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Heavy metals in tundra plants of Bellsund area, Spitsbergen

ABSTRACT: The contents of copper, manganese, zinc, lead and cadmium have been determined in plants of the Spitsbergen tundra, collected at Calypsostranda, Lyellstranda and Chamberlindalen in 1987. Five species of vascular plants, four species of mosses and fourteen species of lichens have been investigated. Manganese content in all the studied plants falls in the physiological limits of this element. Appreciable concentrations of copper, and zinc exceeding the physiological concentrations of these elements and presence of lead and cadmium have been shown for many plants.

Key words: Arctic, Spitsbergen, plants, heavy metals.

Introduction

The investigations of certain heavy metals contents in plants of the Spitsbergen tundra have been carried in 1987 during the Spitsbergen Geographical Expedition organized by the Maria Curie-Skłodowska University in Lublin. The plants have been sampled in June, July and August in the area of Calypsostranda, Lyellstranda and in the Chamberlin Valley, Bellsund Region, western Spitsbergen.

The maritime plains of Calypsostranda and Lyellstranda are the areas of dry tundra covered mainly with lichens and mosses and vascular plants as well. Humid-marshy tundra at Chamberlindalen is covered mostly by mosses.

The obtained results concerning the contents of the following heavy metals: copper, manganese, zinc, lead and cadmium, have been presented already in a preliminary report (Jóźwik 1988).

Materials and methods

Vascular plants, mosses and lichens have been collected at Calypsostranda, Lyellstranda and Chamberlin Valley in the region of the Bellsund fjord, Western Spitsbergen, in June, July and August 1987 (*see* Fig. 1).

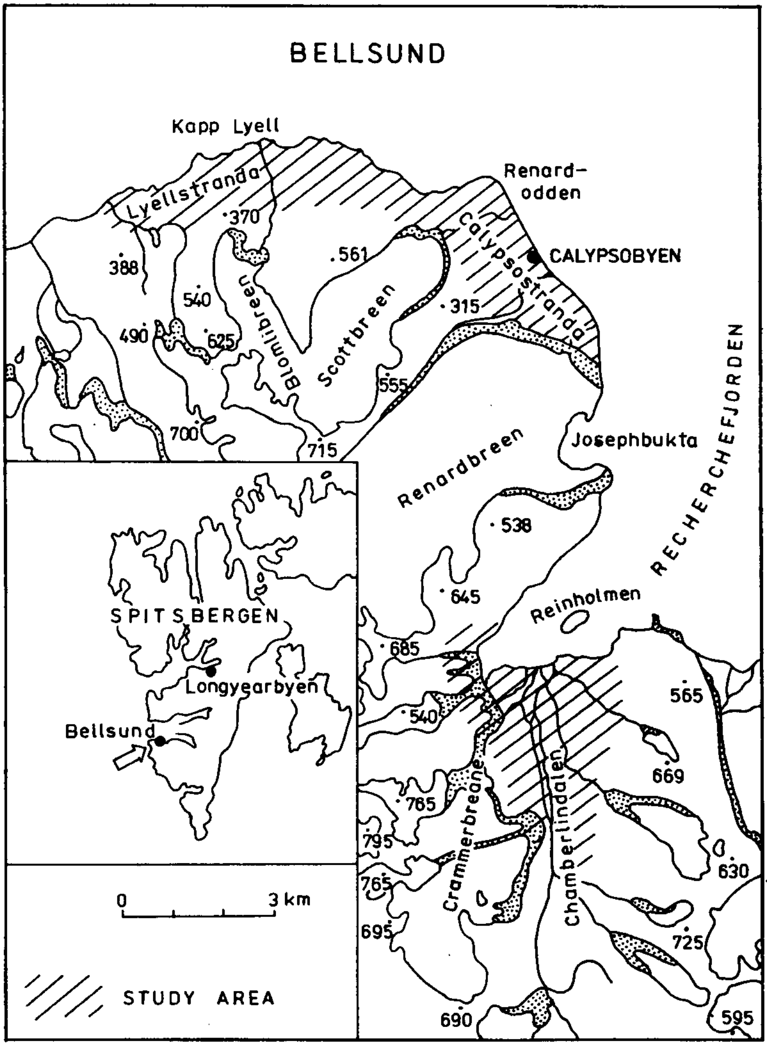

Fig. 1. Location sketch map of the studied area, based on the map of Norway 1:100,000, sheet Van Keulenfjorden, Spitsbergen. Oslo 1985.

