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Studies on epiphytic lichens and pine bark in the vicinity of a cement works in northern Finland

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TIIVISTELMÄ: MÄNNYN KAARNAJÄKÄLÄ- JA KAARNATUTKIMUKSIA POHJOISSUOMALAISEN SEMENTTITEHTAAN YMPÄRISTÖSSÄ

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The element content (Ca, Mg, K, Na, Fe, Mn, Zn, Cu, Pb, S) of pine (*Pinus sylvestris*) bark and *Bryoria* lichens, as well as the occurrence and coverage of epiphytic lichens and the length of *Bryoria* species, were studied in the vicinity of Kolari cement works, NW Finland. Fruticose *Bryoria* species had the highest coverage on pine trunks at a distance of 2 km or more from the cement works. At a distance of 1 km the foliose – or even crustose – *Parmeliopsis* species were most abundant, while nearer to the works lichens were almost completely absent. The length of *Bryoria* was reduced at distances of less than 2 km from the cement works. The calcium content in *Bryoria* species increased very steeply close to the works; by a factor of 60 at a distance of 1 km compared to 16 km. No corresponding increase in other elements was observed near the cement works. All the elements studied in pine bark showed a significant negative correlation with distance, and a significant positive correlation with the calculated dust deposition levels. There were only minor differences between the north and south of the pine trunks, or the side facing or away from the works. Pine bark analysis is recommended for element accumulation studies.

Kolarin sementtitehtaan ympäristössä tutkittiin männyn kaarnan ja luppojen alkuainepitoisuuksia, kaarnajäkälien esiintymistä ja peittävyyttä sekä luppojen pituutta. Tehtaasta 2 km:n etäisyydellä tai kauempana pensasmaiset luppolajit olivat runkojäkälistä peittävimpiä. Yhden kilometrin etäisyydellä peittävimpiä olivat lehtimäiset – tai usein rupimaisiksi muuttuneet – tyvikarpeet. Lähempänä tehdasta oli lähes täydellinen "jäkäläautio". Luppojen pituus väheni alle 2 km:n etäisyydellä tehtaasta. Luppojen kalsiumpitoisuus nousi hyvin voimakkaasti tehdasta lähestyttäessä; 16 km:n etäisyydeltä 1 km:n etäisyydelle tehtaasta pitoisuus kasvoi 60-kertaiseksi. Muiden alkuaineiden pitoisuudet pysyivät lähes muuttumatta. Männyn kaarnan kaikkien alkuaineiden pitoisuudet nousivat tehtaan läheisyydessä ja ne korreloivat leviämismallin avulla laskettujen hiukkaslaskeuma-arvojen kanssa. Rungon pohjois- ja eteläpuolta tai tehtaan ja suojan puolta verrattaessa männyn kaarnan alkuainepitoisuuksien erot olivat vähäiset. Männyn kaarnan käyttöä alkuaineiden kertymätutkimuksiin suositellaan.

Keywords: bark, *Bryoria*, calcium, cement, elements, heavy metals, lichens, *Pinus sylvestris*.
ODC 160.2 + 174.7 + 172.9 + 181.45

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1. Introduction

Epiphytic lichens are one of the oldest tools used in air pollution studies. However, very few such studies have been made in areas north of the Arctic Circle. Esseen et al. (1977) investigated epiphytic lichens on birch near the Kiruna industrial area, and found that both the number of species and their frequency decreased near to the industrial complex; visible damages were also observed. Ablaeva (1974) studied epiphytic lichens in the Lapland Nature Park near Murmansk, the USSR. The effects of a smelter extended over a distance of 35 kilometres in the direction of the prevailing winds. The thalli were deformed on some of the plots and made identification difficult. Ablaeva (1974) does not mention which phorophytes she utilized, but says that the "basic tree species" were studied.

The use of bark analysis is not as common in pollution monitoring as that of epiphytic lichens. Pine bark has been used in some studies in Finland (Laaksovirta and Silvola 1975, Laaksovirta et al. 1976, Kortesharju et al. 1981, Kling et al. 1985). Pine bark was found to be a better indicator for studying lead emissions from motor vehicles than an epiphytic lichen (Laaksovirta et al. 1976).

In other countries the bark of various tree species has frequently been used in air pollution studies, and the indicator value of pine bark has also been investigated (Swieboda and Kalemba 1979). Cieslinski and Jaworska (1986) have even carried out both lichen and pine bark studies around a cement limestone works in Poland.

