Research Note

Cladina stellaris (Opiz) Brodo as a bioindicator of atmospheric deposition on the Kola Peninsula, Russia

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Concentrations of 16 elements (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, C, N, S, P, Ca, Mg) were determined in the lichen *Cladina stellaris* (Opiz) Brodo collected from 26 localities on the Kola Peninsula. Concentrations were higher closer to the emission sources. In Arctic regions affected by local emissions, lichens can be recommended as sensitive indicators of atmospheric pollution.

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Introduction

The Kola Peninsula is one of the areas in the northern hemisphere polluted by heavy metals and sulphur (Kozlov et al. 1992; Tikkanen et al. 1992; Mäkinen 1994; Rühling 1994; Alexeyev 1995; Baklanov et al. 1995; Glazov et al. 1995; Kelley et al. 1995; Moiseenko 1995). The primary sources of pollution are: copper-nickel smelters located near the towns of Monchegorsk (Severonickel smelter) and Zapolyarni (Pechenganickel smelter). Other operations on the Kola Peninsula include an aluminium smelter in Kadalaksha, iron and apatite mines in Kirovsk and Olenegorsk, and coal burning and naval installations in Murmansk (Fig. 1). The Kola Peninsula is also affected by long-range transport of pollutants; however, that contribution is negligible compared with local sources.

Yearly copper emissions on the Kola Peninsula exceed two thousand tonnes (Severonickel two thousand, Pechenganickel 180 tonnes) and nickel emissions exceed three thousand tonnes (Severonickel three thousand, Pechenganickel 300 tonnes) (Mäkinen 1994; Jaffe et al. 1995). Total SO_2 emissions are approximately 600 thousand tonnes/year (Jaffe et al. 1995). The regional depositions of Cu and Ni are: 0.15 and 0.35 kg/ha/year respectively (Alexeyev 1995). Average sulphur deposition on the Kola Peninsula is approximately 0.7–1.0 g/m^2/year, and near the local sources is even as high as 30 g/m^2/year (Moiseenko 1995). Sulphur depositions are higher than critical values across most of the Kola Peninsula (Koptsik & Koptsik 1995).

The Kola Peninsula is part of the Fenno-Scandian Crystalline Shield, built of Palaeozoic granitoids and metamorphic crystalline shields (Skiba 1994). Podzol soils and weakly formed soils are most common. They are acidic (pH about 4), with about 50% organic matter and a C/N ratio of about 30. The concentration of heavy metals is high (iron max. 18,000 µg/g d.wt, copper max. 2000 µg/g d.wt., nickel max. about 2000 µg/g d.wt. (S. Skiba 1994, unpubl. data).

The topography of the Kola Peninsula varies considerably. While areas along the coast of the White and Barents Seas are below 200 m a.s.l., most of the land is between 200 and 500 m a.s.l. Mountains, with the highest peak at 1208 m a.s.l., cover a small area in the middle of the peninsula. Smelter complexes are located at altitudes of 100–350 m a.s.l. (Mäkinen 1994).

The peninsula lies mostly within the cool temperate zone; only the north-eastern part is included in the polar zone. The average summer temperature is about 8–14°C. Annual precipitation averages approximately 400 mm. The growing

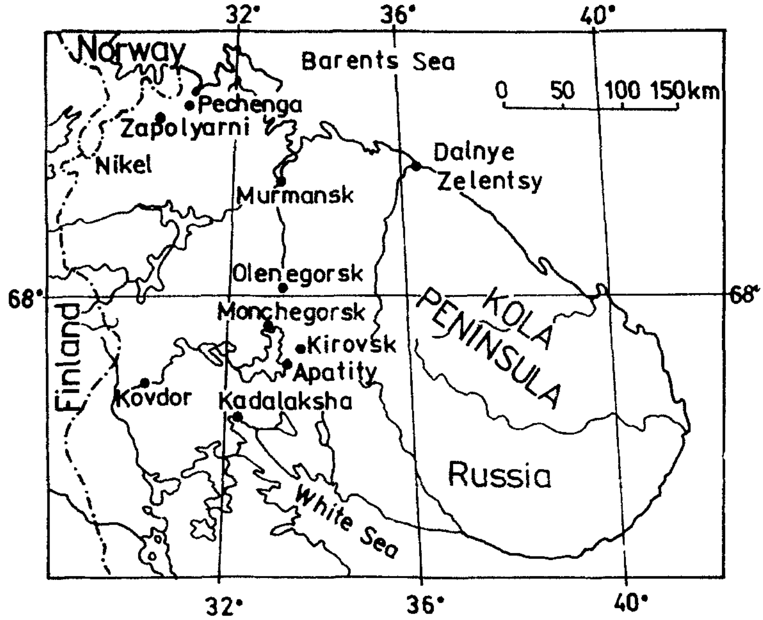


Fig. 1. The Kola Peninsula: major urban and industrial sources.

season is short (120–125 days). South-westerly winds predominate during the winter; in summer they are often north-easterly (Luzin et al. 1994; Mäkinen 1994). The vegetation belongs to the northern boreal and arctic alpine zones and is represented by forest tundra (spruce, Scotch pine, birch) or treeless tundra and mires. Close to the industrial areas the vegetation is seriously damaged; dying forests are common (Mäkinen 1994).

