METSÄNTUTKIMUSLAITOKSEN
TIEDONANTOJA 373

Metsäntutkimuslaitos
Rovaniemen tutkimusasema



RESEARCH INTO FOREST DAMAGE CONNECTED WITH AIR POLLUTION IN FINNISH LAPLAND AND THE KOLA PENINSULA OF THE U.S.S.R.

A seminar held in Kuusamo, Finland, 25-26 May 1990

Eero Tikkanen ja Martti Varmola (eds.)

Rovaniemi 1991

Cover Photo:

The industrial desert near Nickel in the Kola Peninsula (top right). A Norway spruce forest damaged by air pollutants near Monchegorsk in the Kola Peninsula (bottom right). A branch of Scots pine covered with beard lichen Alectoria sp. in western Lapland (top left). A branch of Scots pine with yellow needles in the needle loss area of the summer of 1987 in the Rovaniemi rural commune (bottom left). (Cover design and photoes by E. Tikkanen).

METSÄNTUTKIMUSLAITOS
Jalostusosasto

METSÄNTUTKIMUSLAITOKSEN
TIEDONANTOJA 373

Metsäntutkimuslaitos
Rovaniemen tutkimusasema

RESEARCH INTO FOREST DAMAGE CONNECTED WITH AIR POLLUTION IN FINNISH LAPLAND AND THE KOLA PENINSULA OF THE U.S.S.R.

A seminar held in Kuusamo, Finland, 25-26 May 1990

Editors

Eero Tikkanen and Martti Varmola

Rovaniemi 1991

ISBN 951-40-1144-9
ISSN 0358-4283

Lapin Painotuote Oy
Kemijärvi 1991

Contents

Foreword 4
List of the participants 6
Eero Tikkanen: A review of research into forest damage connected with air pollution in Finnish Lapland 7
Eero Tikkanen & Kari Mikkola: The Lapland Forest Damage Project: multidisciplinary cooperation in environmental sciences 20
John A. Witter: Evaluation of the research plan of the Lapland Forest Damage Project 35
John Derome, Kaarina Niska, Antti-Jussi Lindroos & Pekka Välikangas: Ion-balance monitoring plots and bulk deposition in Lapland during July 1989 - June 1990 49
Hannu Raitio: A comparison of element analyses of pine needle samples 77
Risto Jalkanen: Mineral contents of fruit bodies of three mushroom species in Salla, eastern Lapland 81
Eero Kubin: A survey of element concentrations in the epiphytic lichen *Hypogymnia physodes* in Northern Finland in 1986 86
Sirkka Sutinen: Tissue and cellular effects of air pollutants on coniferous trees 101
Seppo Neuvonen: Field experiments on the effects of pollution at Kevo Subarctic Research Station 109
Jaana Reinikainen, Minna Turunen & Satu Huttunen: Effects of acid irrigation on conifer seedlings 115
Natalia Lukina & Vjatcheslav Nikonov: Pollution-induced changes in the primary production of spruce ecosystems in the Kola Peninsula 120
Zinaida Jevtjugina: The atmospheric pollution load on forest ecosystems in the central part of the Kola Peninsula 132
Galina Kašulina: Spatial variation in podzol development in a spruce ecosystem in the Kola Peninsula 142
Jelena Kruglikova: The chemical composition of wild berries subjected to atmospheric industrial pollution in the Kola Peninsula 153

Foreword

Research into forest damage connected with air pollution in Finnish Lapland is still rather young and disjointed. This is largely due to the belief that the natural environment of Lapland is clean and its forests healthy and vigorous. This impression was altered some 3-4 years ago as a result of the damages observed in the forests of Lapland and the information obtained of the environmental problems in the Kola Peninsula of the U.S.S.R.

To intensify research into forest damage connected with air pollution in Lapland, the Finnish Forest Research Institute established in May of 1989 the Lapland Forest Damage Project. The main objective of this multidisciplinary cooperation project is to investigate the effects of pollutant emissions from the Kola area on the forests of Lapland. About 60 researchers from five Finnish universities and five research institutes are working in the project which is coordinated by Rovaniemi Research Station of the Finnish Forest Research Institute. The Lapland Forest Damage Project is funded by the Ministry of Agriculture and Forestry. Concrete cooperation in the project has also started in environmental sciences with Soviet scientists working for the U.S.S.R.'s Academy of Sciences at the Kola Science Centre in Apatity.