The contents of copper, manganese, zinc, lead and cadmium have been determined in these plants. The sampled population consisted of five species of vascular plants: *Saxifraga oppositiofolia* L., *Saxifraga caespifosa* L., *Silene acaulis* (L.) Jack., *Salix polaris* L. and *Dryas octopetala* L.; four mosses species: *Oncophorus wahlenbergii, Racomitrium lanuginosum, Aulacomnium palustre* and *Drepanocladus revolvens,* and fourteen lichens species: *Cetraria hiascens* (Fr.) Th., *Cetraria nivalis* (L.) Ach., *Cetraria crispa* Nyl., *Thamnolia vermicularis* (Sw.), *Xantoria elegans* (Link), *Umbilicaria* sp., *Stereocaulon* sp. Schreb., *Stereocaulon* *denudatum* Flk., *Ochrolechia frigida* (Sw), *Parmelia* Ach., *Peltigera* sp., *Cladonia mitis* Sandst. and *Cladonia gracilis* (L.).

During the pant collecting, the prevailence of a given species in the sampled environment has been taken into account. Several to several tens whole specimens of each species have been dried, ground in an agate mortar and homogenized by mixing. Then, the obtained plant material has been treated as average samples of individual species of the vascular plants, mosses and lichens. The samples have been mineralized in a mixture of nitric and perchloric acids 7:1 (v/v), and next the heavy metals contents have been determined by use of the atomic absorption spectrophotometer Pye Unicam SP 9.

Discussion of the results

Tables 1, 2 and 3 present the average heavy metals contents (in ppm), derived from two independently carried analyses of the vascular plants, mosses and lichens. The amounts of the studied elements: copper, manganese, zinc, lead and cadmium, in most cases should be bound with a given plant species. Thus, the same species occurring in various localities bear similar amounts of the determined elements. However, the metal content in a plant depends not only on its species. In certain cases there appear also the relations of certain metals concentrations to the plant station. For instance, Silene acaulis from the Calypsostranda plain bears distinctly less lead (4.1 and 1.8 ppm) than the same species from the seaside terrace cliff (14.8 ppm). Lead has not been detected in Salix polaris from the Calypsostranda plain, whereas this willow from the Lyellstranda plain contained 17.0 ppm of this element. Dryas octopetala growing on the seaside terrace cliff bore 57.4 ppm zinc, but the same species from a different locality yielded the zinc concentration of only 7.8 ppm.

However, these are only the single cases, a separate discussion of which will be possible after performing the soil analyses from the localities where the plants have been sampled.

Table 4 shows the concentration ranges of the studied heavy metals in the vascular plants, mosses and lichens. All the analysed elements occur in wide concentration ranges in the discussed plant groups. It seems to be reasonable to discuss in detail the occurrence of the analysed elements for the individual plant species. One should mention however, that there appears a problem in the estimation of toxic concentrations of these metals or deficiency criteria of a given element.

The monograph published by Kabata-Pendias and Pendias (1979) gives certain accepted concentration ranges in ppm for the analysed heavy metals in plant material.

Copper as the component necessary for plant growth and development is accumulated by active mode, which is connected with metabolic processes. It

Table 1

Heavy metals in vascular plants, in ppm. The results are given as the arithmetic means $\pm$ SE (n=2)

