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# On the abundance of epiphytic green algae in relation to the nitrogen concentrations of biomonitors and nitrogen deposition in Finland

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**Abstract**

Green algae have become considerably more abundant in the years 1985–1995 in Finland and their distribution area has expanded northwards. Green algae on conifers were most abundant in southern Finland where the nitrogen deposition is highest. Correlations were observed between the abundance of green algae and a modelled nitrogen and sulphur deposition as well as the nitrogen concentration of the biomonitors. The increased abundance of green algae in Finland may be caused by several concurrent changes which have taken place in the environment and which have all promoted the occurrence of green algae. A slight rise in mean annual temperature, the long-term stability of nitrogen deposition, and the clear fall in the amount of sulphur deposition have probably all increased the growth and abundance of green algae. At a local level, the differences in microclimate have also effect on the abundance of green algae and the microclimate varies, inter alia, by the nutrient-richness of the habitat, the predominant tree species, stand age and stand density.

*Keywords:* Green algae; moss; lichen; pine bark; nitrogen deposition

## Introduction

The deposition of nitrogen has increased in a large part of Europe during the past few decades while at the same time, that of sulphur has considerably diminished (Barrett et al., 1995; Mylona, 1996). The emissions of oxides of nitrogen in Finland have remained approximately at the same annual level, 250 000 tonnes, and those of ammonium, 50 000 tonnes, in the years 1986–1995 (Ympäristökatsaus, 1995). Emissions of sulphur dioxide have diminished during the same period from about 300 000 tonnes to 100 000 tonnes. The total deposition of oxidized nitrogen exceeds 3–4 kg (N) $ha^{-1}$ $year^{-1}$ and of the total reduced nitrogen 2–3 kg (N) $ha^{-1}$ $year^{-1}$ in southern Finland (Ympäristökatsaus, 1995; Hongisto, 1998). Both the oxidized and the reduced nitrogen deposition decrease to the north and they are in northern Finland correspondingly only 1–1.5 kg (N) and 0.5–1 kg (N). Dry deposition varies 20–50% of total with the seasons.

Atmospheric nitrogen in wet deposition is in nitrate and ammonium form ($NO_3^-$, $NH_4^-$) while in dry deposition it is mainly in the form of gaseous nitric acid ($HNO_3$), ammonium ($NH_3$) or nitrogen dioxide ($NO_2$) (Pitcairn et al., 1995; Hongisto, 1998). Nitrogen deposition has a twofold ecological impact. On the one hand, nitrogen causes acidification of the soil due to leaching of base cations. On the other hand, it is a vital plant

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nutrient, which, when in excess, causes eutrophication. It has been observed that increased deposition has caused changes in vegetation, especially in areas of high deposition in Central Europe, to the extent that eutrophic plant species have increased at the expense of oligotrophic species (e.g. Bobbink et al., 1992; Sutton et al., 1993). If the vegetation is not able to bind free nitrogen in the biological cycle, leaching will increase. In areas where nitrogen deposition exceeds about 10–15 kg N $ha^{-1}$ forested catchments show increased leaching of nitrate (Grennfelt and Hultberg, 1986).

Research on nitrogen deposition and its impacts on forest ecosystems has been relatively modest with respect to the use of bioindicators when compared to the research done on sulphur deposition. Part of the reason probably lies in the fact that, due to it being an important plant nutrient, it is more difficult to separate its effects on vegetation than when dealing with sulphur. Green algae have been used a little during the past few years as bioindicators when examining nitrogen deposition because it has been observed that they are sensitive to changes in nitrogen deposition. Green algae are single-celled organisms, which take in their nutrients directly from rain water and the air. Algae live in symbiosis with lichens, among other things with *Scoliciosporum chlorococcum*. Epiphyllic microbial cover often include also various bacteria and fungi. The taxonomy of green algae is still poorly known. Søchting (1997) has found that in Denmark an algal crust on spruce needles consists of among other things species belonging to the families *Apatococcus* spp. and *Desmococcus* spp. The algae require sufficient high temperature, high humidity and suitable light for their growth. It would appear that nitrogen is the most important factor restricting the growth of green algae (Göransson, 1988). They occur in abundance on trees and other suitable substrata in the vicinity of various nitrogen sources, e.g. fertiliser factories, fur farms, cattle farms, and in the urban areas (Ferm et al., 1990, Göransson, 1990). Epiphyllic algae have increased especially on Norway spruce (*Picea abies*) needles in recent years in the southern parts of Fennoscandia and in Central Europe (Göransson, 1988 and 1990; Peveling et al., 1992; Søchting et al., 1992; Thomsen, 1992; Bråkenhielm and Liu Qinghong, 1995).