In May of 1990 the overall research plan of the Lapland Forest Damage Project was evaluated by Prof. John A. Witter from the University of Michigan, School of Natural Resources, U.S.A. The invitation to evaluate the project was made by the project staff and his visit was funded by the Finnish Academy.

A seminar on research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. was held in connection with the evaluation at the Oulanka Biological Station of Oulu University on 25-26 of May 1990. After the seminar, a field excursion was arranged to the north-eastern part of Salla in eastern Lapland. The papers published in this report were presented at the seminar by researchers working on the project. Also the evaluation paper of Prof. John A. Witter is published here. Eero Tikkanen, now at the Arctic Centre of the University of Lapland, organized the evaluation of the project as well as the seminar and the excursion.

Soviet scientists from the Kola Science Centre were unable to participate in the seminar. However, they visited Lapland on 19-23 of June in 1990 to discourse and agree how to establish forest sample plots on the Soviet side for the needs of the project. At Rovaniemi, they gave four discourses on investigations dealing with environmental problems in the Kola Peninsula caused by air pollutants. These presentations are also included in this report.

Thanks are due to Tuija Katermaa for her indispensable role in text processing and in laying out of this report and to Prof. Veijo Ilmavirta and senior scientist Pekka Kauppi for reviewing it. Researcher John Derome has thoroughly checked the English language of the papers presented by Soviet scientists.

Eero Tikkanen

Martti Varmola

List of the participants

Airaksinen Kirsti, Finnish Forest Research Institute, Finland
Banasova Viera, Czechoslovakia
Derome John, Finnish Forest Research Institute, Finland
Havas Paavo, University of Oulu, Finland
Holopainen Toini, University of Kuopio, Finland
Honkanen Tuija, University of Turku, Finland
Härmä Pekka, National Board of Waters and the Environment, Finland
Ilmavirta Veijo, Arctic Centre, University of Lapland, Finland
Jalkanen Risto, Finnish Forest Research Institute, Finland
Jukola-Sulonen Eeva-Liisa, Finnish Forest Research Institute, Finland
Karjalainen-Balk Leena, Ministry of Environment, Finland
Kauppi Matti, University of Oulu, Finland
Kauppi Pekka, Finnish Forest Research Institute, Finland
Klemetti Matti, Koillis-Suomi Forestry Board District, Finland
Kontio Matti, Geological Survey of Finland, Finland
Kubin Eero, Finnish Forest Research Institute, Finland
Kuusinen Mikko, Finnish Forest Research Institute, Finland
Lindroos Antti-Jussi, Finnish Forest Research Institute, Finland
Mikkola Kari, Finnish Forest Research Institute, Finland
Moskaltsuk Leonid, U.S.S.R.
Neuvonen Seppo, University of Turku, Finland
Nikula Ari, Finnish Forest Research Institute, Finland
Niska Kaarina, Finnish Forest Research Institute, Finland
Nöjd Pekka, Finnish Forest Research Institute, Finland
Raitio Hannu, Finnish Forest Research Institute, Finland
Reinikainen Jaana, University of Oulu, Finland
Sutinen Marja-Liisa, Finnish Forest Research Institute, Finland
Sutinen Sirkka, Finnish Forest Research Institute, Finland
Tikkanen Eero, Arctic Centre, University of Lapland, Finland
Turunen Minna, University of Oulu, Finland
Vaarala O. Heikki, Salla, Finland
Varmola Martti, Finnish Forest Research Institute, Finland
Väre Henry, University of Oulu, Finland
Witter John A., School of Natural Resources, U.S.A.
Wulf Anu, University of Kuopio, Finland

A review of research into forest damage connected with air pollution in Finnish Lapland

Eero Tikkanen
Arctic Centre, University of Lapland
P.O.Box 122
SF-96101 Rovaniemi, Finland

