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Eiliv Steinnes and Linn Bryhn Jacobsen:

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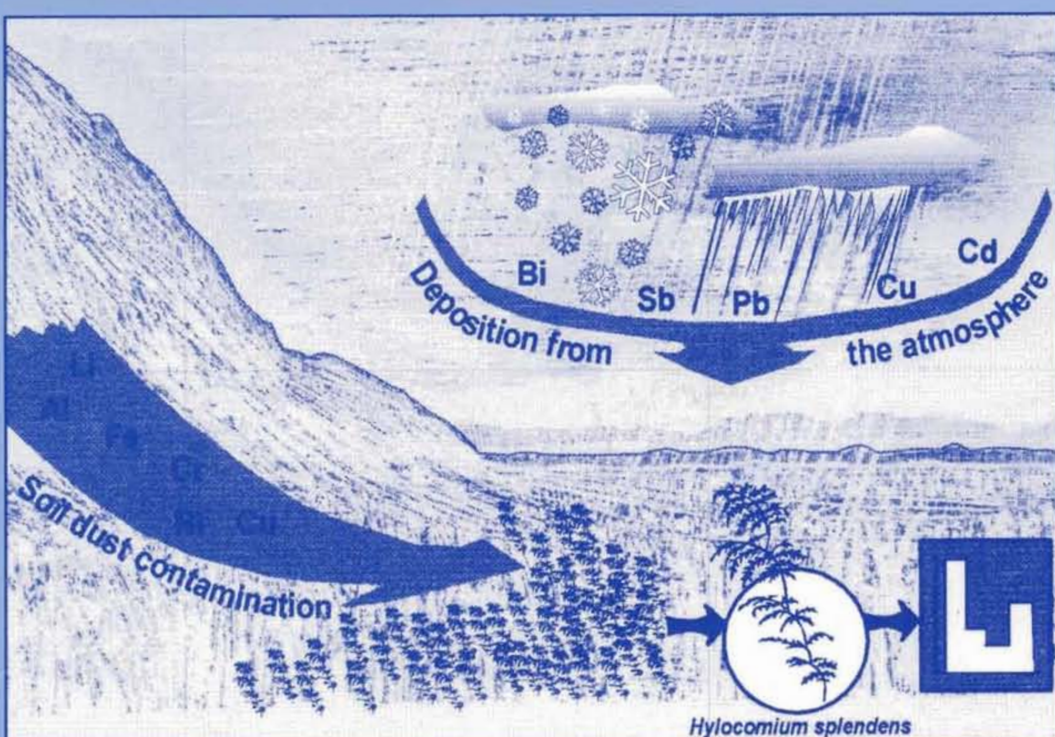

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PREFACE

The mapping of atmospheric deposition of heavy metals by the analysis of terrestrial mosses is a well-established biomonitoring technique in the Nordic countries, and is steadily increasing in use in other parts of the world. In Norway this method has been applied regularly on the mainland since 1977. Sporadic sampling in Svalbard and other polar areas has however implied certain problems in using the technique.

In AMAP the analysis of mosses has been suggested as a technique for systematic monitoring of metal deposition. The decision was therefore taken to conduct this investigation to evaluate the suitability of such measurements. The State Pollution Control Authority (SFT) and the Norwegian Polar Institute (NP) have contributed economically to the investigation.

Trondheim and Oslo, December 1994
Eiliv Steinnes
Linn Bryhn Jacobsen

ABSTRACT

Mosses have proven to be difficult to use in the Arctic for monitoring of heavy metal deposition from the atmosphere because sources other than air pollution, in particular wind erosion of soil, contribute substantially to the observed metal concentrations in the moss. In this investigation targeted field sampling in Svalbard and physical methods for soil-particle removal from mosses were tested in order to improve the general performance of the moss technique. It appeared that careful selection of sampling sites with respect to impacts from wind erosion and extensive contact with running water during snow melt improves the feasibility of the method, and for some elements usually associated with long-distance air pollution the levels observed in Svalbard moss look reasonable. Further use of the method however requires calibration to account for the lower growth rate of *Hylocomium splendens* in the Arctic relative to areas in the boreal zone. Treatment of mosses by washing or shaking prior to analysis appeared not to reduce the influence from soil particles.

INTRODUCTION

Since its introduction more than 25 years ago (Rühling & Tyler, 1968) the moss technique for monitoring of atmospheric deposition of heavy metals has found numerous applications, and it is now being used routinely for large-scale deposition studies in several countries. In Norway nation-wide surveys were carried out in 1975, 1985, and 1990 (Steinnes et al., 1992). Based on this and other experience, the moss technique has also been proposed for routine use in AMAP (Arctic Monitoring and Assessment Programme).