This study is a continuation of the epiphytic lichens survey, carried out using the permanent sample plots of the National Forest Inventory and to deposition mappings using biomonitors (Kubin, 1990; Kuusinen et al., 1990; Kubin and Lippo, 1996; Rühling et al., 1996; Poikolainen et al., 1998). The present study reports on the abundance of green algae on conifers during the years 1985 and 1995 in Finland. The occurrence of green algae has been compared to the nitrogen concentrations of biomonitors, to the deposition of nitrogen and sulphur obtained through modelling and to a few important climate and site factors.

## Materials and methods

The abundance of green algae was mapped by means of nation-wide surveys of epiphytic lichens in 1985 and 1995. These mappings were made on the network of 3009 permanent sample plots established in 1985–1986 in connection with the 8th National Forest Inventory (Kuusinen et al., 1990; Poikolainen et al., 1998). The network consists of clusters of four 300 $m^2$ circular sample plots in southern and central Finland and clusters of tree plots in northern Finland. The clusters are located in a 16×16 km grid in the south and 24×32 km in the north. The mapping of the abundance of thirteen species or genera of epiphytic lichens focused on conifers (*Pinus sylvestris* L., *Picea abies* (L.), Karsten). The lichens were selected for inclusion in the mapping on the basis of their presumed sensitivity to sulphur dioxide. *Scoliciosporum chlrorococcum* + green algae belonged to the group 'tolerant species'. Green algae live in symbiosis with lichens, usually *Scoliciosporum chlorococcum*, and often include also various bacteria and fungi. In this context, only the common name is used because species were not identified in connection of the mappings and their taxonomy is still poorly known (Søchting et al., 1992). The abundance of lichens and green algae were estimated using a scale 0–3 on three dominant trees closest to the plot midpoint between the heights of 0.5–2.0 m around the tree both along the trunk and among the branches (scale: 0 = no lichen and green algae, 1 = sparse, 2 = fairly abundant; 3 = abundant). When comparing the results of 1985 and 1995, only the same trees were taken into consideration.

The same permanent sample plots were also used to obtain biomonitor samples for deposition survey purposes (Kubin, 1990; Rühling et al., 1996). The nitrogen concentrations of the lichens (*Hypogymnia physodes*) and the pine (*Pinus sylvestris* L.) bark were determined from the samples taken in 1985 and of the mosses (*Hylocomium splendens, Pleurozium schreberi*) from the samples taken in 1995. The samples were dried and ground, and the nitrogen concentration was determined using a slightly modified version of the micro-Kjeldahl method (Kubin and Siira, 1980).

Nitrogen oxide, ammonium and sulphur depositions in 1993 were computed by the HILATAR model developed at the Finnish Meteorological Institute (Hongisto, 1998). The model involves solving the pollutants' advection, diffusion, chemical conversion and deposition numerically over a grid with a horizontal resolution of 11 km and ten vertical layers below 3 km. Emissions, meteorological parameters and sink terms are estimated on an hourly basis, long-range transport by using the 28 km resolution of the HILATAR model and results of the EMEP MSC-W Center model Norway.

The abundance of green algae and the nitrogen concentration of the mosses in 1995 were compared also with a few primary climate and site factors: temperature sum of growing season (> +5°C), elevation, forest site type, dominant tree species on the sample plot, and stand age and stand basal area ($m^2$ $ha^{-1}$). The temperature sums for the sample plots were computed from data provided by the Finnish Meteorological Institute, using the model developed by Ojansuu and Henttonen (1983). The temperature data was obtained from observations made by FMI in six localities in different parts of Finland (Kolkki, 1981; Heino and Hellsten, 1983; Meteorological yearbooks, 1986–1995).

When comparing the abundance of the green algae to the deposition data, to the N concentrations of the mosses, to altitude and to the temperature sum, cluster-specific means of all the variables were used. However, when comparing abundance to site factors, sample plot specific values were used. Only those sample plots which had been assessed for abundance of algae were included in the comparisons. The intercorrelations between the abundance of algae and the various variables were computed using Spearmann's order of correlation test, while the intercorrelation between the abundance of algae and the various variables was examined using $\chi^2$-test.

## Results

### *Abundance of green algae on conifers during years 1985 and 1995*

On the basis of the mapping of epiphytic lichens, green algae were observed on conifers in 1985 only in southern and central Finland (Fig. 1). Apart from the capital city, Helsinki, district, the algae cover on trees was usually scant. The northernmost occurrences were recorded in western parts of central Finland (~ 65°N). Green algae have became considerably more frequent during the period 1985–1995. In 1995, a lot of algae were found to be common on conifers in the south. In the case of spruce, their frequency of occurrence rose to 60% in southern Finland. The northernmost occurrences were recorded as far north as above the Arctic Circle (66°33′N).