The purpose of this study carried out in the vicinity of the Kolari cement works was to compare the suitability of different materials for monitoring the effects of limestone dust. The analysis of humus, *Pleurozium schreberi*, and *Cladina* spp. have been treated in another article (Kortesharju et al. 1989).

The main emphasis in this paper is on the mineral content of pine bark and *Bryoria* species. Attention is also paid to the composition and coverage of epiphytic lichens on pine trunks and to the size of the *Bryoria* species.

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2. Materials and methods

21. Study area

The study area is situated in the northern-boreal vegetation zone in NW Finland, in the area around the Kolari limestone quarry and cement works (67°27' N, 23°39' E), and in the adjacent area in Sweden (Fig. 1). The Kolari cement works is a typical point emission source. The quarry and works have operated since 1968. 300 000 tons of limestone were quarried and 200 000 tons of cement produced annually during the time of the study. The fuel used in cement manufacture was Polish coal, which has an SO_3 content of ca. 2 %. Due to the fitting of new filters to the main stack, the deposition was much lower in 1979 than in 1978. Further information about the raw materials and emissions as well as climatic data and details of the settlements and industry in the area have been presented by Kortesharju et al. (1989).

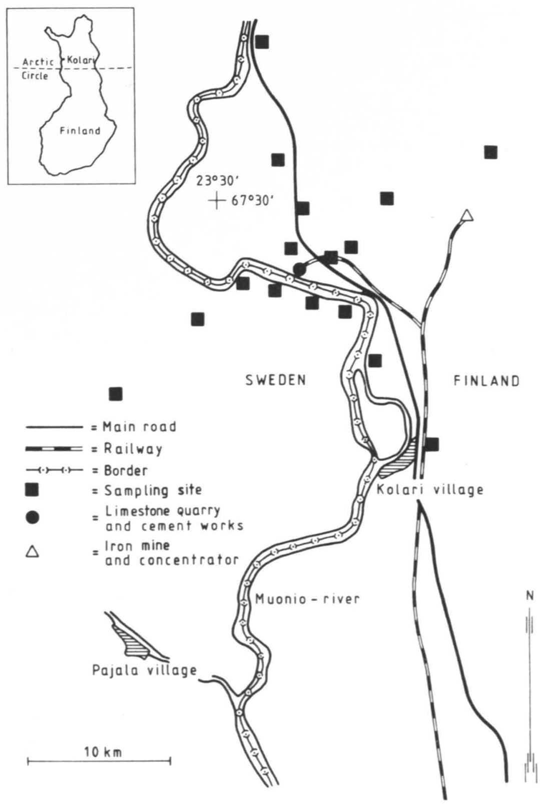

Figure 1. The study area and the sample sites located 2–16 km from the cement works.

Kuva 1. Tutkimusalue ja 2–16 km:n etäisyydellä sementtitehtaasta sijainneet näytteenottoalat.

22. Sample sites and sampling

Twenty-four sites were studied in 1978-79 along four transects running in a NE, SE, SW, and NNW direction from the cement works (Fig. 1). The sites were located at six distances from the works: 0.5, 1, 2, 4, 8, and 16 km. Accordingly, these sample sites are denoted as NE 0.5, NE 1, NE 2 ... NNW 4, NNW 8 and NNW 16. Minor deviations from the exact directions and distances were caused by the lack of suitable sites. Sample sites NE 2-16, SE 2-16 and NNW 16 were sampled in 1978, the others in 1979.

The sample sites were selected in pine forests on sites of the *Ericaceae-Cladonia*, *Empetrum-Vaccinium* and *Empetrum-Myrtillus* forest site type (Sepponen et al. 1982). The forests were of different age, but the stem diameter of the pines (dbh 1.3 m) had to exceed 16 cm. The density of the pine stands varied due to the age of the forest and thinning intensity. The same plots were used in the present study and in the study on humus, forest moss, and reindeer lichens (Kortesharju et al. 1989). One plot, sized 20 x 20 metres, was marked out in the most uniform part of each sample site. The epiphytic lichen species and species coverage were studied on five pine stems, one at each corner of the plot and one in the centre of the plot. The northern and southern side of the trunk extending from the base to a height of 2.5 m was examined separately on each pine.

