Crypt. Bot. 5, 264–269 (1995)

Cryptogamic Botany

Lichens as monitors of nitrogen deposition

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SUMMARY

A method for using lichens as monitors of nitrogen deposition from the air is introduced. Total nitrogen in *Cladonia portentosa* and in *Hypogymnia physodes* growing close to the ground and not receiving canopy throughfall seem to reflect the wet deposition of nitrogen. The nitrogen content of *Hypogymnia physodes* growing at breast hight on 10 m high *Picea abies* is proposed as an indicator of total (dry and wet) deposition. Results of mapping in Scandinavia and northwestern Europe is presented. A transplant method using *H. physodes* is described which can be used for monitoring total nitrogen deposition.

Introduction

There has been a major increase in emission of nitrogenous compounds in Denmark and other countries in northwestern Europe during the last thirty years. The nitrogen is deposited mainly as ammonia, ammonium and nitrate, and may seriously affect ecosystems, where lichens dominate, as these are often nitrogen limited [1, 2, 7, 22]. Such ecosystems include heathlands, dunes and oligotrophic epiphytic communities.

In heathlands the eutrophication, which leads towards dominance of *Empetrum* and grasses, is detrimental to a diverse lichen flora. It is a general but largely undocumented impression, that algal covers on bark have increased in recent years, possibly at the expense of epiphytic lichen communities there. The epiphyllic algal cover on spruce needles is considered to be another effect of nitrogen air pollution, but one which appears beneficial to lichen colonization [24].

Nitrogen emittance, deposition and uptake

Nitrogenous compounds in the air derive mainly from two sources. Nitrogen oxides are produced during combustion and originate from traffic, power plants etc. As they are only slowly deposited they spread over large geographical areas. Ammonia originating from livestock manure and its reaction product ammonium on the contrary have a high velocity of deposition. They are emitted at low altitude and are thus deposited in rather close proximity to the source. In Denmark in general it is estimated that the two sources are equally important.

The nitrogen compounds are deposited onto lichen thalli by both wet and dry deposition. The dose applied to the thalli as wet deposition is dependent on the amount of precipitation, and the dose applied as dry deposition is dependent on wind speed and turbulence. Both are dependent on the concentration of the compounds in the air. Ammonia, ammonium and nitrate are readily dry deposited on thalli as these compounds have a high velocity of deposition, whereas the deposition of NO and NO_2 is very low due to low velocity of deposition.

The sparse knowledge about the assimilation of nitrogenous compounds into lichen thalli was summarized by Brown [3]. Recent studies indicate that ammonium ions are initially bound to the cellular walls [4] and may subsequently be transferred to the cell cytoplasma. Little is, however, known about the velocity of the transport and the mechanisms involved.

0935-2147/95/0005-0264 $ 3,50/0

Monitoring total nitrogen deposition

When trying to measure total nitrogen deposition to forest canopy or to whole ecosystems the wet deposition is rather unproblematic, but estimation of dry deposition can presently only be obtained by micrometeorological approaches [25]. It was therefore attempted to use the nitrogen accumulated in lichen thalli as a monitor for mapping variation in total nitrogen deposition.

Nitrogen in lichens

It has been demonstrated experimentally that at least some lichens are very efficient absorbers of nitrogenous compounds [12, 18]. Considerable uptake was also demonstrated in nature by Crittenden [5].

Measurements of nitrogen content in lichens have been published [6, 13, 14, 15, 16, 17, 19, 20, 21] and are summarized by Søchting [23]. A number of these studies focused on the feeding value of lichens for reindeers. Nitrogen content in lichen thalli has been analysed in connection with pollution studies by Kauppi [11], Holopainen [9, 10] and Hilmo & Wang [8].

Nitrogen content in reindeer lichens

In order to quantify nitrogen deposition to heathlands a number of mostly Danish localities were selected in 1987. From each locality ten samples of *Cladonia portentosa* were collected from the center of large mats. At some sites fewer samples per locality were collected. The lower necrotic and partly gelatinized parts were removed and the thalli dried. Total nitrogen (including nitrate) was determined by the Kjeldahl method.

The average content for all stations was calculated and is illustrated in Fig. 1. In the coastal dunes the nitrogen content in general was 5–7‰ with 5‰ at the most remote area at the extreme north of Jutland. In central and southern Jutland, where most animal farming is concentrated, values are generally about 8‰ or higher. It is anticipated that reindeer lichens might reflect primarily the wet deposition of nitrogen, as air movement close to the soil is fairly low, accordingly the higher values in central Jutland may also reflect a somewhat higher precipitation here.