### *Abundance of green algae in relation to nitrogen concentrations in lichens, bark, and mosses*

The nitrogen concentration of the lichens in the samples (Fig. 1) collected in 1985 varied within the range of 0.75–2.6% (dry weight based) while the concentration in the pine bark varied within the range of 0.18–0.90%. The highest concentrations were recorded in the case of both lichens and bark in southern Finland, and concentrations diminished gradually towards the north. The relation between the abundance of green algae and the biomonitors' nitrogen concentrations was not tested because in 1985 green algae were observed only on a fraction of the sample plots.

The nitrogen concentrations of mosses in the samples collected in 1995 varied within the range of 0.45–2.3% (d.w.b). The highest concentrations were recorded in the south and south western and some parts of central Finland. The concentrations decreased northwards remaining in the north below 0.60% (Fig. 1). A slight correlation was observed to apply between the nitrogen concentrations of the mosses and the abundance of green algae ($r = 0.54$; $p < 0.0001$), as was also the case with the nitrogen concentration of the mosses and $NO_x$, $NH_3$, and S depositions ($r_1 = 0.60$; $r_2 = 0.58$; $r_3 = 0.41$; $p < 0.0001$).

### *Abundance of green algae in relation to nitrogen and sulphur deposition*

With the deposition modelled for the year 1993, $NO_x$ deposition varied within the range of 70–400 mg $m^{-2}$ $year^{-1}$ on the sample plot clusters for which the abundance of algae was estimated; the corresponding range for $NH_3$ was 35–230 mg, and that for S deposition 160–770 mg. Both nitrogen and sulphur deposition were highest in southern Finland and diminished towards the north (Fig. 1). A slight correlation was observed to apply between the $NO_x$, $NH_3$, and S depositions and the abundance of algae ($r_1 = 0.47$; $r_2 = 0.44$; $r_3 = 0.44$; $p < 0.0001$).

The dependence between the abundance (1995) of green algae and the modelled deposition data (1993) was examined by comparing the four abundance categories of algae with varying $NO_x$, $NH_3$ and S deposition values (Table 1). The results showed that the greater the depositions, the greater the proportion of those sample plots having an abundance of algae.

### *Abundance of algae in relation to temperature sum, altitude and some basic site-type factors*

Green algae were found no longer occur in areas with temperature sums (> +5°C) below 950 d.d., and in areas above 250 m above sea level. The higher the temperature sum, and the lower the altitude of the site, the greater the proportion of sample plots with an abundance of algae (Table 1). The more nutrient-rich the site type, the greater the relative abundance of algae on conifers. Algae were mainly found to occur on grove-like or moist upland and corresponding peatland sites (Table 1). Green algae were relatively more abundant in pine-dominated stands belonging to the age classes < 40 year and 41–80 years, in spruce-dominated stands belonging to the age classes 41–80 years and 81–120 years, and in broadleaved-dominated stands belonging to the age class 41–80 years. Another observation was that increasing stand basal area was reflected as relatively greater occurrence of green algae — being most abundant in stands, whose basal area was over 25 $m^2$ $ha^{-1}$.