Ten bark samples and five *Bryoria* (if occurring abundantly enough) samples were collected for chemical analyses. For each *Bryoria* and bark sample few trees adjacent to those trees where lichen cover analyses were done, were sampled. The bark was collected from a height of 0.5 to 2 m, separately from the north and south side of the trees. The thickness of the bark samples was less than 1 cm. Wherever possible, the *Bryoria* samples were collected from the same trees as the bark samples. These samples were collected up to a height of 3 m. The length measurements were also made on these samples. The *Bryoria* samples consisted of several species that were often growing tightly intermingled. We succeeded in separating *B. fremontii* (Tuck.) Brodo & D. Hawksw. from other species, but *B. lanestris* (Ach.) Brodo & D. Hawksw. was included in *B. fuscescens* coll. in the length measurements and chemical analyses.

23. Chemical analyses

The total concentrations of Ca, K, Mg, Na, Fe, Mn, Zn, Cu and Pb were analysed on all the bark and *Bryoria* samples. All analyses were made on unwashed samples. The concentrations were determined by flame atomic absorption spectrophotometry (Perkin-Elmer 300 and 380). The Na concentrations are probably elevated by contamination from laboratory glassware, and the Pb concentrations decreased by the high ashing temperature used. The samples were kept at ca. +40°C until air-dry. A sample of 1 g was ashed at 550°C for two hours. The ash was extracted with 20 % HC1. Distilled water was added to make 25 ml of solution, which was then filtered. The final dilutions were made with distilled water. For the Ca and Mg determinations 1 % lanthanum solution was added to the filtrate. Total S content was measured only on the bark samples from sites NE 0.5–1, SE 0.5–1, SW 0.5–1, and NNW 0.5–16. Sulphur was determined by the gravimetric precipitation method in a commercial laboratory, Viljavuuspalvelu Oy. All concentrations are expressed on air-dry weight basis (40°C).

24. Statistical methods

Regression analysis was used to study the relationship between the distance from the cement works and the element content of the studied materials. Log transformations of both the element content and the distance to the cement works were mainly used in these analyses. Correlation analysis was used to study agreement between the calculated deposition values and the values measured in the pine bark and lichens. The deposition values used in the calculations were from the beginning of the preceding September to the collecting date, e.g. over a period of ca. 10–11 months. The deposition model used in this study, developed by the Department of Air Quality, Finnish Meteorological Institute, is not presented in this paper. The model is based on the emission figures provided by Partek Oy, owner of the works, and meteorological data from the Meteorological Institute. It should be noted that the distance from the cement works to the nearest weather station is ca. 55 km, which introduces some uncertainty to the deposition values.

3. Results

31. Epiphytic lichen studies

311. Species composition

The number of foliose and fruticose lichens epiphytic on the pine trunks was relatively small (Table 1). The number of species decreased strongly at a distance of less than 2 km from the cement works, while the greatest number of species was observed at a distance of 2 km. There was a gradual change in the ratio between foliose and fruticose lichens. The fruticose *Bryoria* species began to disappear at distances of less than 4 km from the works, and the foliose species (mainly *Parmeliopsis ambigua*, *P. hyperopta* and *Hypogymnia physodes*) to replace them.

312. Coverage of epiphytic lichens

Epiphytic lichens were almost completely absent at a distance of 0.5 km from the cement works (Fig. 2). The coverage increased at a distance of 1 km; the most important species were foliose (or sometimes crustose) *Parmeliopsis ambigua* and *P. hyperopta*. The coverage of fruticose species (mainly *Bryoria* cf. *fuscescens*, *B. lanestris*, and *B. fremontii*) increased at greater distances from the works, but decreased slightly at the most remote sites.

313. The length of the thalli of Bryoria species

The average thallus length of *B. fremontii* and *B.* cf. *fuscescens* was in most cases quite

Table 1. Epiphytic lichen species on pine trunks at different distances from the cement works (+ = present, - = absent).
Taulukko 1. Männyn kaarnajäkälälajisto eri etäisyyksillä sementtitehtaasta (+ = esiintyi, - = ei esiintynyt).