The basis of this monitoring technique is that mosses lack a vascular system and therefore depend on surface uptake of chemical substances. This fact, together with a high capacity to retain many heavy metals, has made mosses very popular for relative metal deposition studies, both on a local, regional, and continental scale. As an example the quite extensive atmospheric transport of some heavy metals to southern parts of Scandinavia from source areas elsewhere in Europe was first shown by means of moss analysis (Rühling & Tyler, 1973; Steinnes, 1977). It is quite clear, however, that factors other than air pollution contribute significantly to the element distribution observed in mosses. Evidence from statistical analysis of the data from nation-wide surveys in Norway indicates the following additional contributing factors to be of importance:

- Airborne supply of constituents from the marine environment (e.g. Na, Mg, Sr, Cl, Br, I, B, Se,..)
- The "vascular pump" effect, *i.e.* root uptake of elements in higher plants and subsequent transfer to the moss through leaching from living or decaying plant material (e.g. K, Ca, Mn, Zn, ...).
- Deposition of windblown soil dust on the moss surface, mainly of local origin (*e.g.* Al, Fe, Na, Ti, ...).

The relative contributions from these additional sources vary considerably between different natural habitats and geographical regions, and may in some cases limit the general applicability of the moss technique for the monitoring of air pollutants, in particular in areas with very low pollution load.

Attempts to use the moss technique in Arctic areas have so far been limited. Observations from Iceland, Greenland and Svalbard (Rühling et al., 1987; Grodzinska & Godzik, 1990; Steinnes et al., 1993 b) show that samples from these areas generally exhibit high and variable concentrations of many elements typically found as constituents of mineral soil. Apparently, wind erosion of surface material is a factor contributing strongly to the element distribution observed in mosses in these areas with a generally sparse vegetation. Recent experience from Alaska (Ford et al., 1994) indicates an additional "hydrological" factor to be particularly important in areas with permafrost, notably the exposure of the moss carpet during snow melt to drainage water containing dissolved (and particulate) soil components.

Altogether the experience gained so far indicated that more work was necessary in order to study the applicability and limitations of the moss technique for the monitoring of heavy metal deposition in polar regions. Therefore the present investigation of mosses from Svalbard was carried out, in order to see whether careful selection of sampling sites with respect to impacts from wind erosion and different treatments of samples prior to analysis could reduce the problems indicated from previous work.

MATERIAL AND METHODS

The materials discussed in this report are from two different investigations:

1. Field sampling in Svalbard in different habitats and regions, in order to see whether careful selection of sampling sites could reduce the problems explained in the preceding text.

2. Experimental treatments of moss samples from Arctic regions previously shown to be strongly contaminated with soil dust.

Field sampling in Svalbard

The field work was carried out primo August 1993 at locations accessible from Longyearbyen and Ny-Ålesund by foot, rubber boat, or helicopter. The main work was concentrated on *Hylocomium splendens*, the moss species most frequently used for heavy-metal monitoring at more southerly latitudes, and also to a limited extent in Svalbard (Steinnes et al., 1993b). Since *H. splendens* is not easily found everywhere in Svalbard, additional sampling of *Racomitrium lanuginosum*, also under evaluation as a monitoring moss species in arctic North America (Ford et al., 1994), was performed at some sites in order to facilitate a comparison with *H. splendens*.

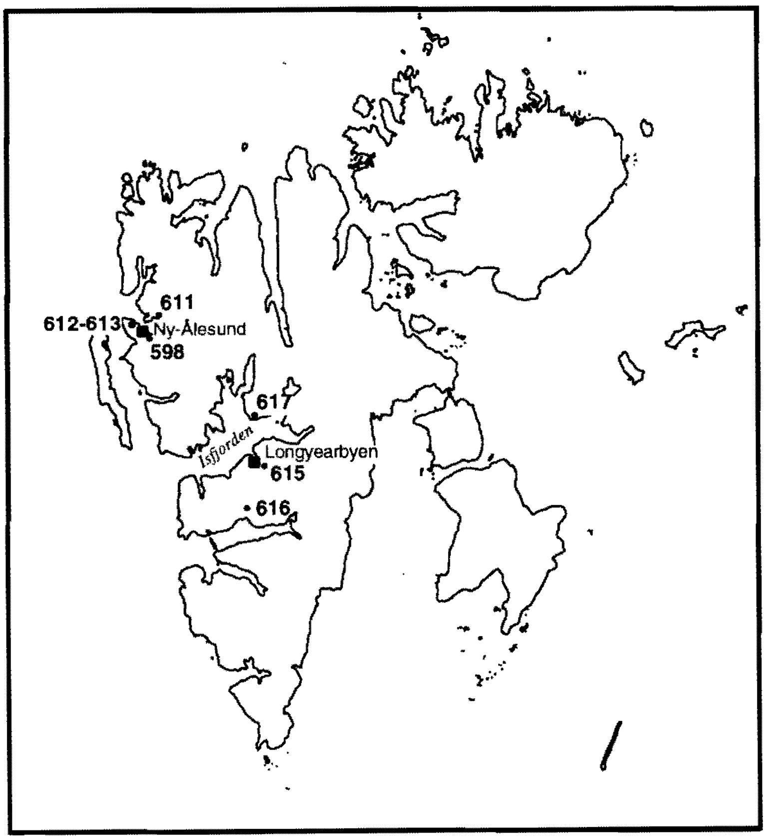

Fig. 1. Sampling sites in Svalbard for mosses studied in the present work.