Abstract

Not until in the middle of 1980's was more attention focused on the health and vitality of Lapland's forests. A network of permanent forest sample plots covering Lapland was established in Finland by the Finnish Forest Research Institute in 1985-86. Estimations made on these sample plots showed that the defoliation of Scots pine was severe in Lapland and especially in eastern Lapland in 1986, 1987 and 1988. The effect of the emissions of sulphur from the Kola Peninsula was seen to reflect in the reduced number of epiphytic lichens, in the lack of intolerant species and in the plentiful occurrence of tolerant species in northeastern Lapland. Nickel and copper concentrations in *Hypogymnia physodes*, an epiphytic lichen species, was found to be at its highest in eastern parts of the county of Lapland whereas the concentration of chrome was at its highest near the coastal area in the southwest. Severe needle loss by Scots pine in the summer of 1987 in southern Lapland and the Scleroderris canker attack on Scots pine in the northeastern parts of Salla in eastern Lapland were the final factors leading to the intensification of further research into forest damage connected with air pollution in Finnish Lapland in 1989. More accurate knowledge gained about the vast pollution emissions in the Kola Peninsula of the U.S.S.R. also influenced.

Introduction

Research into forest damage connected with air pollution was initiated in Finland actually in the 1960's. For a long time, research was local in character. The effects of air pollutants on trees and ground vegetation of forests were investigated mainly in the vicinity of individual industrial plants. Little by little, however, more comprehensive studies on the health of forests were made and finally in 1985 a national survey of the vitality of forests was launched by the Finnish Forest Research Institute.

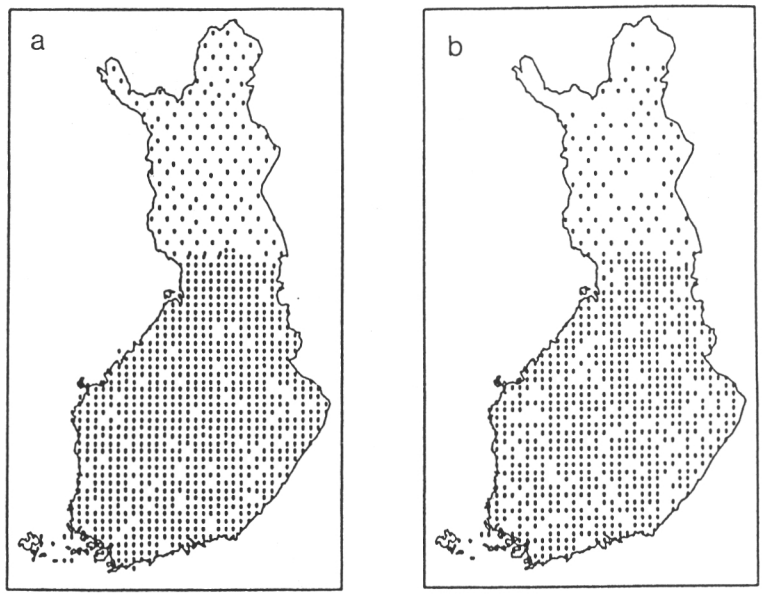
In Lapland research into forest damage connected with air pollution is especially young and sporadic. Until very recently, the general view has been that the forests of Lapland are healthy and vigorous and damages observed in them are caused by so-called natural stress factors, i.e. frost, drought, barren soil etc. Special interest was focused on the forests of Lapland, however, during the latter half of the 1980's as a consequence of damages observed and information gained about the massive pollution in the Kola Peninsula of the U.S.S.R. Now forest damage and air pollution research in Lapland is done in cooperation by many Finnish research organizations - and for good reason.

The ILME project

In 1985-86, as the 8th national forest inventory (VMI 8) was about to begin, the Finnish Forest Research Institute (FFRI) established a network of approximately 3000 permanent sample plots based on systematic sampling. The objective was to investigate the vitality of the forests, their state of health and changes taking place in these (Jukola-Sulonen et al. 1987). This was a part of a larger project, ILME (i.e. Effect of Air Pollution on Forest Ecosystems), launched for the purpose of studying the effects of air pollutants on forests. Since Lapland was considered to be a pure background region, the sample plot network in Lapland was made less dense than elsewhere in Finland with some 400 sample plots being established in the County of Lapland and approximately 2600 in central and southern Finland (Figs. 1a and 1b). These sample plots will be remeasured at intervals of 5 years.