Plant	Sampling locality	Cu	Mn	Zn	Pb	Cd
Saxifraga oppositifolia L.	Lyellstranda	9.43±0.16	81.57± 2.16	27.24± 4.91	13.20±0.04	0.78±0.08
Saxifraga oppositifolia L.	Calypsostranda	5.24±0.14	61.20± 0.89	25.64± 2.35	34.14±4.23	0.64±0.18
Saxifraga caespifosa L.	Calypsostranda	7.41±0.12	91.31± 2.35	29.88± 1.14	20.30±1.49	1.44±0.07
Silene acaulis (L) Jacq.	Calypsostranda	6.96±0.17	380.60±28.30	33.28± 3.41	14.79±2.52	2.50±0.08
Silene acaulis (L) Jacq.	Calypsostranda	3.92±0.02	249.59±22.42	20.27± 1.68	4.14±0.38	1.17±0.05
Silene acaulis (L) Jacq.	Calypsostranda	4.52±0.44	281.02±18.71	24.24± 2.08	1.84±0.03	0.28±0.01
Silene acaulis (L) Jacq.	Lyellstranda	7.06±0.35	202.78± 6.74	18.08± 0.02	11.90±0.02	1.91±0.01
Salix polaris L.	Lyelstranda	5.73±0.21	89.81± 2.92	104.11±26.25	17.00±0.15	1.85±0.01
Salix polaris L.	Calypsostranda	9.98±0.22	98.43± 2.71	99.36± 9.21	-	1.25±0.05
Salix polaris L.	Calypsostranda	8.51±0.71	7.54± 4.13	121.12± 2.17	-	8.29±0.76
Dryas octopetala L.	Calypsostranda	5.61±0.15	27.76± 0.94	57.38± 3.73	11.13±0.49	0.89±0.00
Dryas octopetala L.	Calypsostranda	6.27±0.41	32.19± 2.13	7.76± 0.13	18.78±1.56	0.74±0.00

Table 2

Heavy metals in mosses, in ppm. The results are given as the arithmetic means $\pm$ SE (n=2)

Plant	Sampling locality	Cu	Mn	Zn	Pb	Cd
Oncophorus wahlenbergii	Calypsostranda	8.93±0.47	245.41±39.97	58.86± 0.18	26.61±2.48	1.84±0.07
Oncophorus wahlenbergii	Lyellstranda	8.43±0.20	127.53± 2.38	10.48± 3.33	14.12±0.27	1.26±0.01
Racomitrium lanuginosum	Chamberlindalen	3.39±0.08	53.45± 0.49	55.78± 1.95	4.11±0.46	-
Racomitrium lanuginosum	Chamberlindalen	3.48±0.05	53.17± 0.85	13.77± 0.50	0.75±0.39	-
Aulacomnium palustre	Chamberlindalen	33.01±1.18	282.21± 3.69	43.49± 8.92	17.94±0.17	0.91±0.05
Aulacomnium palustre	Chamberlindalen	21.80±0.23	252.36±40.04	65.88± 3.06	13.71±0.86	0.43±0.05
Drepanocladus revolvens	Lyellstranda	7.77±0.01	54.81± 1.66	41.33±11.67	13.10±0.14	1.01±0.01

Table 3

Heavy metals in lichens, in ppm. The results are given as the arithmetic means ± SE (n = 2)

Plant	Sampling locality	Cu	Mn	Zn	Pb	Cd
Cetraria hiascens (Fr.) Th. Fr.	Calypsostranda	3.58 ± 0.25	5.82 ± 0.42	60.80 ± 5.58	25.52 ± 0.03	0.96 ± 0.01
Cetraria nivalis (L.) Ach.	Calypsostranda	1.79 ± 0.09	11.83 ± 0.38	3.40 ± 0.84	11.46 ± 0.36	0.89 ± 0.05
Cetraria crispa Nyl.	Calypsostranda	3.41 ± 0.08	7.99 ± 0.12	27.66 ± 0.98	20.88 ± 1.63	0.16 ± 0.01
Thamnolia vermicularis (Sw)	Calypsostranda	2.98 ± 0.07	9.50 ± 0.25	45.20 ± 0.62	6.43 ± 0.09	0.69 ± 0.01
Xantoria elegans (Link)	Calypsostranda	6.57 ± 0.18	35.01 ± 1.22	57.85 ± 7.85	2.99 ± 0.25	2.85 ± 0.75
Umbilicaria sp.	Chamberlindalen	29.41 ± 1.15	14.73 ± 0.32	68.22 ± 8.84	21.60 ± 1.23	0.86 ± 0.02
Umbilicaria sp.	Chamberlindalen	36.78 ± 0.83	9.40 ± 1.47	39.22 ± 6.60	22.86 ± 0.05	0.85 ± 0.03
Stereocaulon sp.	Calypsostranda	4.57 ± 0.00	25.21 ± 0.21	27.46 ± 4.14	22.10 ± 2.45	0.49 ± 0.22
Stereocaulon denudatum Flk.	Calypsostranda	7.03 ± 0.05	49.24 ± 0.29	27.03 ± 0.37	23.40 ± 5.91	6.13 ± 0.16
Ochrolechia *frigida* (Sw)	Calypsostranda	10.08 ± 0.18	244.47 ± 29.03	68.21 ± 23.38	50.01 ± 1.29	1.42 ± 0.13
Parmelia Ach.	Calypsostranda	6.78 ± 0.20	25.67 ± 1.48	23.68 ± 5.15	52.75 ± 2.52	1.34 ± 0.32
Peltigera sp.	Chamberlindalen	18.85 ± 1.50	3.91 ± 1.22	58.90 ± 0.43	7.35 ± 3.77	1.67 ± 0.12
Cladonia mitis Sandst.	Chamberlindalen	4.02 ± 0.13	13.37 ± 0.46	29.90 ± 8.33	-	0.85 ± 0.25
Cladonia gracilis (L)	Chamberlindalen	4.38 ± 0.07	15.49 ± 0.34	39.51 ± 13.91	26.24 ± 0.15	1.38 ± 0.38