The geographical locations from which samples were obtained are shown on the map in Fig. 1. A further description of the sampling habitats is given in Table 1. Samples were collected in the field using disposable polyethylene gloves and stored in polyethylene bags. After return to the laboratory the samples were air-dried and cleaned prior to analysis. The entire living part of the *H. splendens* plant was taken for analysis, since it was difficult to separate the different annual increments. In the case of *R. lanuginosum* the upper 3 cm were analysed.

Table 1. Description of sampling sites of *Hylocomium splendens* (HS) and *Racomitrium lanuginosum* (RL).

Site	°N	°E	Species	Site description	Quality with respect to wind erosion
598 I, II	78°55'	11°56'	HS. RL	Coarse till, ~ 10% vegetation cover	Very poor
611	79°00'	12°18'	HS, RL	Relatively continuous vegetation cover	Fair
612 A	78°58'	11°37'	HS	Continuous vegetation cover, affected locally by strong reindeer grazing	Good/fair
612 B	78°58'	11°37'	HS	200 m from 612 A, continuous moss cover on boulders, influence from bird cliff	Good
613	78°10'	11°41'	HS	2 km east of 612, relatively continuous vegetation cover	Fair
615	78°56'	15°49'	HS	Relatively continuous vegetation cover, but still some wind erosion	Fair/poor
616	77°56'	15°32'	HS, RL	Homogeneous vegetation broken by barren patches. Considerable soil erosion	Poor
617	78°28'	15°39'	HS, RL	Continuous vegetation on peat, below bird cliff, possible influence from drainage water	Fair/good

Experimental treatment of previously-analysed samples

Among a limited number of samples from arctic regions analysed in connection with the 1990 deposition survey in Norway (Steinnes et al., 1993b), some were strongly affected by soil-dust contamination, as evident e.g. from very high Al values. Aliquots of these samples, three of which (599, 600, 601) were from Iceland and three (602, 603, 604) from Svalbard, were subjected to different forms of physical treatment before re-analysis; either washing with distilled water, or mechanical shaking for 15 hours. In both cases the intention was to remove "bothersome" soil particles adhered to the moss surface without removing any ions or microscopic particles potentially supplied to the moss by atmospheric deposition.

Chemical analysis

0.5 gram samples from field sampling as well as from laboratory investigations were decomposed with concentrated HNO_3 in a pressured PTFE bomb and analysed by induction-coupled plasma-mass spectrometry (ICP-MS) as described elsewhere (Steinnes et al. 1993a) with respect to 31 elements. The analyses were carried out by the Norwegian Institute for Air Research, which was also responsible for the corresponding analyses in the 1990 Norwegian moss survey. As a quality check two samples from the 1990 survey with low contributions from the soil factor were submitted to the laboratory as unknowns in between the Svalbard samples. Data for these samples are shown in Table 2 along with the corresponding values from 1990. With a few exceptions (Cd, Al, Ca, Y in sample 584) the agreement is entirely satisfactory.

Table 2. Re-analysis of two *Hylocomium splendens* samples from the 1990 moss survey with low contents of soil-derived elements. Data are in ppm.

	584		596	
	1990	1993	1990	1993
Lead	15.8	17.8	2.64	2.87
Cadmium	0.36	0.08	< 0.03	0.02
Copper	6.5	5.4	3.5	3.0
Zinc	63	51	19.6	16.0
Chromium	1.1	1.2	< 0.5	< 0.3
Nickel	1.6	1.5	0.8	1.1
Cobalt	0.20	0.12	0.12	< 0.09
Iron	367	398	219	239
Manganese	181	156	347	386
Vanadium	3.3	1.7	0.80	0.67
Arsenic	0.42	0.35	0.11	< 0.02
Barium	16.4	14.2	28.5	36.6
Strontium	8.8	8.3	15.4	21.6
Aluminum	375	674	241	241
Antimony	0.24	0.29	0.049	0.034
Bismuth	0.05	< 0.004	0.007	< 0.004
Thallium	0.17	0.15	0.018	0.015
Uranium	0.032	0.024	0.010	0.007
Thorium	0.064	0.073	0.022	0.042
Beryllium	0.04	< 0.01	0.04	< 0.01
Lithium	0.19	0.27	0.10	0.10
Rubidium	13.9	14.6	11.0	14.0
Cesium	0.25	0.19	0.17	0.15
Magnesium	960	1150	920	1090
Sodium	224	237	96	116
Calcium	2280	1530	3170	3190
Molybdenum	0.24	0.28	0.02	< 0.15
Yttrium	0.14	1.14	0.086	0.078
Lanthanum	0.29	0.25	< 0.21	0.26
Boron	3.5	3.4	2.2	2.3
Gallium	0.19	0.20	0.06	0.06