On some of the permanent sample plots, however, measurements will be made every year. Such sample plots are called extensive level sample plots and there are approximately 150 of them in Lapland (Fig. 1b). Intensive level sample plots mean that measurements made on them are even more complex and greater in number than the former. They consist of permanent sample plots and old FFRI sample plots. Of the approximately 100 intensive level sample plots in all of Finland, Lapland has 20.

The ILME project was part of the Acidification Project, HAPRO, funded by the Ministry of Agriculture and Forestry and the Ministry of the Environment (Kauppi et al. 1987). The fifth and last year of the project was 1989 and the main results of the project were reported in 1990 (Kauppi et al. 1990).



Figures 1a. and 1b. The ILME project's system of permanent sample plots. Fig. 1a. The blocks of permanent sample plots of the 8th National Forest Inventory. Fig. 1b. The blocks containing extensive level sample plots. Each point in southern Finland contains 1 - 4 sample plots and 1 - 3 sample plots in northern Finland (Jukola-Sulonen et al. 1987).

The defoliation of conifers

One of the methods used in the ILME project for monitoring the vitality and state of health of conifers has been to estimate the degree of defoliation of the trees (i.e. the relative loss of needles). The survey conducted during the years 1986, 1987 and 1988, involving the extensive level sample plots, revealed that the needle surface area was reduced in Lapland over the period 1986-87, but then increased again in 1988 (e.g. Jukola-Sulonen 1989, Jukola-Sulonen et al. 1990). This was the result not only when the degree of defoliation was estimated, but also when the annual needle classes were counted. Weather factors at least are believed to have contributed to this change in Lapland during 1986-87, because the trees afflicted by needle loss have been noted to be doing better after the warm summer of 1988. However, sulphur deposition, too, in Lapland exceeds the critical amount, and consequently soil acidification and the ensuing damage to trees caused by sulphur are also possible.

The estimation of the degree of defoliation is a subjective method; it depends on the person doing it, and it is non-specific. This being so, the principle adopted in the ILME project's so-called diagnostic studies has been to concentrate on the fundamental causes of exceptionally great loss of needles or some other local forest damage (e.g. Raitio 1990, Raitio & Tikkanen 1986, 1989, Raitio et al. 1990a, 1990b, Tikkanen 1990, Tikkanen & Raitio 1990a, 1990b, 1990c).

In addition to estimating the degree of defoliation, several other methods have also been used in the ILME project. Furthermore, permanent sample plots have been inventoried for the presence of lichens, and lichens and needles have been collected for chemical analysis. FFRI's Department of Soil Science is carrying out acidification studies related to soil and soil water. Stand throughfall is also being studied on permanent sample plots.

Lichens as bio-indicators

The results obtained by Jukola-Sulonen & Kuusinen (1989) and Kuusinen et al. (1990) in the ILME project concerning the occurrence of epiphytic lichens indicate that the air in Finland is at its purest in central Lapland and in the northern parts of central Finland. At its worst it is in southeastern Finland, in the regions surrounding the cities of Tampere and Turku and in northeastern Lapland (Fig. 2). The effects of the vast emissions of sulphur from the Kola Peninsula are reflected in the reduced number of species of lichen, in the lack of intolerant species and in the plentiful occurrence of tolerant species in northeastern Lapland.