Because of their anatomical structure, lichens and mosses have a great ability to accumulate various chemical elements, including air pollutants, making them useful for assessing environmental contamination (Markert 1992). Various lichen and moss species have been used as indicators of environmental pollution in Arctic areas by Rühling et al. (1987), Grodzińska & Godzik (1991), Heino et al. (1992), Grodzińska et al. (1993), Mäkinen (1994), Steinnes et al. (1994) and Glazov et al. (1995).

Cladina stellaris (Opiz) Brodo (= *Cladonia alpestris* [L.] Rabenh.) has been used as a sensitive bioindicator of heavy metal pollution several times (Pakarinen et al. 1978; Nuorteva et al. 1986; Kortesharju et al. 1990; Nuorteva 1990; Glazov et al. 1995). According to Folkeson & Andersson-Bringmark (1988), this species is an especially effective accumulator of Cu and Zn.

The aim of this study was to determine the concentrations of 16 elements, mostly pollutants, in *C. stellaris*, which is common in the area.

Methods

During summer 1992, lichen samples were collected along two transects which were located along the road network, and spanned forest tundra and treeless tundra ecosystems. The first transect (ca. 200 km) ran southward from Zapolyarni (the location of the Pechenganickel smelter), via Murmansk, to Monchegorsk (Severonickel smelter). The second (ca. 150 km) ran eastward from Murmansk to Dalnye Zelentsy (Fig. 2). The sampling density was about one composite sample every 10–15 km. No samples were collected within 5 km of the smelters. Sampling sites were no less than 150 m and no more than 200 m from the roads. At each sampling site, three subsamples were taken within an area of 20–30 m^2, and then combined in one collective sample of 20–25 g d.wt. Sampling and sample handling were performed without polyethylene gloves.

The samples stored in the field in polyethylene bags were transported to the laboratory and cleaned of litter and other debris. Unwashed samples (whole lichen) were dried at 600°C, then homogenized. Samples of 0.5–0.6 g d.wt (ICP-AS)

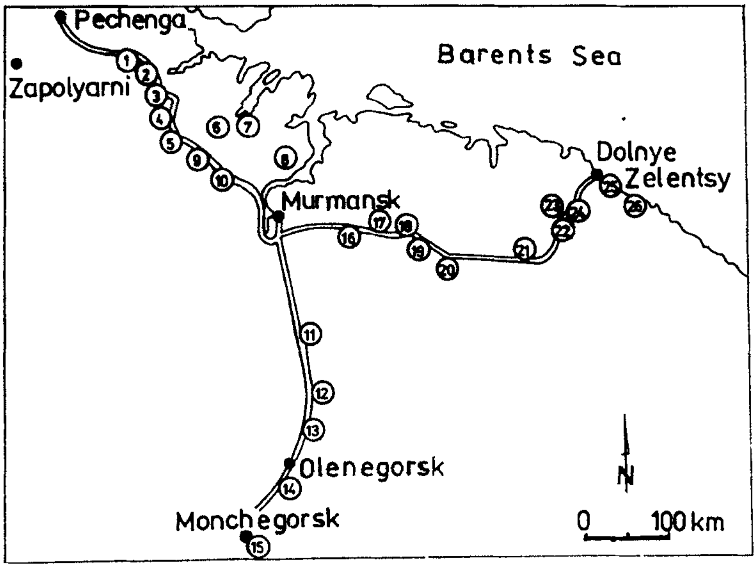


Fig. 2. The study area with sampling sites. North–south (sites 1–15) and west–east (sites 16–26) transects.

or 5–10 mg (elemental analyser CHNS-O) were digested in the mixture of spectral pure concentrated acids (HNO_3/HCl, proportion 2:1) in microwave CEM-MDS 2000. Digestion samples were then diluted to about 50 ml in bidistilled water.

Thirteen elements (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, P, Ca, Mg) were analysed by plasma mass spectrometry (ICP-AES, model POLYVAC) and the other three elements (C, N, S) by elemental analyser (CHNS+O, FISONS Instruments, model 1108). The analyses were done at the Institute of Ecology, Polish Academy of Sciences, in Dziekanów.