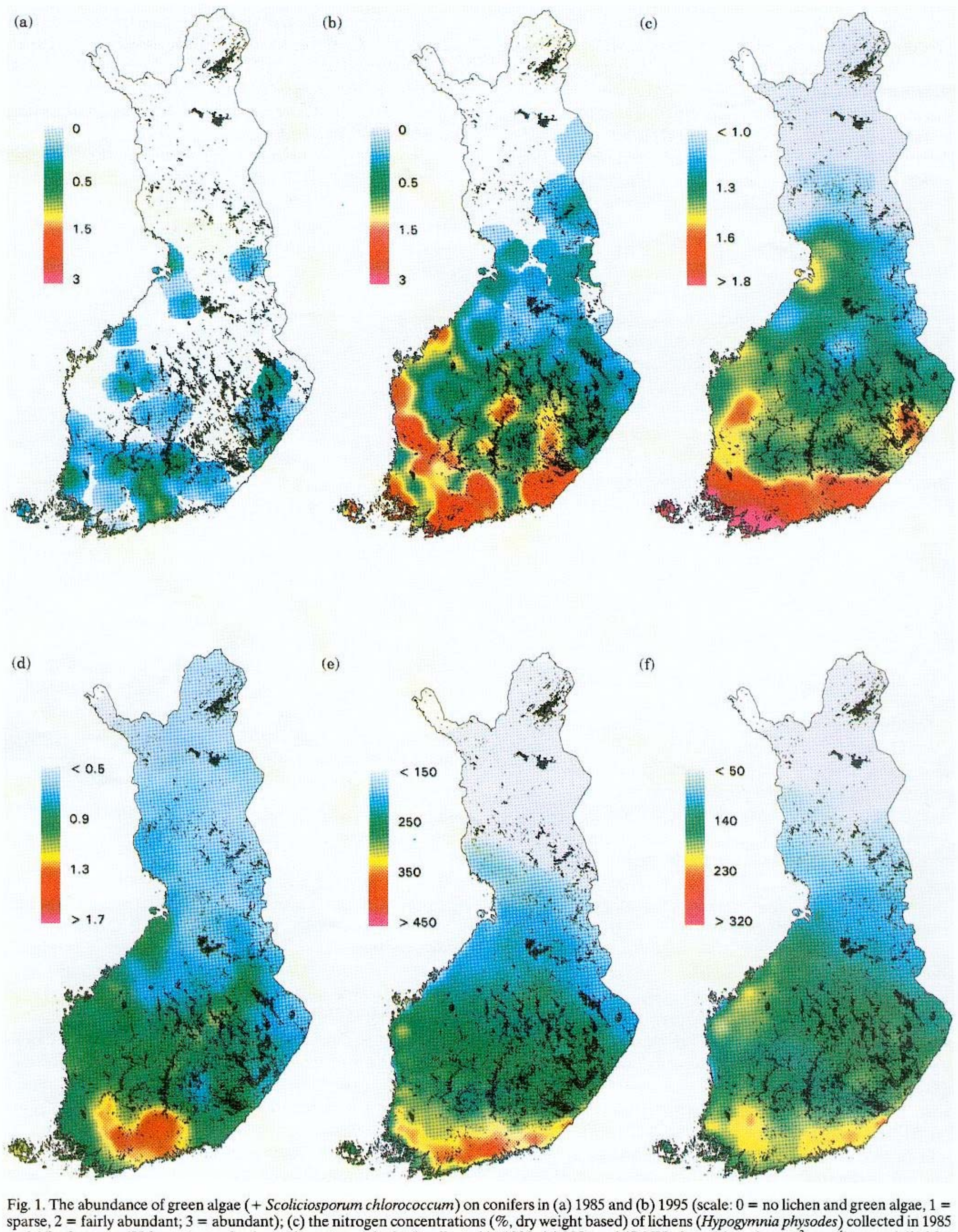


Fig. 1. The abundance of green algae (+ *Scoliciosporum chlorococcum*) on conifers in (a) 1985 and (b) 1995 (scale: 0 = no lichen and green algae, 1 = sparse, 2 = fairly abundant; 3 = abundant); (c) the nitrogen concentrations (%, dry weight based) of lichens (*Hypogymnia physodes*) collected in 1985 and (d) of mosses (*Hylocomium splendens*, *Pleurozium schreberi*) collected in 1995; (e) $NO_x$ and (f) $NH_3$ depositions (mg $m^{-2}$ $year^{-1}$) as modelled for 1993. These maps were produced on the basis of the deposition data computed per sample plot clusters used in National Forest Inventory and using the abundance of green algae which were assessed.

Table 1

The dependence between the abundance of green algae and $NO_x$-, $NH_3$- and S-deposition (mg $m^{-2}$ $year^{-1}$) and some climatic and site-type factors