Some 2400 samples of *Hypogymnia physodes* (L.) Ach., an epiphytic lichen on the stems and branches of trees, were collected from FFRI's permanent sample plots established in 1985-86. The data obtained from their chemical analysis provided the material for drawing up a national deposition situation. A total of 18 elements were analysed. According to the results obtained by Kubin (1990a, 1990b), the deposition of sulphur in Lapland is less than elsewhere in Finland. The highest concentrations for Lapland were recorded in the southwestern corner and in the northeastern part of Lapland. The highest chromium concentrations in lichen for the entire country were recorded in the southwestern corner, on the coast of the Gulf of Bothnia. The highest copper and nickel concentrations in lichen for Lapland were recorded in the eastern parts of the county where they rose to concentrations equivalent to those in some of the industrial areas in southern Finland. The iron concentrations in Lapland, on the other hand, were among the lowest for the entire country. Zinc and lead concentrations in lichen were occasionally in excess of the average for Lapland.

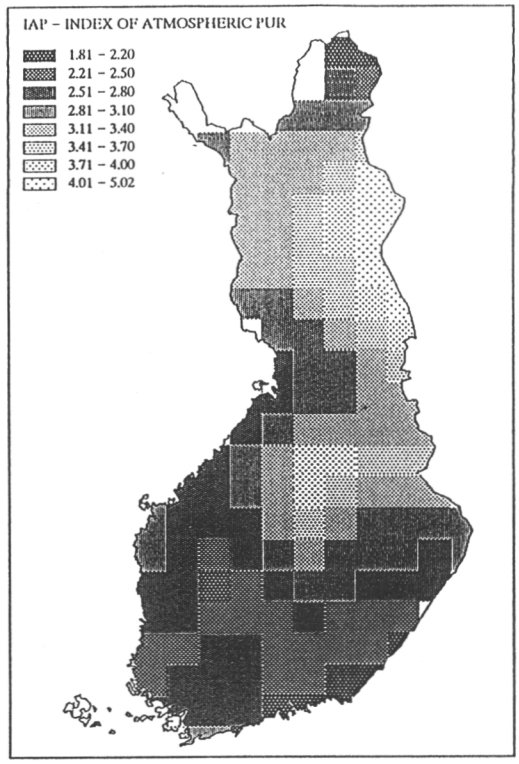


Figure 2. Air quality in Finland on the basis of indicator lichens. The darker the area (and the smaller the index value), the less species of lichens, and especially of intolerant lichens, but more of tolerant species. The lighter the area (and the greater the index value), the more species of lichens, including intolerant species, and the purer the air (Kuusinen et al. 1990).

The needle loss of the summer of 1987

An extensive occurrence of needle loss burst out in the early summer of 1987 in trees of various ages growing on peat soils and barren mineral soils in southern Lapland and Kainuu (eastern part of central Finland). The investigation of the causes of this was begun immediately on mineral soils as part of the ILME project. This investigation meant that pine needles collected from these areas were studied to determine their chemical composition, water status, wax structure and the microscopic structure of the cells. In addition, this diagnostic investigation included root and soil studies and measurements to determine the type of deposition in the regions. The occurrence of needle loss was surveyed by means of a questionnaire addressed to every planning technician employed by the National Board of Forestry in Lapland and the northern parts of central Finland.

The responses obtained to the questionnaire indicated that needle loss was most prevalent in southern Lapland and in Kainuu. The densest concentration of needle loss observations was in the rural commune of Rovaniemi and in Pello as well as in the northern parts of Ranua and the western parts of Kemijärvi, all of which are located in Lapland (Fig. 3). The phenomenon was clearly most frequently observed to be afflicting Scots pine (Fig. 4). The first symptoms were mostly noted by the beginning of July. Needle loss was concentrated in naturally arisen young stands and in stands approaching the stage of the first commercial thinning. On mineral soils, it occurred in stands growing on both moraine and stratified soils.