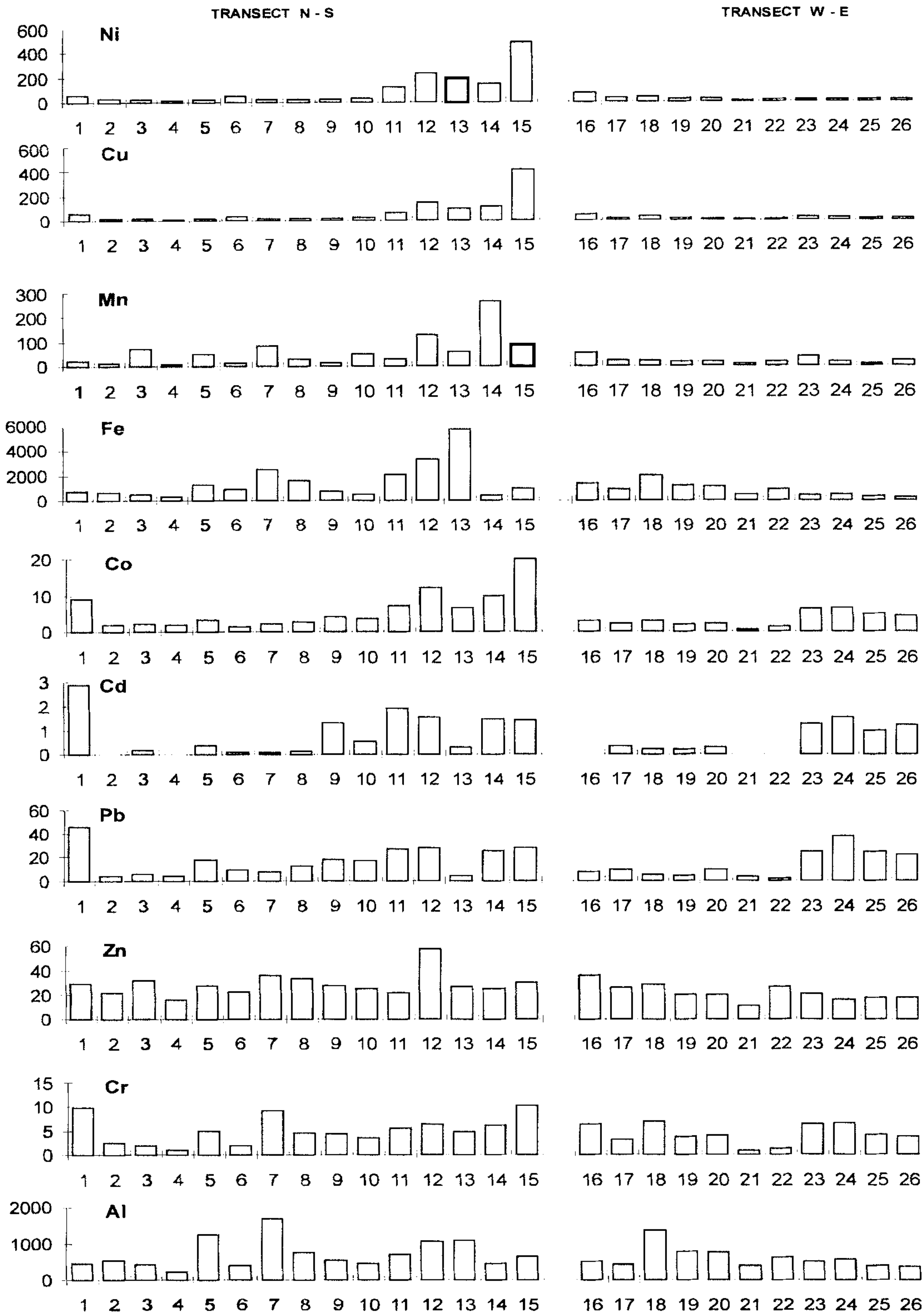
Results

The concentration of heavy metals in *C. stellaris* varied among the sites (Fig. 3). Ranges were as follows ($\mu g\ g^{-1}$): Cd: DL–2.86; Co: 0.61–19.90; Cr: 0.79–10.2; Cu: 5.34–428; Fe: 255–5648; Mn: 6.48–266; Ni: 9.08–486; Pb: 1.82–45.6; Zn: 11.4–57.6; and Al: 214–1665. The greatest variation among sites was observed with Cu, Ni and Mn. There was much less variation with Pb, Fe, Cd, Co and Cr, and the least with Zn. The maximum concentrations of most of the metals were found in lichen collected close to the Monchegorsk and Zapolyarni smelter complexes (Fig. 3, sites 1, 11–15). High values of Cd, Pb and Co were also found in samples from sites located closer to the Barents Sea (Fig. 3, sites 23–26). The concentration of Zn and Cr in *C. stellaris* was less dependent on the distance from emission sources than other elements. Such dependence was not found for Al.