| | | Green algae abundance category | | | | $n$ | $\xi^2$ |
|---|---|---|---|---|---|---|---|
| | | 0 | <1 | 1–2 | 2–3 | | |
| $NO_x$ | <200 | 89.86 | 6.76 | 1.45 | 1.93 | 207 | 205.94 |
| $NO_x$ | 201–300 | 48.10 | 32.87 | 13.23 | 5.81 | 499 | $p < 0.001$ |
| $NO_x$ | >301 | 15.63 | 33.33 | 26.04 | 25.00 | 96 | |
| $NH_3$ | <100 | 93.49 | 5.33 | 0.59 | 0.59 | 169 | 160.66 |
| $NH_3$ | 101–200 | 47.29 | 31.29 | 13.73 | 7.80 | 590 | $p < 0.001$ |
| $NH_3$ | >201 | 9.30 | 39.53 | 27.91 | 23.26 | 43 | |
| S | <350 | 71.05 | 20.26 | 6.58 | 2.11 | 380 | 145.54 |
| S | 351–450 | 48.01 | 32.12 | 13.58 | 6.29 | 302 | $p < 0.001$ |
| S | >451 | 21.67 | 30.00 | 23.33 | 25.00 | 120 | |
| Temp.sum | <1000 | 90.56 | 9.44 | 0.00 | 0.00 | 233 | 278.61 |
| Temp.sum | 1001–1100 | 62.13 | 28.09 | 7.23 | 2.55 | 235 | $p < 0.001$ |
| Temp.sum | >1101 | 24.01 | 37.08 | 23.40 | 15.50 | 329 | |
| Altitude | <100 m | 29.30 | 29.67 | 24.54 | 16.48 | 273 | 180.82 |
| Altitude | 101–200 m | 61.99 | 28.06 | 6.89 | 3.06 | 392 | 0.001 |
| Altitude | >201 m | 85.61 | 14.39 | 0.00 | 0.00 | 132 | |
| Pine forest | | 84.89 | 8.24 | 2.87 | 4.01 | 1396 | 356.45 |
| Spruce forest | | 44.73 | 17.82 | 16.55 | 20.91 | 550 | $p < 0.001$ |
| Broadleaf forests | | 65.98 | 12.37 | 9.28 | 12.37 | 97 | |
| Tree age | <40 years | 78.51 | 12.13 | 4.85 | 4.51 | 577 | 75.13 |
| Tree age | 41–80 years | 67.12 | 11.42 | 8.37 | 13.09 | 657 | $p < 0.001$ |
| Tree age | 81–120 years | 63.41 | 12.73 | 10.91 | 2.95 | 440 | |
| Tree age | >120 years | 84.30 | 9.42 | 2.24 | 4.04 | 223 | |
| Basal area | <10 $m^2$/ha | 86.67 | 8.63 | 2.55 | 2.16 | 510 | 236.11 |
| Basal area | 10–15 $m^2$/ha | 81.85 | 12.42 | 2.55 | 3.18 | 314 | $p < 0.001$ |
| Basal area | 15–20 $m^2$/ha | 73.32 | 11.22 | 8.98 | 6.48 | 401 | |
| Basal area | 20–25 $m^2$/ha | 60.99 | 12.06 | 8.16 | 18.79 | 282 | |
| Basal area | >25 $m^2$/ha | 49.61 | 15.58 | 14.55 | 20.26 | 385 | |

Green algae: The mean abundance of algae on the sample plot (three trees) or on the cluster according to the variables.
$NO_x$, $NH_3$, S: Cluster-specific means; deposition modelled for the year 1993 (Hongisto, 1998).
Temperature sum (> + 5°C): Cluster-specific means; used the model developed Ojansuu and Henttonen (1983).
Altitude (m above sea-level): Cluster-specific means; the average altitude of the 3–4 sample plots.
Forest site type: Sample plot specific estimates; after predominant tree species.
Tree age: Sample plot specific estimates; the average age of the three sample trees.
Stand basal area ($m^2$ $ha^{-1}$): Sample plot specific estimates.

### *Air temperature in 1986–1995 in relation to long-term means*

The possible change in air temperature could be one reason for the increase in abundance of green algae on conifers. This is why we looked into whether the mean annual temperature during the period 1986–1995 and the mean winter temperature deviated from long-term means. The mean annual temperature of the years in question for the country as a whole was 0.5°C higher than during the period 1931–1980; similarly, the mean winter temperature (October–March) was about 0.8°C higher (Table 2). Towards the end of the period, in 1991–1995, it was even warmer on average. The rise in mean temperature was higher in southern than in northern Finland.

## Discussion

The increase in the abundance of green algae on conifers and the expanding of their distribution area northwards during the past ten years are surprising results because the climate factors in Finland are not as favourable to the growth of the algae as they are in Central Europe. Furthermore, the forests in Finland are mainly coniferous forests growing on fairly nutrient-poor soils characterised by inadequate supplies of nitrogen for plants. Nitrogen deposition even in the south amounts to no more than about half of the amounts in the southern parts of Scandinavia and in Denmark, where green algae are believed to have clearly become more abundant (Göransson, 1990; Søchting, 1997; Thomsen, 1992).

Table 2

Mean annual temperature and mean winter temperature (X-III) in some localities in Finland during the years 1931–1960, 1961–1980, and 1986–1995 (Kolkki, 1981; Heino and Hellsten, 1983; Meteorological Yearbooks, 1986–1995)

| Locality | | 1931–1960 | | 1961–1980 | | 1986–1995 | |
|---|---|---|---|---|---|---|---|
| | | Annual | Winter | Annual | Winter | Annual | Winter |
| Helsinki | N60°19′ E24°58 | 4.4 | −2.7 | 4.5 | −2.7 | 5.1 | −1.5 |
| Tampere | N61°25′ E23°35′ | 3.8 | −3.4 | 3.8 | −3.5 | 4.4 | −2.5 |
| Jyväskylä | N62°24′ E25°41′ | 2.8 | −4.7 | 2.7 | −5.0 | 3.1 | −4.1 |
| Oulu | N64°56′ E25°22′ | 2.3 | −5.3 | 2.0 | −5.9 | 2.7 | −4.8 |
| Rovaniemi | N66°34′ E25°50′ | 0.8 | −7.0 | 0.2 | −8.0 | 0.7 | −7.0 |
| Sodankylä | N67°22′ E26°39′ | −0.4 | −8.6 | −1.0 | −9.6 | −0.4 | −8.5 |

However, in those parts of Sweden which are at the same latitude as Finland, no clear increases on Norway spruce branches in the abundance of algae have been found (Bråkenhielm and Liu Qinghong, 1995) over the 10 year monitoring period, but the amount of monitoring sites was relatively little in this study, only fifteen sites in all Sweden.