RESULTS AND DISCUSSION

Concentrations of 31 elements in samples of *H. splendens* collected in Svalbard 1993 are shown in Table 3. Median values from this work are compared with corresponding values from the 1990 Norwegian survey for areas in the northernmost and southernmost region of the country, respectively. Results from a principal component factor analysis (PCA) of the same data and positioning of samples along factor 1 and factor 2 are shown in Table 4 and Fig. 2. A comparison of values for *H. splendens* and *R. lanuginosum* collected at the same sites is shown in Table 5. Table 6 shows results from re-analysis of samples from the 1990 moss survey with high content of soil-derived elements, after treatment either by washing or shaking.

Table 3. Concentrations of 31 elements in *Hylocomium splendens* from Svalbard (ppm).

	Pb	Cd	Cu	Zn	Cr	Ni	Co	Fe	Mn	V	As
Sample no.											
598 I	8.9	0.52	3.0	35.7	2.1	3.3	1.08	1197	55	4.0	0.55
598 II	4.8	0.46	2.5	66.0	1.8	2.5	0.77	1084	103	3.0	0.05
611	3.7	0.19	2.4	24.8	1.6	2.1	0.58	1438	79	2.7	1.04
612 A	5.6	0.30	1.2	20.7	1.2	1.8	0.16	437	27	1.7	0.19
612 B	5.2	0.33	2.2	7.7	0.9	1.3	0.19	429	10	2.0	0.21
613	5.1	< 0.01	1.0	10.5	1.0	0.6	0.10	279	312	2.3	0.40
615	6.3	0.35	4.7	30.7	6.8	8.4	1.88	4644	125	13.9	1.76
616	9.6	0.12	5.5	41.3	6.8	7.7	2.06	4232	145	10.2	2.03
617	2.0	0.18	3.2	17.6	2.7	2.6	0.51	1394	325	5.7	0.45
Median values:											
Svalbard	5.2	0.30	2.5	24.8	1.8	2.5	0.58	1197	103	3.0	0.45
Finnmark, N. Norway (1990)	3.7	0.07	5.4	34.0	0.9	1.7	0.32	370	340	1.3	0.26
Southernmost Norway (1990)	31.0	0.32	8.0	52.0	1.4	2.1	0.27	550	270	4.8	0.64

	Ba	Sr	Al	Sb	Bi	Tl	U	Th	Be	Li
Sample no.										
598 I	27	18.6	2210	0.11	0.026	0.075	0.174	0.43	0.08	1.27
598 II	519	163.2	2093	0.04	0.023	0.004	0.150	0.56	0.22	1.81
611	299	93.3	2142	0.02	0.021	0.070	0.107	0.44	0.26	1.58
612 A	6	20.0	533	0.07	< 0.004	0.031	0.084	0.11	0.02	0.41
612 B	6	18.9	668	< 0.01	0.014	0.034	0.049	0.16	0.02	0.50
613	346	107.2	356	0.14	< 0.003	0.011	0.287	0.10	0.02	0.42
615	73	169.0	6868	0.09	0.026	0.110	0.170	0.86	0.14	4.21
616	64	29.8	6946	0.10	0.027	0.122	0.097	0.83	0.17	3.91
617	460	127.4	2468	0.04	0.020	0.072	0.139	0.28	0.10	2.16
Median values:										
Svalbard	73	93.3	2142	0.07	0.02	0.070	0.139	0.43	0.10	1.58
Finnmark, N. Norway (1990)	22	9.8	270	0.05	0.02	0.030	0.020	0.03	< 0.02	0.14
Southernmost Norway (1990)	23	9.7	530	0.33	0.09	0.200	0.050	0.13	0.03	0.34

Table 3 continued..