The average nitrogen content of Danish reindeer lichens (*Cladonia portentosa*) is 6.9‰. This value is compared with measurements from other localities in northwestern Europe in Fig. 2. Reindeer lichens (*Cladonia arbuscula* ssp. *mitis*) from northern Scandinavia and eastern Siberia (Søchting, unpubl.) contain between 2 and 3‰ nitrogen, and similar concentrations are reported also from northeastern Finland [17] and Scotland [15]. A nitrogen content of 2–4‰ thus seems to be the natural background level although some variation may occur due to species and habitat. Observations of damaged thalli in the Netherlands suggest that about 13‰ total nitrogen is lethal to reindeer lichens, but lower values may lead to reduced vitality.

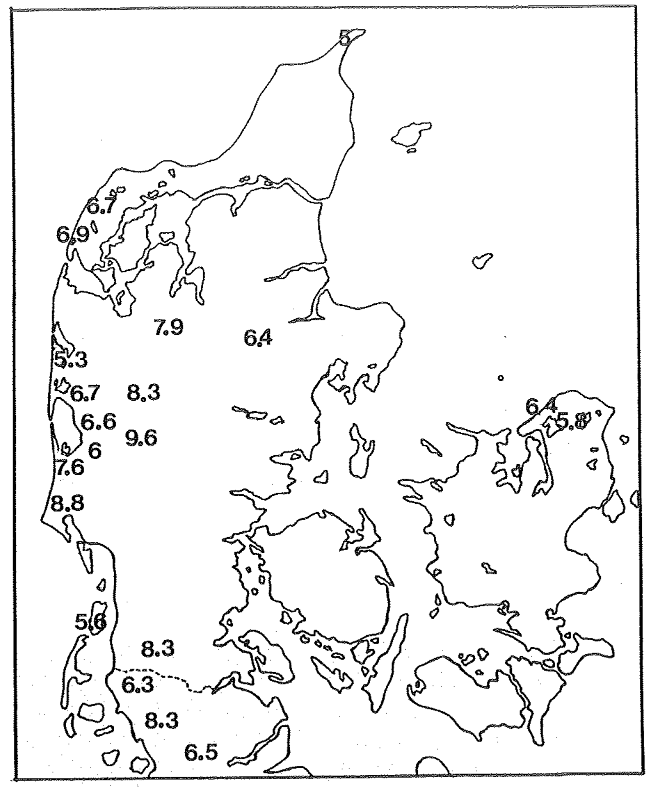

Fig. 1. Nitrogen concentration (‰) in *Cladonia portentosa* in Danish heathlands and dunes.

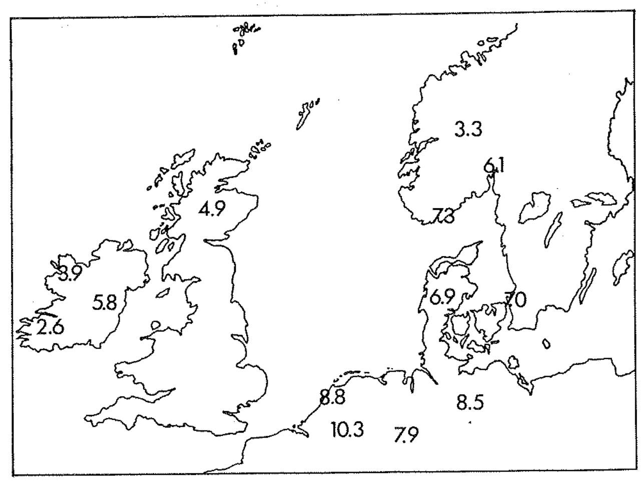

Fig. 2. Nitrogen concentration (‰) in *Cladonia portentosa* in Northwest Europe. Mean values based on different number of samples.

Monitoring in Denmark with *Hypogymnia*

In order to monitor also the dry deposition of nitrogen the epiphytic lichen *Hypogymnia physodes* was chosen as an accumulator due to its acid thallus (pH = 4.4) and its high frequency. A nitrogen content of about 30‰ appears to be lethal [23], and in the Netherlands it has partly disappeared probably due to excess nitrogen (van Dobben, pers. com.).