Distinguishing between the effects of air pollutants and other factors affecting the abundance of algae over large areas with more than one climate zones is difficult. When the abundance of the algae, climate factors and deposition show strong intercorrelation, it is difficult to distinguish between cause and effect relations. Similar problems as those encountered in this study have also been observed in extensive studies looking into the abundance of the algae. Liu Qinghong and Bråkenhielm (1995) have analysed the occurrence of algae on spruce branches in Sweden in more detail by using various statistical methods (Principal Component Analysis, Redundancy Analysis) in order to separate the effects of the various variables, climatic variables (growing season, moisture, temperature sum), geographic variables (longitude, latitude, altitude) and pollutional variables (S- and N-deposition). They concluded that climatic factors mainly determine the distribution of green algae, whereas nitrogen deposition has a growth-promoting effect on the algae. Their results suggest that under the same climate conditions algae can be a good indicator of sulphur and nitrogen deposition. In Finland, too, the distribution area of green algae would seem to be primarily determined by climatic factors. In the light of the results obtained in the present study as well as that of Thomsen (1992) in Norway, the mean annual temperature of 1.0°C would appear to be the limit below which the algae no longer occur. The length of the growing season and air humidity also affect the occurrence of the algae (Thomsen, 1992; Liu Qinghong and Bråkenhielm, 1995). Warm and moist autumns promote the growth of colonies of the algae. In recent years, the mean annual temperature, and particularly the mean temperatures in the autumn, have been above average in southern and central Finland.

Even though nitrogen deposition is relatively low in most parts of Finland, it has, nevertheless, remained unchanged for a long time whereas sulphur deposition has distinctly diminished. In Sweden green algae have been observed to occur mainly in areas where the modelled annual nitrogen deposition exceeds 6 kg per hectare (Göransson, 1990). In the case of Finland, green algae would appear to occur also in areas where the nitrogen deposition is distinctly below this level. The present study failed to obtain as clear a correlation between the abundance of the algae and nitrogen deposition as has been obtained in some other studies (Thomsen, 1992; Bråkenhielm and Liu Qinghong, 1995); the reason probably lies in the scope and heterogeneity of the study area. The abundance of the algae seems to also correlate with sulphur deposition (Bråkenhielm and Liu Qinghong, 1995). It has been observed that sulphur and ammonium erode the cuticle of conifer needles, and it has even been proposed that algae may spread over to damaged needles more readily than to sound needles (Merilä, 1992; Bråkenhielm and Liu Qinghong, 1995; Bäck et al., 1997). However, sulphur is harmful to algae when present in high concentrations, and thus it might be assumed that algae would benefit from a decline sulphur deposition.

It has been observed that in areas of low nitrogen deposition green algae occur more frequently on grove-like sites and on moist upland sites than on sites with less nutrients (Göransson, 1988 and 1990; Merilä, 1992). This is partly due to the differences in microclimate. Spruce forests and broadleaved forests are usually more humid than pine forests. Stand density also affects the abundance of algae, e.g. spruce needles have been observed to bear algae most abundantly in dense stands less than 40 years old (Göransson, 1988; Merilä, 1992). Algae on tree stems occur usually more abundantly on older than younger trees. Also in these cases the differences in the abundance of algae due mainly to the differences in microclimate in different localities. It has been observed that even within the same site algae are more abundant on spruce needles than on pine needles (Göransson, 1988 and 1990; Merilä, 1992). Spruce has more age classes of needles than pine and also the denser foliage of spruces collects moisture more efficiently than that of pines.

Nitrogen concentrations of mosses and lichens appear to correlate relatively well with nitrogen deposition and the abundance of green algae. In the present study, the nitrogen concentration of the mosses varied within the range of 4.5 and 23 g per kg, which is in good agreement with previously published figures on the nitrogen concentrations of mosses (e.g. Kubin, 1983; Mäkipää, 1995; Pitcairn et al., 1995). In areas where the nitrogen deposition has been observed to have distinctly risen in the course of the past few decades, the concentrations of nitrogen in mosses have also risen and the moss communities have become less dense (e.g. Baddeley et al., 1994; Pitcairn et al., 1995). Nitrogen accumulating in the snow during winter in Finland may have an effect of its own on the nitrogen concentrations of mosses. As it happens, the cover of snow is an efficient collector of nitrogen in nitrate form (Kubin and Lippo, 1987), the main part of which will be washed away in the course of spring thaw into water systems. Part of the nitrogen in spring-thaw waters binds itself into the undergrowth, including mosses.