Species *Laji*	Distance *Etäisyys* km 0.5	1	2	4	8	16
Alectoria sarmentosa	-	-	-	-	+	-
Bryoria capillaris	-	+	+	+	+	+
Bryoria fremontii	-	+	+	+	+	+
Bryoria furcellata	-	-	+	+	+	+
Bryoria cf. fuscescens (including *B. lanestris*)	+	+	+	+	+	+
Bryoria simplicior	-	-	+	+	+	+
Cetraria chlorophylla	-	-	+	-	-	-
Cetraria pinastri	-	-	+	-	+	+
Hypogymnia physodes	+	+	+	+	+	+
Parmeliopsis ambigua	+	+	+	+	+	+
Parmeliopsis hyperopta	+	+	+	+	+	+
Usnea sp.	-	-	+	-	-	-
Number of species *Lajimäärä*	4	6	11	8	10	9

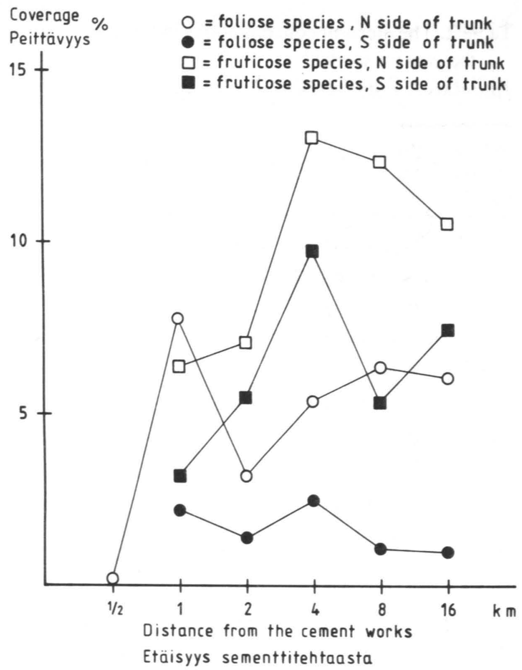

Figure 2. The coverage of epiphytic lichens at different distances from the cement works.
Kuva 2. Kaarnajäkälien peittävyys eri etäisyyksillä sementtitehtaasta (○ = lehtijäkälät, rungon pohjoispuoli ● = lehtijäkälät, rungon eteläpuoli □ = pensasjäkälät, rungon pohjoispuoli ■ = pensasjäkälät, rungon eteläpuoli).

normal (Fig. 3), and only at distances of 0.5 and 1 km from the cement works were they shorter. Many of the thalli of *B. fremontii* near the works were completely covered with limestone dust and in very bad condition, but even so they always appeared to belong to old and relatively long individuals. The thalli of *B.* cf. *fuscescens*, on the contrary, were exceptionally short.

314. Element concentrations in the thalli of Bryoria species

In *Bryoria* species, the Ca concentration increased sharply close to the cement works (Table 2). The Ca concentration in *B. fremontii* was 61.7 times higher at a distance of 1 km from the cement works compared to 16 km. The content of other elements was rather surprising. In the case of *Bryoria* species there was no increasing trend on moving towards the works (except for a slight increase in lead and copper), but instead either a decreasing trend or no trend at all (Table 2). The contents of most elements were higher in Bryoria cf. fuscescens than in *B. fremontii,* the differences in iron, zinc, manganese, and magnesium being the clearest.

32. Element concentrations in pine bark

The highest calcium value, 3.8 % of dry weight, was measured at sample site NNW 0.5. The calcium content of the bark was thus relatively low near the cement works, and it was greater by only a factor of 3–6 when the sample sites at distances of 0.5 and 16 km are compared. The cement works, however, had an inevitable effect on the content of all studied elements (Fig. 4).

The regression between the distance from the works and the concentrations of Ca, Fe, Na, Mn, K, Cu, and Pb was very significant

Table 2. The element concentrations in the thalli of *Bryoria fremontii* and *B.* cf. *fuscescens* at different distances from the cement works.
Taulukko 2. Luppojen keskimääräinen alkuainepitoisuus eri etäisyyksillä sementtitehtaasta.

Distance *Etäisyys* km	Species *Laji*	Ca	K	Mg	Na	Fe ($\mu g \cdot g^{-1}$)	Mn	Zn	Cu	Pb
1	*B. fremontii*	31528	1852	168	50	116	16	42	3	13
	B. cf. *fuscescens*	16250	1810	181	60	375	18	52	4	8
2	*B. fremontii*	11526	2136	198	145	130	15	36	2	16
	B. cf. *fuscescens*	10621	1990	235	138	413	23	47	3	17
4	*B. fremontii*	1934	1905	181	96	120	20	41	2	6
	B. cf. *fuscescens*	4363	1948	188	89	301	25	53	3	12
8	*B. fremontii*	586	2013	166	76	130	17	39	1	5
	B. cf. *fuscescens*	573	2174	194	129	352	21	56	3	10
16	*B. fremontii*	511	2130	180	120	129	22	45	1	8
	B. cf. *fuscescens*	558	2341	204	116	233	29	63	3	10