Table 4

Ranges of the heavy metal concentrations (ppm) in individual plant groups in the studied region

Plant group	Cu	Mn	Zn	Pb	Cd
Vascular plants	3.92 – 9.98	27.76 – 380.60	7.76 – 121.12	1.84 – 34.14	0.28 – 8.29
Mosses	3.48 – 33.01	28.17 – 282.21	10.48 – 65.88	0.75 – 26.61	0.43 – 1.84
Lichens	1.79 – 36.78	3.91 – 244.47	3.40 – 68.22	2.99 – 52.75	0.16 – 6.13

may be also accumulated passively due to the water transpiration passage. The amount of this element in highly-organized plants is directly proportional to its concentration in solution. In some cases this amount can,however, exceed the real demands.

Average copper content in the overground plant parts equals 5 to 20 ppm, depending on the plant location and climate conditions.

Among the vascular plants, copper (3.9 ppm) has been detected in *Salix polaris*, the willow collected at Calypsostranda, but among lichens there have been found several species accumulating copper in an amount below 5 ppm (Tables 1—3).. The concentrations of 33.0 and 21.8 ppm Cu have been detected in mosses *Aulacomnium palustre* from Chamberlindalen which should be considered as the toxic amount (Table 2).

Certain species of the vascular plants are characterized by a significant tolerance for high copper concentrations exceeding many times the plant demands for this element. For instance, the amount of 20 ppm Cu in the culture medium causes neither metabolic changes nor disturbation of the physiological processes of *Spinacia oleracea* L. (Baszyński *et al.* 1982).

Manganese is the element accumulated by plants both passively and metabolically, and in the latter case the accumulation depends less on soil factors. Reportedly, the manganese content in plants ranges from 1 to 900 ppm. The amounts of this element, not fitting to these concentration ranges, have not been found in the analysed plants samples collected in Spitsbergen. The highest manganese concentration occurs in *Silene acaulis* (360.6 ppm), and the lowest one — in a lichen sample of the *Peltigera* species (3.9 ppm, *see* Tables 1 and 3).

Zinc is an element necessary for the regular plant growth. Its concentration in most plants is in the ranges 15—80 ppm. It is accumulated actively by plants, but it may be also accumulated passively and in the areas influenced by an industrial emission its amount in plants increases in proportion to the atmospheric dust fall (Kaźmierczakowa 1975).

Except for the polar willow (*Salix polaris*), the other plant species bear this element in the limits given above. *Salix polaris* bore in three different locations 104.1, 99.4 and 121.1 ppm zinc. Thus one can suppose that these concentrations are already toxic for this plant.

The highly-organized plants accumulate lead both from dusts plus atmospheric precipitation and from their breeding ground. Thus, the ascertaining of lead presence in mosses and lichens indicates its occurrence in atmosphere of this area.