The increase in the abundance of green algae in Finland during the past few years may be ascribed to certain concurrent changes. A slight rise in mean annual temperature, long-term stable nitrogen deposition, and the clear fall in sulphur deposition are all factors which promote the growth of the algae. More detailed research is needed to clear up the reasons influencing the increase in abundance of the algae. Green algae taxonomy, ecology, and their symbiosis with various lichens, and the parasitic fungi occurring in the company of green algae are specific topics on which there is rather few research.

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## References

Baddeley, J.A., Thompson, D.B.A., Lee, J.A., 1994. Regional and historical variation in the nitrogen content of *Racomitrium lanuginosum* in Britain in relation to atmospheric nitrogen deposition. Environmental Pollution, 84, 189–196.

Barrett, K., Seland, Ø., Foss, A., Mylona, S., Sandnes, H., Styve, H., Tarrason, L., 1995. European transboundary acidifying air pollution: Ten years calculated fields and budgets to the end of the first Sulphur Protocol. EMEP MSC-W report 1995, Report 1/95. The Norwegian Meteorological Institute, Research Report no 17, pp. 71 + appendices.

Bobbink, R., Boxman, D., Fremstad, E., Heil, G., Houdijk, A., Roelofs, J., 1992. Nitrogen eutrophication and critical load for nitrogen based upon changes in flora and fauna in (semi)-natural terrestrial ecosystems. Nord (Miljörapport), 41, 115–119.

Bråkenhielm, S., Liu Qinghong, 1995. Spatial and temporal variability of algal and lichen epiphytes on trees in relation to pollutant deposition in Sweden. Water, Air, and Soil Pollution 79, 61–74.

Bäck, J., Turunen, M., Ferm, A., Huttunen, S., 1997. Needle structures and epiphytic microflora of Scots pine (*Pinus sylvestris* L.) under heavy ammonia deposition from fur farming. Water, Air, and Soil Pollution, 100, 119–132.

Ferm, A., Hytönen, J., Lähdesmäki, P., Pietiläinen, P., Pätilä, A., 1990. Effects of high nitrogen deposition on forests: Case studies close to fur animal farms. In: P. Kauppi, P. Anttila and K. Kenttämies (Eds.), Acidification in Finland. Springer Verlag, Berlin, pp. 635–668.

Grennfelt, P., Hultberg, H., 1986. Effects of nitrogen deposition on the acidification of terrestrial and aquatic ecosystems. Water, Air, and Soil Pollution 30, 945–963.

Göransson, A., 1988. Luftalger och lavar indikerar luftföroreningar. Summary: Airborne algae and lichens indicate air pollutants. Statens naturvårdsverket Rapport 3562. Swedish Environmental Protection Agency, Laboratory of Environmental Control, Uppsala, pp. 1–17.

Göransson, A., 1990. Alger, lavar och barruppsättning hos unggranar längs en kvävegradient från Sverige till Holland — en pilotstudie. Summary: Algae, lichens and number of needle year classes on young spruces along the nitrogen gradient from Sweden to the Netherlands — a pilot study. Statens naturvårdsverket Rapport 3741. Swedish Environmental Protection Agency, Laboratory of Environmental Control, Uppsala, pp. 1–37.

Heino, R., Hellsten, E., 1983. Climatological Statistics in Finland 1961–1980. Supplement to the Meteorological Yearbook of Finland. Vol. 80 Part 1a: 1980. The Finnish Meteorological Institute, Helsinki.

Hongisto, M., 1998. HILATAR, a regional scale grid model for the transport of sulphur and nitrogen compounds. Finnish Meteorological Institute Contributions 21, 1–152. Helsinki.

Kolkki, O., 1981. Tables and Maps of Temperature in Finland during 1931–1960. Supplement to the Meteorological Yearbook of Finland. Vol. 65 Part 1a: 1965. The Finnish Meteorological Institute, Helsinki.

Kubin, E., 1983. Nutrients in the soil, ground vegetation and tree layer in an old spruce forest in Northern Finland. Ann. Bot. Fennici, 20, 361–390.

Kubin, E., 1990. A survey of element concentrations in the epiphytic lichen *Hypogymnia physodes* in Finland 1985–86. In: P. Kauppi, P. Anttila and K. Kenttämies (Eds.), Acidification in Finland. Springer Verlag, Berlin, pp. 421–446.