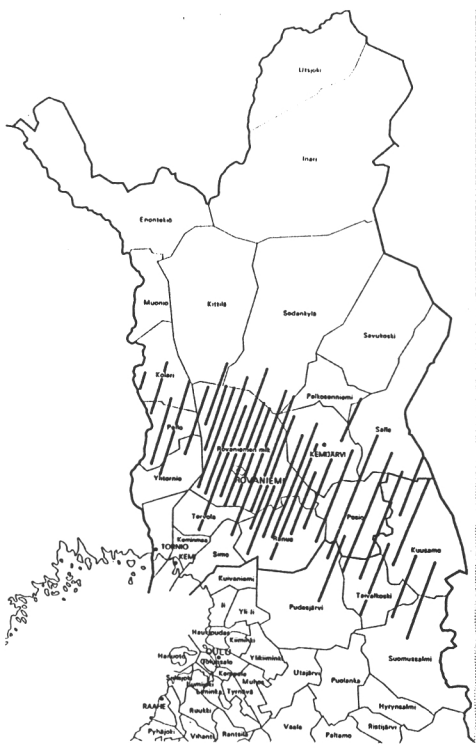




Figure 3. (On the left). The occurrence of needle loss in northern Finland during the summer of 1987 (Tikkanen & Raitio 1990a, 1990b).

Figure 4. (On the right). Defoliated Scots pines on the 1987 defoliation area situated in the rural commune of Rovaniemi; photographed in the summer of 1989. (Photo E. Tikkanen).

The results of needle, root and soil studies carried out by Tikkanen (1990) and Tikkanen & Raitio (1990a, 1990b, 1990c) indicated that the sampled Scots pines were suffering from a lack of both water and nutrients; this was made apparent by the translocation of mobile nutrients and the lack of immobile nutrients. The soil, on the other hand, contained a normal amount of nutrients, but the roots of the trees were observed to be damaged.

The nutrient imbalance was caused by root or needle damages brought about by stress induced by the climate or the combination of climate and air pollutants. It is also possible that both forms of damage may have appeared simultaneously as the result of the above factors. According to Tikkanen (1990) and Tikkanen & Raitio (1990a, 1990b), these results support the view that root damage has been the primary form of damage and it has been largely the result of climatic stress.

Forest damage in the northeastern parts of Salla

Following the summer of 1987, Scots pines of various ages in the northeastern parts of Salla, in the vicinity of the Finno-Soviet frontier, were observed to be damaged (Fig. 5). In May and November of 1988, needle samples were collected from eleven sample plots established to supplement the ILME project network of sample plots. Soil samples were collected from some of these plots in August of the same year. The objective of this diagnostic investigation was to examine the nutrient status of the pines in order to find out the cause of the Salla forest damage. At two locations investigated, Sätsi and Lautakotaoja, the stands of pine were badly afflicted by the Scleroderris canker. In addition to the other measurements made at these locations, radial growth at breast height was measured from borings taken from 25 dominant trees.

According to Raitio et al. (1990a, 1990b), the results of the soil analyses indicate that the soils sampled are barren and the levels of soluble aluminium are fairly high. The nutrient status of trees in the Salla area was poor according to the results of the needle analyses. The nutrient status of the Scots pines was poor mainly due to the properties of the soil. It is also possible that a pollution load of external origin may have had a negative influence on the nutrient status of the trees by either accelerating their growth or by causing leaching of nutrients from the soil.



Figure 5. Scots pine afflicted by Scleroderris canker (*Ascocalyx abietina*) in the Naruskajärvi forest damage area in northeastern Salla in the summer of 1988. (Photo E. Tikkanen).

The sulphur concentration of the pine needles was relatively low in all areas investigated and it became less with increasing age. The reduction in sulphur concentration in the Salla area was, however, considerably less than in the other areas; Raitio et al. (1990a, 1990b) believe this could be partly due to air pollutants of external origin. Even the weather conditions of the growing season have a decisive effect on the nutrient concentrations of needles; after a cold and rainy growing season, the nutrient status of trees is below normal. It would seem that because of their poor nutrient status, the Scots pines in the Salla region have become susceptible to attacks by Scleroderris canker.

In the Sätsi pine stand, the average trend of radial growth has been a downward one since 1940 and since 1985 it has been especially so. In Lautakotaoja, on the other hand, the trend has been a rising one since 1960 (Raitio et al. 1990a, 1990b). These measurements, combined with the nutrient analyses made of the soil and the needles, indicate that if Scots pine stands located in sufficiently extreme climatic conditions and varying in site fertility and silvicultural treatment are selected for increment studies, then the effects of air pollutants can be assessed better than in climatically congenial conditions.