About 1000 samples of *H. physodes* were collected from coniferous forests in Denmark at locations believed to vary with respect to annual nitrogen deposition. At each forest stand ten samples of *Hypogymnia* thalli were collected at breast hight from Norway spruce of about 10 m height. These samples had received throughfall from the above canopy, but at some localities thalli were also collected from low dead branches not exposed to throughfall from an overlying canopy.

The results reported by Søchting [23] are shown in Tab. 1. South Jutland with high farming activity and a considerable concentration of live stock had significantly higher levels of nitrogen in *Hypogymnia* compared to North Zealand. The difference between thalli which had received throughfall and those that received no throughfall was slightly higher in southern Jutland, where dry deposition was expected to be high. Within a single woodland there was variation between stands. This is believed to be due to different impaction rates owing to differences in forest architecture and topography. The level of nitrogen in *Hypogymnia* also disclosed strong nitrogen sources situated up to a few km away.

Table 1. Nitrogen content (‰) in Swedish and Danish *Hypogymnia physodes* that has or has not received throughfall. Only localities with five or more replicates of "nothroughfall" thalli are included.

Locality	With throughfall		Without throughfall	Difference	Precipitation mm/y
Reivo (Sweden)	7	a[1]	7	0	730
Stormyran (Sweden)	8	a	8	0	
Vindeln (Sweden)	8	a	9	−1	700
Aneboda (Sweden)	11	b	12	−1	815
Tandövala (Sweden)	14	c	10	4	770
North Zealand (Denmark)	17	d	10	7	600
South Jutland (Denmark)	20	e	12	8	750
Berg (Sweden)	25	f	20	5	1110

[1] Values followed by the same letters are not significantly different using the Student Newman-Keuls test (P > 0.01).

Large-scale monitoring in Sweden

Hypogymnia was collected during 1990 from 12 Swedish woodlands used for integrated monitoring of environmental quality. Thalli were collected at breast height from Norway spruce *c.* 10 m tall and again thalli which were not exposed to canopy throughfall were also collected from some stations. Each sample consisted of 10 replicates of about 2 g. The total nitrogen content was determined using a LECO FP-428 nitrogen determinator. The standard deviation was about 10%.

The levels of nitrogen for the 12 stations are illustrated in Fig. 3 together with figures for two Danish and two Norwegian localities. The results from some stations were analysed by a one-way analysis of variance (ANOVA) (Tab. 1). The northern part of Sweden presents contents of 7–8‰, which is elevated compared to the 3–5‰ encountered in parts of Norway and in Siberia (Søchting, unpubl.). In central and southeastern Sweden the total nitrogen content of *Hypogymnia* is 11–14‰. Local sources may influence the results, for instance a local paper mill near Tividen may explain the 17‰ recorded in central south Sweden. Elevated levels along the Swedish west coast can be explained by deposition from regional towns like Göteborg, long-range transported air pollution and a very high precipitation.