	Rb	Cs	Mg	Na	Ca	Mo	Y	La	B	Ga
Sample no.										
598 I	4.5	0.19	1892	146	2667	< 0.14	1.16	2.00	9.7	0.77
598 II	77.7	0.21	19209	154	3763	< 0.14	7.05	26.28	142.3	0.64
611	44.4	0.35	10769	98	6647	< 0.14	1.45	15.12	16.8	0.80
612 A	1.8	0.05	1927	183	10934	< 0.14	0.35	0.54	15.2	0.21
612 B	3.0	0.12	1739	183	3143	< 0.14	0.44	0.71	2.9	0.29
613	51.1	0.05	12464	154	10501	0.23	4.64	17.50	30.2	0.15
615	8.9	0.49	1815	243	2607	0.24	2.37	3.54	16.0	0.35
616	8.9	0.59	2311	262	3417	0.34	2.34	3.37	8.4	0.20
617	60.4	0.42	12300	831	2540	0.59	1.26	23.35	90.7	0.77
Median values:										
Svalbard	8.9	0.21	2311	183	3417	< 0.14	1.45	3.54	16.0	0.35
Finnmark, N. Norway (1990)	9.4	0.10	1200	89	3500	0.07	0.13	0.26	3.1	0.12
Southernmost Norway (1990)	14.0	0.28	1000	120	2400	0.38	0.29	0.55	2.8	0.32

It is evident from Table 3 that even a very careful selection of sampling site is not going to exclude the problem of soil contamination. There is some general correspondence however between the general site characteristics and the soil contamination, as evident e.g. from the Al and Fe data, showing excessive problems at sites 615 and 616 while 612 and 613 are little affected. It seems therefore to be a clear advantage to choose sampling sites where the vegetation cover is reasonably continuous, located as far as possible from areas with no or only sparse vegetation cover.

The results from the PCA (Table 4) must be evaluated with care because of the small number of samples on which it is based. Nevertheless there appear to be at least two factors that look consistent. Factor 1, with very high loading for Al and some other elements (Fe, Li, Cr, Cu, Ni, Co, Cs, V), appears as a typical soil component.

Table 4. Principal component analysis of data for trace elements in *Hylocomium splendens* from Svalbard. Factor scores above 0.4 are denoted by bold type.

Element	Communality	Factor				
		1	2	3	4	5
Lead	0.878	**0.413**	**−0.562**	0.219	0.386	**0.441**
Cadmium	0.914	−0.055	−0.147	**0.899**	−0.117	0.261
Copper	0.969	**0.958**	−0.086	0.193	−0.055	−0.064
Zinc	0.905	0.372	**0.443**	**0.517**	0.044	**0.548**
Chromium	0.979	**0.971**	−0.118	−0.025	0.143	−0.020
Nickel	0.973	**0.957**	−0.175	0.086	0.118	0.071
Cobalt	0.996	**0.950**	−0.110	0.193	0.133	0.162
Iron	0.984	**0.985**	−0.087	−0.025	0.057	0.046
Manganese	0.973	0.099	**0.543**	−0.356	**0.437**	**−0.592**
Vanadium	0.937	**0.938**	−0.084	0.016	0.185	−0.129
Arsenic	0.975	**0.931**	−0.194	−0.255	0.009	0.074
Barium	0.994	−0.143	**0.973**	−0.031	−0.013	−0.157
Strontium	0.737	0.271	**0.800**	−0.004	0.131	−0.081
Aluminum	0.995	**0.993**	−0.055	0.034	0.059	0.039
Antimony	0.905	0.220	−0.072	−0.207	**0.892**	0.114
Bismuth	0.917	**0.715**	0.146	**0.562**	−0.261	−0.001
Thallium	0.937	**0.877**	−0.333	0.011	−0.106	−0.215
Uranium	0.856	−0.070	**0.399**	−0.143	**0.817**	−0.057
Thorium	0.998	**0.930**	0.106	0.210	−0.001	0.278
Beryllium	0.920	**0.521**	**0.548**	0.095	**−0.466**	0.349
Lithium	0.986	**0.985**	0.104	0.058	0.017	−0.035
Rubidium	0.993	−0.179	**0.976**	−0.030	−0.014	−0.082
Cesium	0.987	**0.940**	0.127	−0.013	−0.213	−0.203
Magnesium	0.992	−0.253	**0.963**	−0.022	−0.009	0.035
Sodium	0.904	0.169	0.252	0.059	−0.082	**−0.895**
Calcium	0.875	**−0.552**	−0.043	**−0.673**	0.211	0.267
Yttrium	0.936	0.023	**0.770**	0.063	**0.399**	**0.423**
Lanthanum	0.992	−0.153	**0.971**	−0.019	−0.012	−0.160
Boron	0.877	−0.119	**0.863**	0.339	−0.001	−0.056
Gallium	0.686	−0.015	**0.422**	**0.556**	**−0.394**	−0.210
Eigen values		12.98	7.52	3.59	2.65	1.23
% explained		43.3	25.1	12	8.8	4.1