in all cases, the degree of significance decreasing in the above order. When linear regression was calculated using the logarithmic values of both the distance and the element contents, the degree of significance increased for all elements except lead. The corresponding regression between the distance and the zinc concentration was also very significant. Surprisingly, the strongest regression existed between the distance and the bark magnesium concentration. The distance to the cement works explained 71 % of the variation in the magnesium content and 69 % for calcium.

There were clear differences in element contents along the gradient lines running in different directions from the cement works. The concentrations were highest in the NNW direction, and lowest in both the NE and SW directions. However, the differences were small and fairly random further than 2 km from the works. The difference between the north and south side of the trunk was in most cases only small. Higher element concentrations occurred quite regularly on the southern side of the trunk, which faces the cement works only at sample sites NNW 0.5 and NNW 1.

The highest sulphur concentration in pine bark, 1.64 mg/g, occurred at sample site SE 0.5. In all directions there was a higher concentration of sulphur at a distance of 0.5

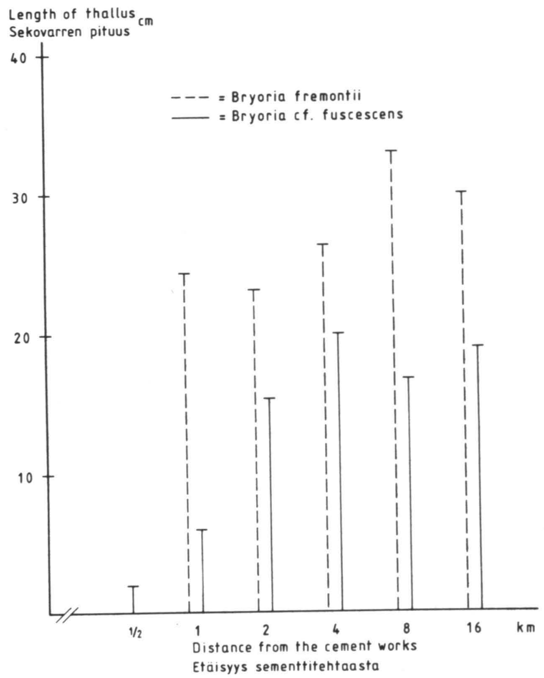

Figure 3. The average length of *Bryoria* thalli at different distances from the cement works.
Kuva 3. Luppojen keskimääräinen pituus eri etäisyyksillä sementtitehtaasta.

km than at a distance of 1 km. All distances (0.5–16 km) were studied in the direction NNW. The sulphur concentration at 0.5 km