Kubin, E., Lippo, H., 1987. Determining acid deposition in snow in northern Finland. In: International Symposium on Acidification and Water Pathways. Bolkesjø, Norway, 4–8 May 1987. Norwegian National Committee for Hydrology. Volume II, pp. 239–248.

Kubin, E., Lippo, H., 1996. Atmospheric heavy metal deposition in Finland from 1985 to 1990. Applied Geochemistry 11, 155–161.

Kubin, E., Siira, J., 1980. On the suitability of the phenyl hypochlorite procedure for the determination of total nitrogen from plant and soil samples. Aquilo Ser. Bot. 17, 11–17.

Kuusinen, M., Mikkola, K., Jukola-Sulonen, E-L., 1990. Epiphytic lichens on conifers in 1960´s to 1980´s in Finland. In: P. Kauppi, P. Anttila and K. Kenttämies (Eds.), Acidification in Finland. Springer Verlag, Berlin, pp. 397–420.

Liu Qinghong, Bråkenhielm, S., 1995. A statistical approach to decompose ecological variation. Water, Air, and Soil Pollution 85, 1587–1592.

Merilä, P., 1992. Viherleväkasvusto kuusen neulasilla —bioindikaatiomerkitys ja levinneisyys Suomessa 1990. (Green algae on spruce needles — bioindication meaning and distribution in Finland 1990). Pro graduate-work. University of Helsinki, Department of Limnology & Environmental Protection. Helsinki. pp. 1–79.

Meteorological Yearbook of Finland. Climatological data 1986–1995. Vol. 86–95. The Finnish Meteorological Institute. Helsinki.

Mylona, S., 1996. Sulphur dioxide emissions in Europe 1880–1991 and their effect on sulphur concentrations and depositions. Tellus, Ser. B. Chemical and Physical Meteorology, 48, 662–689.

Mäkipää, R., 1995. Sensitivity of forest-floor mosses in boreal forests to nitrogen and sulphur deposition. Water, Air, and Soil Pollution, 85, 1155–1160.

Ojansuu, R., Henttonen, H., 1983. Kuukauden keskilämpötilan, lämpösumman ja sademäärän paikallisten arvojen johtaminen Ilmatieteen laitoksen mittaustiedoista. Summary: Estimation of local values of monthly mean temperature, effective temperature sum and precipitation sum from the measurements made by the Finnish Meteorological Office. Silva Fennica 17(2), 143–160.

Peveling, E., Burg, H., Tenberge, K.B., 1992. Epiphytic algae and fungi on spruce needles. Symbiosis 12, 173–187.

Pitcairn, C.E.R., Fowler, D., Grace, J., 1995. Deposition of fixed atmospheric nitrogen and foliar nitrogen content of bryophytes and *Calluna vulgaris* (L.) Hull. Environmental Pollution 88, 193–205.

Poikolainen, J., Kuusinen, M., Mikkola, K., Lindgren, M., 1998. Mapping of the epiphytic lichens on conifers in Finland in the years 1985–86 and 1995. Chemosphere 36, 2001–2006.

Rühling, Å., Steinnes, E., Berg, T., 1996. Atmospheric heavy metal deposition in Northern Europe 1995. Nord 37, 1–47.

Sutton, M.A., Pitcairn, C.E.R., Fowler, D., 1993. The exchange of ammonia between the atmosphere and plant communities. In: M. Begon and A.H. Fitter (Eds.), Advances in Ecological Research, Vol 24. Academic Press, pp. 301–393.

Søchting, U., Jensen, B., Unger, L., 1992. Epifylfloraen på Rødgran. En undersøgelse af belægninger på grannåle. Summary: Epiphyllic florae on Norway spruce. A research of epiphyllic growth on spruce needles. Miljøministeriet, Skov- og Naturstyrelsen og Københavns Universitet, Institut for Sporeplanter (Ministry of Environment, the Danish Forest and Nature Agency and University of Copenhagen, Institute of Cryptogams), Copenhagen. pp. 1–44.

Søchting, U., 1997. Epiphyllic cover on spruce needles in Denmark. Ann. Bot. Fennici 34, 157–164.

Thomsen, M.G., 1992. Epifyttisk belegg på barnåler i Norge i relasjon til nitrogendeposisjon og klima. Summary: Epiphytic growth on spruce needles in Norway in relation to nitrogen deposition and climate. Rapport fra Skogforsk, Norsk Institutt for Skogforskning 23, 1–11.

Ympäristökatsaus no 3 (Environmental report no 3), 1995. Ilma (Air). Finnish Environment Institute. Helsinki. pp. 1–20.