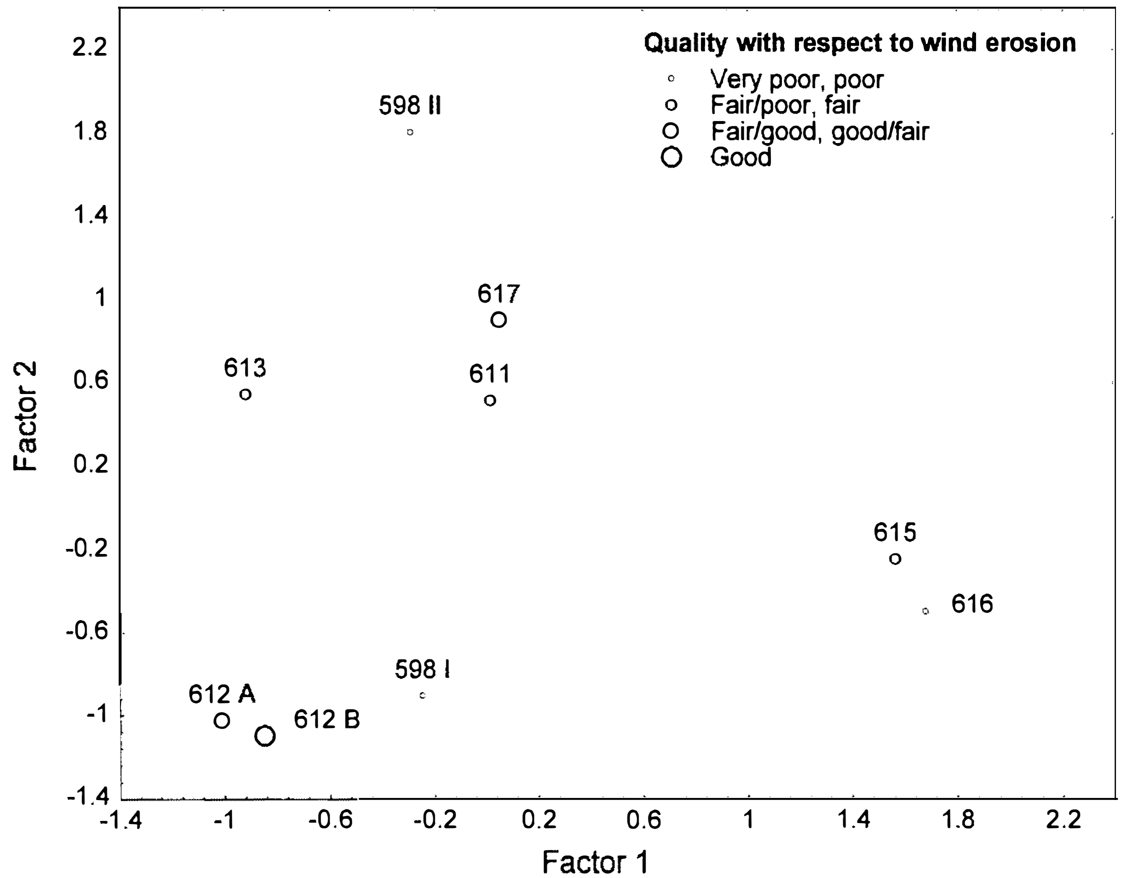

Fig. 2. Positioning of sample sites along PCA factor 1 and PCA factor 2.

The positioning of sample sites along factor 1 (Fig. 2) confirms that careful selection of sampling sites will reduce soil contamination, as no samples expected to have good quality with respect to wind erosion have high loading for this factor. Factor 2 (high loading for Rb, Ba, La, Mg, B, Sr) seems more complicated, with possible contribution both from a marine and a rare mineral component. Unlike similar analyses performed on moss materials from mainland Norway (Schaug et al., 1990; Berg et al., 1994), the present analysis did not reveal any component typical of long-range transported air pollutants.

The samples of *R. lanuginosum* (RL) and *H. splendens* (HL) subject to pairwise comparison in Table 5 are all from sites with assumed moderate or high risk of interference from wind erosion. This is reflected in the results, which show high Al and Fe values in many cases, and no strong correspondence between samples from the same site. For example the 598 RL sample is quite different from both the 598 HS samples, which were taken only about 100 m apart, but are still strongly different from each other. It is also virtually impossible to evaluate relative uptake efficiencies of different elements in the two moss species on the basis of the present data. The generally lower levels for elements such as Ca, Mg and B in *R. lanuginosum* however, may indicate that the habitats where this moss grows are less subject to interference from the "hydrological" factor associated with snow melt.

Table 5. Concentrations of 31 elements (ppm) in *Hylocomium splendens* (HS) and *Racomitrium lanuginosum* (RL) from Svalbard collected at the same sites.