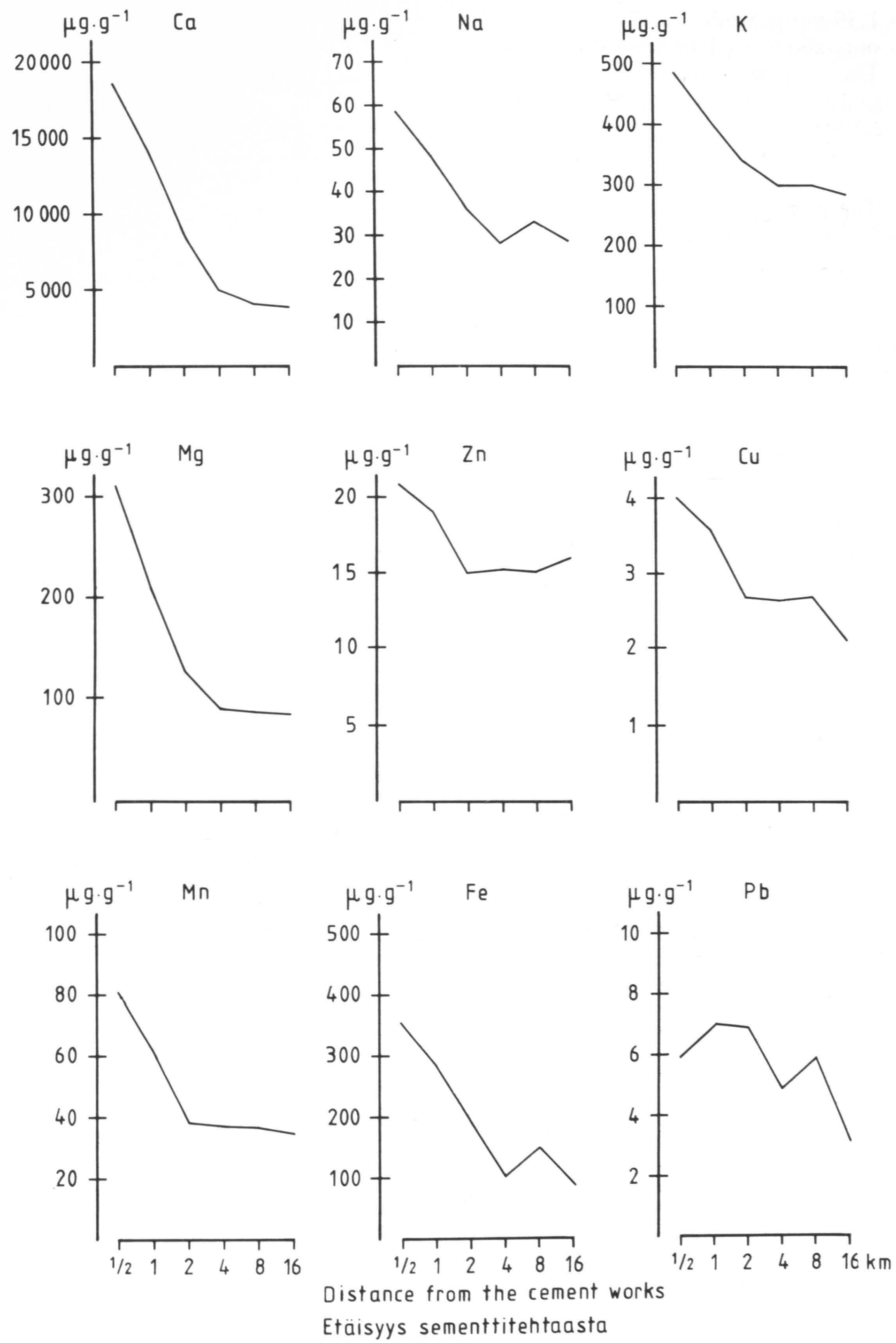

Figure 4. The element concentrations in pine bark at different distances from the cement works.
Kuva 4. Männyn kaarnan alkuainepitoisuudet eri etäisyyksillä sementtitehtaasta.

was 1.39 mg/g, while at a distance of 4 km it was only about one half this value (0.71 mg/g). The sulphur concentration no longer decreased at distances further from the cement works.

33. The correlation between the calculated deposition levels and the element concentrations in the studied materials

As was earlier shown, all the element concentrations in the bark were higher near the cement works, whilst in *Bryoria* species only the concentration of calcium clearly increased (Fig. 4, Table 2).

The bark concentration of all elements except lead shows a highly significant correlation with the calculated rate of deposition derived from the works when all the observations are combined (Table 3, 0.5–16 km). When the observations are divided into three groups according to the distance of the sample sites from the cement works (0.5–1 km, 2–4 km, 8–16 km), only bark calcium, iron, and manganese correlate significantly with the deposition in every group (Table 3). The correlations are high up to a distance of 1 km from the cement works where the deposition is still considerable. At distances of 2–4 km from the works, the correlations are still mostly significant. At greater distances from the works the significances are considerably reduced. It would thus appear that factors other than the deposition derived from the works largely determine the

Table 3. The correlation between the calculated particle deposition[1] and the element concentrations in pine bark at different distances from the cement works.

Taulukko 3. Leviämismallin avulla saadun hiukkaslaskeuman[1] ja männyn kaarnan alkuainepitoisuuksien väliset korrelaatiot eri etäisyyksillä sementtitehtaasta.