Needle, lichen and bryophyte studies

In addition to being examined in connection with the ILME project, the sulphur and heavy metal contents of needles, lichens and bryophytes in Lapland have also been the topics of other studies. The microscopic structure of needles has also been studied in order to gain knowledge of the load and damage to forests caused by air pollutants.

Research carried out by Huttunen (oral information) on the sulphur concentration of needles indicate that the concentration has risen in eastern Lapland and this rise cannot be explained solely by differences in the soil. The structural analyses made of needles collected from defoliated trees in Lapland indicate, according to Sutinen & Pesonen (1990), a resemblance to structural changes in cell structure caused by air pollutants. Even though the results of the analyses do not point to weather factors as being the primary causes of these damages, Sutinen & Pesonen (1990) do consider it to be obvious that so-called natural stress factors, such as frost, do have an effect on the intensity and the time that the outward symptoms of trees make themselves apparent.

Helle et al. (1990) have made a study of the changes in the amount of beard lichen (*Alectoria* sp.) in Lapland over the period 1978-88 and the results obtained by them indicate that the biomass of beard lichen has been reduced by 50 % in Sodankylä. Moreover, the maximum length of beard lichen in the tops of trees in 1988 was noticeably less than when inventoried in 1976. According to Helle et al. (1990), the most rational explanation for the reduced occurrence of beard lichen is sulphur dioxide, the deposition of which in southern Finland is estimated to be 0.4-1.0 g/m2/a. In southern Finland this amount has been observed to be sufficient to destroy arboreal lichen growing on trees.

As part of a joint-Nordic investigation, samples of *Hylocomium splendens* (Hedw.) B.S.G. and *Pleurozium schreberi* (Brid.) Mitt. bryophytes collected in 1985 were analysed in order to clarify the matter of heavy metal deposition in Finland (Rühling et al. 1987). The analyses were carried out to determine the presence of eighteen elements of which nine are heavy metal environmental pollutants. On the part of Lapland, the most alarming results were those concerning chromium,

nickel and copper. The highest chromium concentrations were recorded for samples collected from the southwestern corner of Lapland and the highest copper and nickel concentrations were obtained for bryophytes collected from northeastern Lapland.

Soil studies

Geological Survey of Finland has conducted a study delving into the acidification sensitivity of the soil in Lapland. Preliminary results have now been made available. According to Räisänen (1990), acidification of the mineral soil has become somewhat more pronounced in certain parts of northern Finland. This disturbance manifests itself mainly in the form of increased solubility of aluminium in geologically barren mineral soils. Fertile sites, on the other hand, showed no sign of leaching of nutrients associated with acidification. According to Räisänen (1990), the acidification process in the moraine soils of eastern Lapland around Salla, which are rich in weathering aluminium, has been accelerated by acid deposition more than has been the case in the fertile moraine soils of eastern Lapland (e.g. Pelkosenniemi, locality of Vuotos). As a phenomenon, the increased acidification observed in Lapland resembles the acidification process in the proximity of industrial plants.

Experimental research

Irrigation trial

A long-term experiment simulating the effects of acid deposition was begun in 1985 in northern Lapland at the Kevo Research Station of the University of Turku. Eighty sample plots were established, each being 5 x 5 m in size and with at least one naturally established Scots pine and one Silver birch growing on each plot. The sample plots were randomized in clusters into four treatments (with 20 repetitions of each treatment): dry controls (not treatment), irrigation water controls (irrigation during the growing season using sprinklers, three times a week, 5 mm at a time, water pH 6), irrigation using water with pH 4 (as above, but water pH 4), and irrigation using water with pH 3 (as above, but water pH 3). The acidity of the water in the last two treatments is achieved by mixing sulphuric and nitric acid into the irrigation water in the ratio of 2:1. Since 1989 one of the sample plots have been irrigated separately with solutions of nitric acid or sulphuric acid. A wide variety of different parameters related to trees and other vegetation have been measured annually from the sample plots. Particular attention has been directed at changes in the trees' resistance to insect attacks and the decomposition rate of litter (Neuvonen & Suomela 1987, Neuvonen et al. 1990).