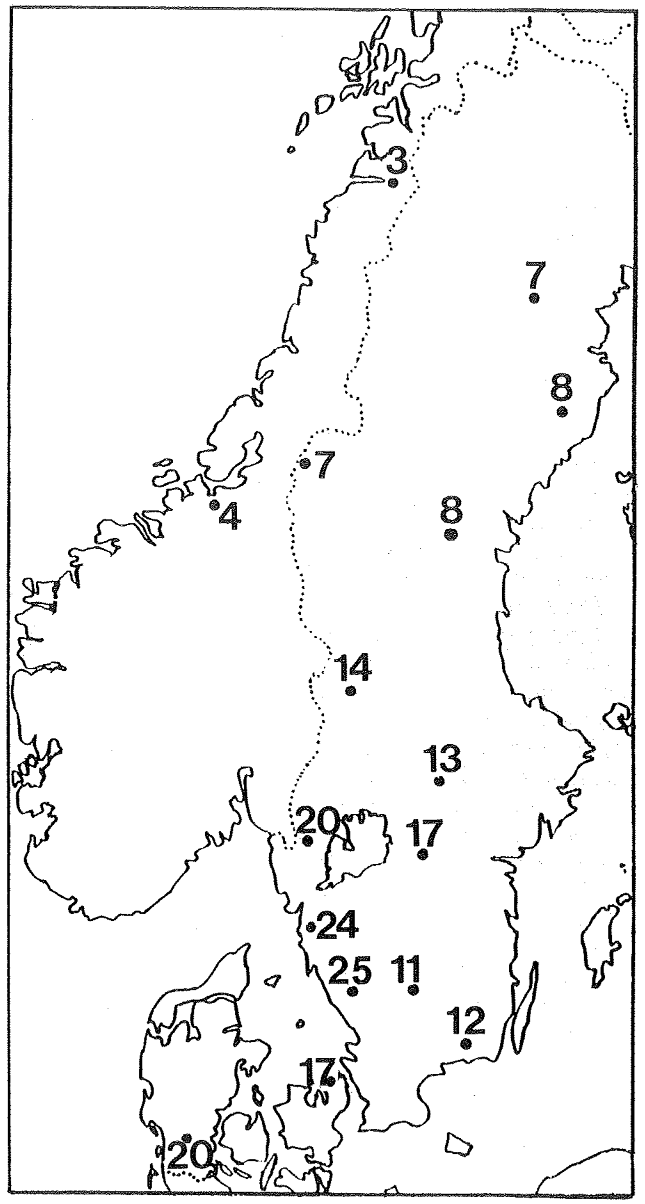

Fig. 3. Nitrogen concentration (‰) in *Hypogymnia physodes* in Scandinavia. Samples from breast hight of 10 m high *Picea abies*.

Comparing the total nitrogen of thalli that have received throughfall with that of thalli without throughfall can tell us something about the importance of dry deposition to the lichen surface. Table 1 shows the additional nitrogen taken up due to throughfall compared with the level of precipitation. The localities presenting the lowest nitrogen contents are all situated in northern Sweden and have little difference between thalli exposed to throughfall and those that received no throughfall. These localities are far from ammonia sources and possibly receive only little dry deposition. Berg is situated in a part of Sweden with very high precipitation influencing the dose of nitrogen received as wet deposition. The fairly large difference between the nitrogen content of thalli with and without exposure to throughfall in South Jutland can be explained by the high level of ammonia emission in the area due to intensive animal farming.

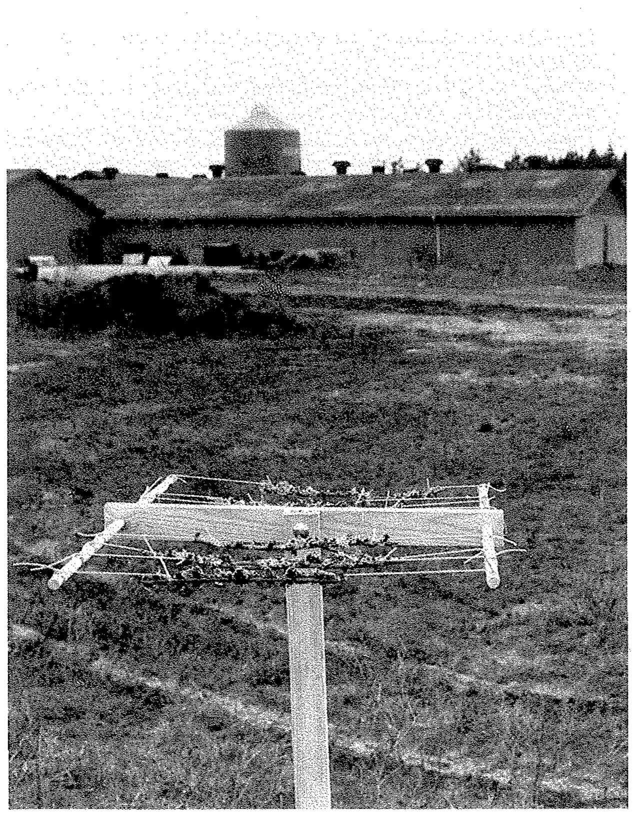

Fig. 4. Transplanted *Hypogymnia physodes* near pig farm. Pole with eight twigs, which are suspended with silicone strings.

Transplantation

In order to study the pattern of nitrogen enrichment around a point source of ammonia, *Hypogymnia physodes* growing on twigs of *Larix* was transplanted to the surroundings of a pig farm in southern Jutland.

