreased with increasing distance from the colonies (Krzyszowska 1985).

Similarly, the concentrations of N, P and S in mosses collected within little auk colonies at Hornsund were higher than those found in mosses growing on sites not inhabited by birds. This indicates the effect bird colonies have on the levels of macroelements in tundra vegetation of the region. Such elevations of macroelement concentrations were also found in higher plants of Spitsbergen by Staaland et al. (1983).

The range of colony-related effect is small. The concentrations of heavy metals in mosses collected less than 100 m from bird nests are simi-

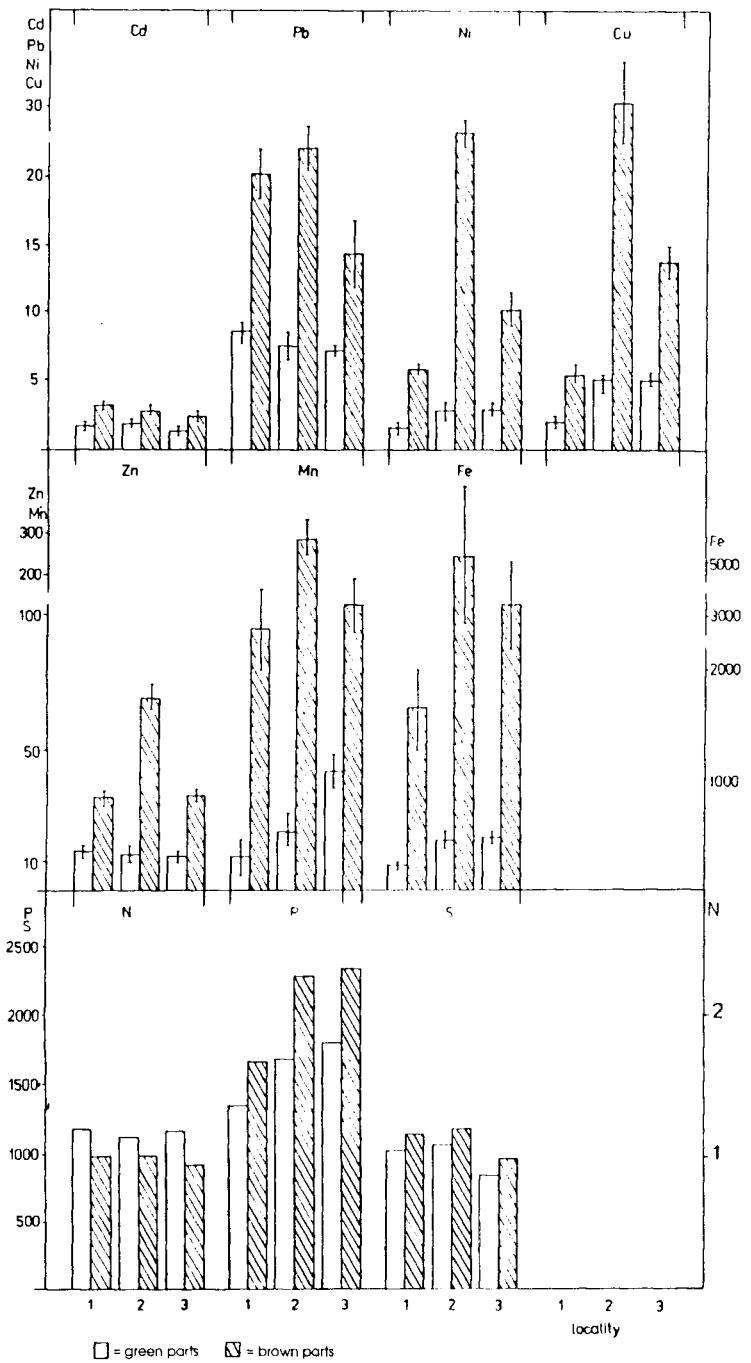

Fig. 4. Heavy metal, phosphorus, sulphur (μg g^{-1} d. wt) and nitrogen (%) concentrations in green and brown parts of the moss *Sanionia uncinata* (localities 1, 2, and 3, southern slope of Mt. Ariekammen).

Table 5. Heavy metal, phosphorus, sulphur (μg^{-1}d. wt) and nitrogen (%) concentrations in the green (a) and brown (b) parts of the moss *Sanionia uncinata* (localities 1, 2, and 3 on the southern slope of Mt. Ariekammen).

Locality	1				2				3			
Element	a	SD	b	SD	a	SD	b	SD	a	SD	b	SD
Cd	1.74	0.104	3.21	0.226	1.90	0.223	2.75	0.193	1.34	0.166	2.43	0.221
Pb	8.6	1.00	20.2	1.87	7.50	1.21	22.6	1.70	7.2	0.29	15.3	2.45
Ni	1.5	0.10	5.8	0.59	2.5	0.57	23.2	0.92	2.9	0.42	10.3	1.32
Zn	13.9	2.31	34.1	2.69	13.2	3.20	68.8	5.55	12.5	1.67	34.6	3.76
Cu	2.1	0.29	5.4	0.75	5.2	0.96	28.1	3.50	5.0	0.29	13.8	1.42
Mn	12.0	2.42	95.3	6.01	21.1	2.30	298.4	20.48	43.3	3.70	116.3	8.14
Fe	239.2	15.70	1661.3	261.68	451.1	62.83	5184.7	499.81	474.7	41.68	3218.7	375.43
P	1340	—	1650	—	1690	—	2290	—	1810	—	2333	—
S	1035	—	1143	—	1204	—	1059	—	949	—	834	—
N	1.19	—	0.97	—	1.12	—	0.97	—	1.18	—	0.91	—

lar to (except for cadmium) the levels found elsewhere in Hornsund. According to data by Grodzińska & Godzik (1991, this volume), mean concentrations of heavy metals in *Sanionia uncinata* from many locations in Hornsund area are ($\mu g\, g^{-1}$): Cd, 0.59; Pb, 7.07; Ni, 4.25; Cu, 6.01; and Zn, 21.13. *Hylocomium splendens* accumulates similar quantities of these elements. Since concentrations of cadmium, lead and zinc in *Sanionia uncinata* and *Hylocomium splendens* collected within bird colonies are considerably higher than the levels found on many locations elsewhere in southern Spitsbergen, the faeces of sea birds is an important source of heavy metals in sites inhabited by birds.

Higher concentrations of heavy metals found in older (brown) parts of mosses compared with younger (green) parts agree well with findings by other authors (Lötschert et al. 1975; Grodzińska 1978).

It may thus be concluded that colonies of seabirds play an important role in introducing heavy metals and macroelements to the tundra ecosystems of southern Spitsbergen. The range of this effect is limited to the closest surroundings of colonies of nests.

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