The carbon content in the lichen ranged from ca 32–50%, depending on the site, and nitrogen content from 0.44 to 0.94%, with the highest values found near Monchegorsk (Table 1). The mean C/N ratio was 66 ± 11 (min. 45.10, max. 93.18). Sulphur concentrations in *C. stellaris* were the highest near the smelters in Monchegorsk (max. 982 $\mu g\ g^{-1}$). Calcium accumulation in the lichen was clearly higher near the smelters (2000 $\mu g\ g^{-1}$, max. 3781 $\mu g\ g^{-1}$), while at other sites it generally remained 1000 $\mu g\ g^{-1}$ (min. 312 $\mu g\ g^{-1}$). Phosphorus concentrations fluctuated from 264 to 1015 $\mu g\ g^{-1}$ and magnesium from 235 to 1180 $\mu g\ g^{-1}$ without a clear dependence on distance from emissions sources (Table 1).

Discussion

In this region air pollutants are transported up to 100 km, with the wind blowing from the southwest in summer and the north in winter. The samples of *C. stellaris* collected along the north-



TRANSECT N - S
TRANSECT W - E
Ni
Cu
Mn
Fe
Co
Cd
Pb
Zn
Cr
Al

Table 1. Concentrations of essential elements (% and µg g^{-1} d. wt) in *Cladina stellaris* collected along north–south (nos. 1–14) and west–east (nos. 16–26) transects on the Kola Peninsula.

Locality	N%	C%	C/N	S µg g^{-1}	Ca µg g^{-1}	Mg µg g^{-1}	P µg g^{-1}
1	0.44	41.00	93.18	621	1195	480	589
2	0.54	44.59	82.57	409	895	453	313
3	0.69	42.58	61.71	537	1018	480	570
4	0.62	43.27	69.79	348	312	235	354
5	0.72	40.03	55.59	434	1116	507	518
6	0.59	44.94	76.16	498	627	331	398
7	0.65	41.32	63.56	609	2348	1180	612
8	0.69	44.08	63.88	660	1539	602	820
9	0.64	42.47	66.35	475	719	323	411
10	0.65	42.64	65.60	541	928	333	614
11	0.75	41.67	55.56	468	1039	396	490
12	0.94	42.40	45.10	882	2511	697	1015
13	0.64	31.92	49.87	551	2322	810	715
14	0.86	50.19	58.36	982	3781	843	516
16	0.63	43.49	69.03	639	1264	480	655
17	0.71	42.32	59.60	463	561	888	497
18	0.76	40.56	53.36	549	939	840	551
19	0.64	40.35	63.04	339	711	456	361
20	0.58	40.75	70.25	315	739	438	305
21	0.51	42.04	82.43	301	494	290	264
22	0.58	42.53	73.32	468	916	496	447
26	0.60	42.74	71.23	449	1258	–	482

south and west-east transects are within the range of metallic dust depositions throughout the year.

The concentration of heavy metals and sulphur in the air and in precipitation on the Kola Peninsula is high and is correlated with the distance from emission sources (Äyräs et al. 1995; Glazov et al. 1995; Jaffe et al. 1995; Kelley et al. 1995; Reimann et al. 1995). This accounts for the varying concentrations found in the species studied since lichens obtain minerals as well as pollutants from precipitation and from dry deposition (Tyler 1990). Levels of most of the chemicals in the lichen studied, particularly the heavy metals, were related to the distribution of emission sources. The highest accumulation of metals in *C. stellaris* was found near smelters, iron ore mines and processing plants (Monchegorsk, Olenegorsk, Nikel, Zapolyarni). Why concentrations of Cd, Pb and Co in lichen collected near the Barents Sea were higher than in samples from sites closer to the emission sources is difficult to explain. The large shipping port at Murmansk may be an additional source of these elements.

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Fig. 3. North–south (sites 1–15) and west–east (sites 16–26) gradients of heavy metal (Ni, Cu, Mn, Fe, Co, Cd, Pb, Zn, Cr) and Al concentrations (µg g^{-1}) in lichen samples collected along transects running southward from Zapolyarni, via Murmansk, to Monchegorsk and eastward from Murmansk to Dalnye Zelentsy.

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