	Pb	Cd	Cu	Zn	Cr	Ni	Co	Fe	Mn	V
598 RL	12.1	-0.01	2.2	6.6	1.9	1.5	0.39	981	13	2.0
598 HS I	8.9	0.52	3.0	35.7	2.1	3.3	1.08	1197	55	4.0
598 HS II	4.8	0.46	2.5	66.0	1.8	2.5	0.77	1084	103	3.0
611 RL	5.6	0.04	1.6	10.8	1.1	0.9	0.30	540	27	1.7
611 HS	3.7	0.19	2.4	24.8	1.6	2.1	0.58	1438	79	2.7
616 RL	10.9	0.06	3.9	22.4	9.1	6.8	2.32	6500	95	15.0
616 HS	9.6	0.12	5.5	41.3	6.8	7.7	2.06	4232	145	10.2
617 RL	4.4	0.46	7.2	28.7	6.7	6.4	1.48	3441	77	17.2
617 HS	2.0	0.18	3.2	17.6	2.7	2.6	0.51	1394	325	5.7

	As	Ba	Sr	Al	Sb	Bi	Tl	U	Th	Be
598 RL	0.15	13	8.8	2547	0.07	0.03	0.082	0.075	0.31	-0.01
598 HS I	0.55	27	18.6	2210	0.11	0.03	0.075	0.174	0.43	0.08
598 HS II	0.05	519	163.2	2093	0.04	0.02	0.004	0.150	0.56	0.22
611 RL	0.27	9	7.2	828	0.03	0.06	0.043	0.041	0.27	0.03
611 HS	1.04	299	93.3	2142	0.02	0.02	0.070	0.107	0.44	0.26
616 RL	3.04	66	22.8	9515	0.04	0.02	0.107	0.246	1.36	0.31
616 HS	2.03	64	29.8	6946	0.10	0.03	0.122	0.097	0.83	0.17
617 RL	1.45	54	26.4	5730	0.11	0.02	0.131	0.362	0.67	0.13
617 HS	0.45	460	127.4	2468	0.04	0.02	0.072	0.139	0.28	0.10

	Li	Rb	Cs	Mg	Na	Ca	Mo	Y	La	B	Ga
598 RL	0.61	2.6	0.08	821	283	689	-0.14	0.74	1.31	1.5	0.00
598 HS I	1.27	4.5	0.19	1892	146	2667	-0.14	1.16	2.00	9.7	0.77
598 HS II	1.81	77.7	0.21	19209	154	3763	-0.14	7.05	26.28	142.3	0.64
611 RL	0.32	1.9	0.10	711	104	1080	-0.14	0.59	0.87	1.7	0.28
611 HS	1.58	44.4	0.35	10769	98	6647	-0.14	1.45	15.12	16.8	0.80
616 RL	4.83	12.1	0.75	1830	277	200	0.50	4.47	4.85	8.1	0.59
616 HS	3.91	8.9	0.59	2311	262	3417	0.34	2.34	3.37	8.4	0.20
617 RL	2.71	12.3	0.51	2698	580	3441	1.16	2.24	2.65	10.3	0.00
617 HS	2.16	60.4	0.42	12300	831	2540	0.59	1.26	23.35	90.7	0.77

The washing or shaking of moss samples with high content of soil-derived elements (Table 6) apparently did not remove any particulate material. In some samples an opposite effect was observed, notably a strong increase of Ba, La and in some cases Rb and Sr. These are some of the elements showing high loading in factor 2. It seems likely that those elements are located in discrete, but rare mineral particles, that would occur in some aliquots of a given moss sample but not in others.

Table 6. Re-analysis of samples from the 1990 moss survey with high content of soil-derived elements, after treatment either by washing (w) or shaking (s). Values deviating strongly from the original analyses are denoted by bold type. Data are in ppm.

Sample no.	599		600		601	
Element	1990	1993 (w)	1990	1993 (s)	1990	1993 (w)
Pb	4.0	6.2	1.5	2.3	3.6	4.7
Cd	0.09	0.12	0.15	0.04	0.14	< 0.01
Cu	9.2	9.9	9.7	12.4	6.2	7.8
Zn	36	26	34	37	33	34
Cr	5.2	5.4	2.9	4.6	3.4	4.3
Ni	5.7	6.2	3.2	4.2	3.3	4.8
Co	2.1	2.5	2.8	4.2	1.3	1.4
V	10.0	11.9	15.3	24.9	8.0	10.5
As	0.08	0.11	0.14	0.26	0.03	0.26
Ba	10.1	13.6	20	**299**	11.1	**517**
Sr	18	19	23	33	23	**171**
Sb	< 0.01	0.02	< 0.01	0.05	< 0.01	< 0.01
Bi	0.018	0.020	0.008	< 0.003	0.011	< 0.004
Tl	0.008	0.011	0.013	0.008	0.030	0.004
U	0.024	0.020	0.085	0.087	0.028	0.049
Th	0.051	0.029	0.129	0.118	0.058	0.091
Be	0.04	< 0.01	0.09	0.15	0.07	0.11
Li	0.27	0.35	0.34	0.72	0.22	0.50
Rb	2.8	2.1	8.1	12.7	2.4	**81.6**
Cs	0.02	0.02	0.25	0.32	0.03	0.01
Mo	0.12	< 0.14	0.11	0.19	0.06	< 0.14
Y	1.07	1.40	2.4	4.3	0.81	**7.3**
La	0.81	0.74	2.2	**15.2**	0.64	**26.2**
B	1.7	1.8	6.9	7.3	3.1	2.6
Ga	0.75	1.02	1.12	1.28	0.62	0.70