Many reports present the opinion that it is difficult to determine the natural lead content in plants. One supposes that the lead concentration in plants ranges from 0.9 to 9.0 ppm (Zimdahl and Arvik 1973). There, where plants are affected by an immediate industrial emission, their lead concentration may exceed even 100 ppm (Tyler 1972, Pakarinen and Tolenen 1976, Karweta 1976, Kaźmierczakowa 1975).

Among the analysed plants there have been found species bearing more then 9 ppm lead, namely *Saxifraga oppositifolia* (34.1 ppm), *Oncophorus wahlenbergii* (26.6 ppm) and a lichen of the *Parmelia* species (52.8 ppm lead). These concentrations should be evaluated as relatively high, especially taking into account that the plant sampling areas are not affected by an immediate influence of industrial emissions. The absence of lead in *Salix polaris*, a willow collected at the Calypsostranda and in the lichen *Cladonia mitis* from the locality Chamberlindalen seems to be worth noting.

One supposes that lead may be accumulated by mode of endocytosis on the basis of the quick appearance of this metal in a cellule. Plants may accumulate an appreciable lead amount without distinct negative external symptoms. Even if such symptoms are observed (*e.g.* the root shortening), they are not typical only for this metal. It seems, that lead accumulated endocytostatically is isolated in places inactive in a metabolic sense, *e.g.* in the vacuole or in cell membrane (Ważny 1987).

Cadmium is the element relatively easily accumulated by plants, although supposedly it is not necessary for their development. For the non-polluted regions one supposes its amount under 1 ppm as characteristic for plants. Most plants have high tolerance of this metal and even a significant cadmium concentration in the breeding ground gives no intoxication symptoms of these plants. The ability to synthesize special proteins or peptides binding the toxic ions into non-toxic complexes is the most common biochemical mechanism of this tolerance (Baszyński *et al.* 1980, 1988). The protein and peptide presence, playing an important role in this detoxication is presently ascertained commonly in many organisms, from primitive algae to vascular plants. These compounds are named phytochelatines or "metallothionein-like complexes" (Gekeler 1988; Grill 1988).

Cadmium, like lead, is the element intensively accumulated by mosses. If 1.0 ppm is the upper concentration range of cadmium in most plants, certain species collected in the Bellsund region displayed a significant exceeding of this value. For instance, *Salix polaris* bears 8.29 ppm, the lichen *Stereocaulon denudatum* — 6.1 ppm the genus *Peltigera* — 1.7 ppm, *Xantoria elegans* — 2.9 ppm, and the moss *Oncophorus wahlenbergii* — 1.8 and 1.3 ppm Cd.

It is supposed that the certain plant species tolerance of heavy metals is connected with formation of special immunity mechanisms. These mechanisms are based either on the free ions immobilization in cellule structures (Vacuoles, cell membrane), or on their binding with a chemical cellule component. Such heavy metal ion complexes with organic acids, aminoacids and peptides are frequently observed (Tukendorf 1988).

Conclusions

1. Copper, zinc, lead and cadmium occur in certain Spitsbergen tundra plants in amounts exceeding accepted concentrations of these elements.
2. Manganese concentration in all the studied plants falls in the physiological limits of this element.
3. The studied metal concentrations in plants are associated with the plant species and in certain cases the amounts of zinc and lead should be also associated with the plant location.

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Streszczenie

W roku 1987, w ramach Wyprawy Geograficznej na Spitsbergen zorganizowanej przez Uniwersytet Marii Curie-Skłodowskiej w Lublinie, zajęto się badaniami nad zawartością niektórych metali ciężkich w roślinach zebranych na Spitsbergenie w okolicach fiordu Bellsund. Terenem badań były równiny Calypsostranda, Lyellstranda i dolina Chamberlin (fig. 1).

Metale ciężkie: miedź, mangan, cynk, ołów i kadm oznaczono u 5 gatunków roślin naczyniowych, 4 gatunków mszaków i 14 gatunków porostów (tab. 1—3). Wykazano u wielu roślin tundry spitsbergeńskiej znaczne nagromadzenie miedzi, cynku, ołowiu i kadmu, co może być znacznym obciążeniem a nawet zagrożeniem dla naturalnego środowiska tego regionu (tab. 4).