Twigs with healthy *Hypogymnia* were collected in Asserbo Plantage, North Zealand. The thalli had a nitrogen content of 14‰. Eight twigs were mounted on each pole as shown in Fig. 4. The poles were positioned as indicated in Fig. 5 and the transplants were exposed from 21 November 1989 to 26 March 1990. Thalli were also transplanted to a forest clearing about 1 km away and also back to the place of origin. After the four winter months

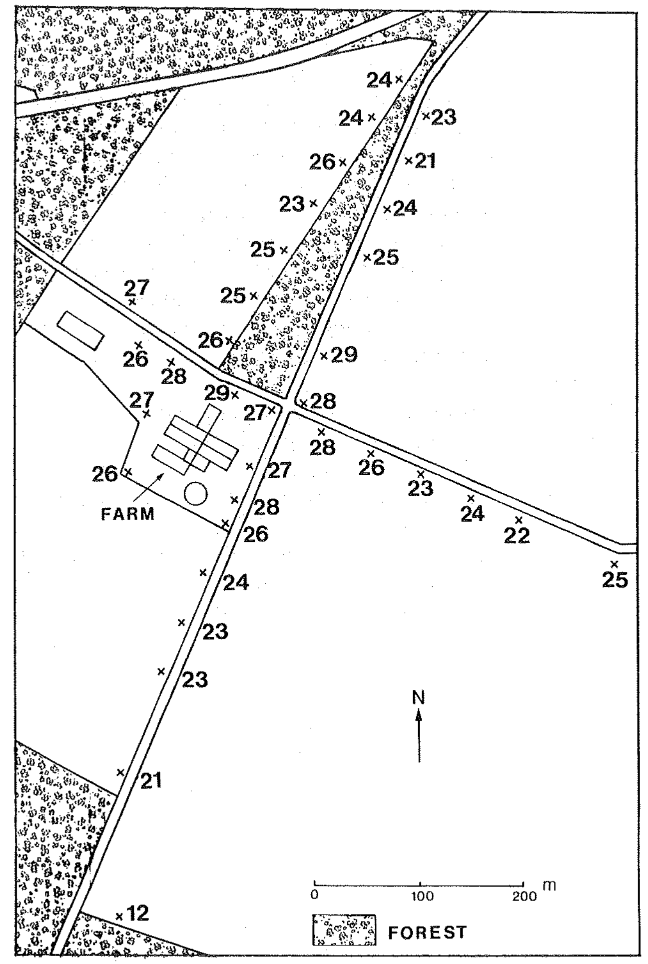

Fig. 5. Transplant experiment with *Hypogymnia physodes* around a pig farm in South Jutland. Figures represent average concentrations of nitrogen (‰) for each pole after transplantation for four winter months. Initial mean value was 14‰.

the twigs were collected, and eight samples from each pole were analysed for total nitrogen by the Kjeldahl method.

The thalli had increasing levels of nitrogen with decreasing distance to the farm (Fig. 5). Values up to 29‰ were found closest to the farm. However, the thalli here were very dark green and unhealthy. Indeed, at one pole the thalli of seven twigs had died and fallen off. The expected concentration gradients around the farm were reflected in the concentrations of nitrogen, particularly at the southern transect. To the east, down wind from the farm the pattern was less clear, as even the most remote transplants had very elevated nitrogen concentrations. It is expected, that a much shorter exposure time would have been more appropriate.

Twigs with *Hypogymnia* transplanted to the low canopy of Norway spruce in the region over the same exposure period as above showed that an effect of the nitrogen source could be traced up to 1000 m from the farm [23].

Conclusion

The studies presented demonstrate that lichens have an extraordinary capacity of nitrogen uptake in nature. This seems to be a rapid process and indicates that the nitrogen content of lichen thalli reflect nitrogen deposition in the recent past. Elevated nitrogen concentrations in epiphytic lichens may be due in part to increased dry deposition onto tree canopies resulting in increased nitrogen in canopy throughfall. It must be emphasized, however, that lichens only provide information about the nitrogen dose received at the spot, where the thallus is growing and is dependent on the precipitation, the nitrogen concentrations in the air, and also on the extent of exposure to air movement.

Preliminary results [23] from transplant experiments along a freeway indicate, as expected, that nitrogen oxide from car exaust is deposited on and taken up in the lichens to a very limited extent. However, more information is needed on the deposition rate of different nitrogen compounds and their uptake in lichen thalli. Furthermore the dynamics of uptake and release of nitrogen compounds must be further studied in order to determine the time needed for an equilibrium to be established with the ambient air.

Acknowledgements

The project was supported by the Danish Forest and Nature Agency. Sven Bråkenhielm, Swedish Environmental Protection Agency provided the material from Swedish forests, Else Meier Andersen performed the nitrogen analyses and Esben Nielsen assisted in the transplant experiment. Their cooperation is highly appreciated.

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Key words: Air pollution, nitrogen, lichen, agriculture

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