Sample no.	602		603		604	
Element	1990	1993 (w)	1990	1993 (s)	1990	1993 (w)
Pb	7.3	8.8	5.2	5.0	6.2	7.7
Cd	0.21	0.14	0.11	0.13	0.15	0.09
Cu	3.1	4.1	4.9	3.9	3.6	3.6
Zn	20	20	33	35	34	37
Cr	3.7	4.2	9.1	7.3	1.5	1.0
Ni	2.6	2.7	5.1	3.6	1.3	1.1
Co	0.83	0.92	2.4	1.8	0.48	0.57
V	5.3	5.5	17.4	14.0	2.9	2.8
As	0.68	1.02	2.73	2.84	0.53	0.60
Ba	31	**234**	91	69	44	55
Sr	27	35	145	150	21	24
Sb	0.03	0.09	0.01	0.02	0.03	0.06
Bi	0.041	0.052	0.046	0.017	0.078	0.113
Tl	0.068	0.065	0.081	0.072	0.061	0.015
U	0.21	0.25	0.137	0.148	2.30	2.74
Th	0.62	0.85	0.93	1.08	0.89	1.06
Be	0.15	0.17	0.25	0.22	0.34	0.36
Li	2.5	3.8	6.3	4.6	2.0	2.9
Rb	6.4	7.6	10.3	9.2	9.0	8.6
Cs	0.47	0.54	0.96	0.71	0.92	0.80
Mo	0.13	0.25	0.33	0.42	0.09	0.26
Y	1.11	1.73	1.76	1.83	1.60	2.20
La	2.5	3.1	4.7	4.0	6.8	7.3
B	6.1	7.0	47.1	41.3	4.3	4.9
Ga	0.83	1.01	1.87	1.86	0.84	0.99

It is known from studies of air particles (Mauenhaut et al., 1988) that Svalbard at times receives considerable amounts of air pollutants by long-range atmospheric transport from Eurasia, the mean deposition levels of heavy metals being of the same order of magnitude as in northern Norway. On the other hand the variety of *H. splendens* found in Svalbard has a different growth pattern and most likely considerably lower growth rate than that growing in Fennoscandia, which would imply higher metal concentration in the moss at the same deposition rate. It is therefore possible that metal concentration levels similar to or slightly higher than the median values for Finnmark still reflect mainly airborne supply.

Considering the individual data and the Svalbard median values for *H. splendens* in Table 3, it is obvious that many elements are present in the moss samples in concentrations far exceeding those that would be expected to result from air pollution in a remote area. In order to discuss this matter in further detail, however, it is advantageous to consider the experience available from similar studies at more southerly latitudes with regard to the behaviour of different elements in mosses (Steinnes et al., 1992). In the following the elements are discussed groupwise on this basis:

I. *Mn, Zn, Cu (Rb)*: These elements show lower median values in Svalbard than in northern Norway. Their concentration in the moss, however, is to a great extent determined by the "vascular pump" effect, and therefore lower levels were to be expected at conditions with lower abundance of vascular plants. With the possible exception of Cu, the concentrations of these elements in the Svalbard mosses are much higher than what might be explained from atmospheric deposition.

II. *Pb, Sb, Bi*: These elements show fairly stable concentration levels, and their median values are similar to those observed in Finnmark. These elements are among the most typical representatives of long-range atmospheric transport (Steinnes et al., 1993b), and their concentrations in Svalbard mosses are consistent with what might be expected in this respect.

III. *Cr, Ni, Co, Fe, As, Tl*: These elements are quite strongly affected by soil dust, as evident e.g. where looking at data for samples 615 and 616. Their concentration levels in the samples least affected by wind erosion are still of the same order as the median values for Finnmark, and therefore the levels may to some extent reflect contribution from air pollution, although other factors are still expected to contribute quite strongly.

For most of the remaining 17 elements the recorded concentrations probably have very limited relation to air pollution.

CONCLUSIONS

1. Although the moss technique provides limited information about atmospheric deposition of trace elements when employed in arctic regions, careful selection of sampling sites to avoid contribution from local wind erosion improves the feasibility of the method considerably.

2. For some elements normally associated with long-range atmospheric transport of pollutants the levels observed in Svalbard moss may approach those expected from air pollution alone. In order to compare these levels to those observed at more southerly latitudes, however, it is necessary to calibrate for differences in growth rate.

3. Treatment of mosses by washing or shaking prior to analysis does not seem to reduce the influence from soil particles.

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