Element *Alkuaine*	0.5–1 km	2–4 km	8–16 km	0.5–16 km
Ca	0.61^{xxx}	0.59^{xxx}	0.50^{xxx}	0.70^{xxx}
Mg	0.63^{xxx}	0.52^{xxx}	0.11 N.S.	0.64^{xxx}
K	0.63^{xxx}	0.21^{o}	0.64^{xxx}	0.41^{xxx}
Na	0.55^{xxx}	0.49^{xxx}	0.05 N.S.	0.55^{xxx}
Fe	0.52^{xxx}	0.49^{xxx}	0.24^{x}	0.57^{xxx}
Mn	0.45^{xxx}	0.39^{xxx}	0.24^{x}	0.55^{xxx}
Zn	0.30^{xx}	0.32^{xx}	0.17 N.S.	0.38^{xxx}
Cu	0.35^{xx}	0.11 N.S.	0.07 N.S.	0.35^{xxx}
Pb	0.09 N.S.	0.08 N.S.	0.01 N.S.	0.10 N.S.

[1] The deposition values were estimated from the beginning of the preceding September to the sample collection date.

[1] *Laskeuma-arvot arvioitiin edeltävän syyskuun alun ja näytteen keräyspäivän väliseltä ajalta.*

mineral content of pine bark at distances greater than 4 km. The correlations between particle deposition and the calcium concentration in *Bryoria* species were also significant, although in the case of *B. fremontii* only 12.4 % of the variation in the calcium concentration was explained by the deposition. The corresponding value for *B.* cf. *fuscescens* was 39.9 %.

4. Discussion

The visible effect of the cement works on the pine forest ecosystems on dry site extended to a distance of ca. 2 km. The maximum number of epiphytic lichen species was observed at this distance, but the coverage was still low reflecting the abnormal situation. A fairly similar phenomenon has been described by Pihlström (1982) in South Finland near a small limestone quarry. In more southern areas, eutrophic species can grow on pine in the area effected by limestone dust emission (Pihlström 1982, Cieslinski and Jaworska 1986). At Kolari, however, no eutrophic lichens were recorded on pine. All species occurring near the cement works were found on pine by Räsänen (1927) in the area ca. 100–300 km south of our study area. In his materials *Bryoria capillaris* and *B. furcellata*, which are common at Kolari, were mentioned as

being rare on pine trunks, and he found *B. simplicior* only on small lateral branches.

Westman (1976) presented encouraging results concerning the use of *Usnea* and *Bryoria* species length in a study carried out around a sulphite paper mill in Sweden. In our study *Bryoria* cf. *fuscescens* was in this respect better than *B. fremontii*. It seems, however, that a denser sample site network should have been used.

Information about the element content of corticolous *Bryoria* species is quite scarce, but some measurements have been made by Solberg (1967) in South Norway. The concentration of manganese, magnesium, and potassium were lower in our study area, as also was the calcium concentration at distances of 8 and 16 km from the cement works. The *Bryoria* species at Kolari differed clearly from the other materials studied, because the cement works seemed to have no marked effect on the contents of any element other than calcium. The level of the most important elements emitted by the cement works, calcium, magnesium, and iron, was much lower in the *Bryoria* species than in humus or in a moss *Pleurozium schreberi* (Kortesharju et al. 1989). The calcium concentration of *Bryoria* species was clearly higher compared to reindeer lichens, while the concentration of iron and magnesium were mainly of the same order of magnitude (Kortesharju et al. 1989). Near to the works *Bryoria* species tended to have a higher Ca concentration than their substrate, pine bark, but farther away the Ca concentration was higher in the bark.

The cement works clearly elevated the element content in pine bark. Our figures are, however, only one half or less the concentrations of Ca, K, Na, and Mg measured in pine bark by Cieslinski and Jaworska (1986) near a cement limestone works in Poland. The element contents at Kolari are lower in pine bark than in humus or *Pleurozium schreberi*, but are rather similar to those in reindeer lichens (Kortesharju et al. 1989). The correlation between the calculated deposition and the content of elements other than calcium in the bark is higher than that for *Pleurozium schreberi*, *Cladina stellaris* or humus (Kortesharju et al. 1989). The deposition/Ca correlation is highly significant in all these materials.

The materials used in this study were all rather suitable for environmental monitoring, although the use of *Bryoria* thalli cannot be recommended in monitoring low deposition levels. The changes in lichen species composition, lichen coverage, the dominance of foliose or fruticose species on pine trunks, and the length of the thalli of *Bryoria* cf. *fuscescens* all reflected the effect of the cement works. Pine bark proved to be very practical in element analysis. It most probably gives a more reliable result in nutrient studies than humus (Kortesharju et al. 1989), although wash-down from the tree crown may cause some errors. As this method is very easy to carry out and has little destructive effect on nature, we recommend the use of pine bark in element accumulation studies in the northern pine forests.

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