Root system stress experiment

A root system stress experiment was established in the autumn of 1987 in FFRI's experimental area in Kivalo, situated in the rural commune of Rovaniemi, in order to examine the causes of the exceptionally hard needle loss which occurred in southern Lapland and Kainuu during the summer of 1987. A more detailed research plan was drawn up for the year 1988 on the basis of the experiences gained from the previous year.

This experiment comprises three separate experimental areas, two in Lapland (in Kivalo and Sodankylä) and the third in Hämeenkangas, in southwestern Finland. The purpose in locating the areas in this manner is to have them in different environments in terms of deposition. The experiment includes several stress treatments (Jalkanen et al. 1990a, 1990b).

In 1988-89, the root system of trees was stressed by freezing the soil deep down by watering it and keeping it clear of snow. The melting process was prolonged in the spring of 1989 by insulating the surface of the soil. The experiment involves examining the effect of root system stress on trees and testing of a hypothesis according to which the main reason for the 1987 needle loss was root damage caused by exceptional weather conditions in 1986-87. Methods used in soil research, plant physiology, biochemistry, plant ecology and the forest sciences are employed in this experiment (Jalkanen et al. 1990a, 1990b).

The studies delving into the microscopic structure of needles, which were begun in the summer of 1988, will be continued. These studies already showed damage to needles in the Kivalo root stress experiment and this damage was probably mainly connected to lessened availability of nutrients (Holopainen 1990). This may be due to the site's natural nutrient deficiency and root damage. The damage observed in chloroplasts, however, had characteristics resembling those caused by ozone. This is why Holopainen (1990) is of the opinion that the possibility of ozone being involved in the damage should not be ignored; at least it maybe a factor accompanying nutrient deficiency.

In conclusion

Until very recently, the nature of Lapland was considered to be among the purest in all of Europe. This is why the threat to forests imposed by air pollutants took us by surprise. Even though sulphur deposition in Lapland is estimated to be only about one tenth of the amount deposited in the most polluted parts of central Europe (and the Kola Peninsula), there are grounds for being concerned about the future of these forests; one must always keep in mind the fact that the climate of Lapland is a harsh one and the soil is often poor in nutrients. The envi-

ronmental changes caused by air pollutants can reduce organisms' tolerance with regard to natural climatic and edaphic stresses. This is why it is often difficult for researchers to find out the fundamental causes of damages.

Research in Lapland concerning forest damages associated with air pollutants is being intensified. FFRI has launched the Lapland Forest Damage Project with the objective of determining the effect on the forests of Lapland of pollution emissions from the Kola Peninsula. A noteworthy aspect of this project is that the experts from various Finnish research institutes and universities, who have been invited to participate in the project, are keen to collaborate in research requiring versatile expertise and capacity to use various research methods. Finno-Soviet cooperation in the environmental sciences has also been initiated for the first time through this project.

References

Helle, T., Norokorpi, Y. & Saastamoinen, O. 1990. Reduction of arboreal lichens in two spruce stands in northern Finland between 1976 and 1988. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17 - 19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2: 57-65.

Holopainen, T. 1990. Männyn neulasten rakennevauriot juuriston jäädytyskokeilla Hietaperänkankaalla. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 64-69.

Huttunen, S. 1989. Oral information. University of Oulu, Department of Botany, Finland.

Jalkanen, R., Airaksinen, K. & Niska, K. 1990a. Ecology of sudden mid-summer needle loss of Scots pine in northern Finland in 1987. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17 - 19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2: 169-170.

–, Airaksinen, K. & Niska, K. 1990b. Juurten jäädytyskokeet Hietaperänkankaalla. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 43-47.

Jukola-Sulonen, E.-L. 1989. Ilman epäpuhtaudet ja metsien terveys. In: Suomen Metsäyhdistys (publ.). Metsien terveys ja terveydenhoito. Metsätaloudellinen Aikakauskirja Oy, Helsinki. p. 6-9.

– & Kuusinen, M. 1989. Jäkälät kertovat ilman puhtaudesta. Tiedote. Metsäntutkimuslaitos. 2 p.

–, Mikkola, K., Nevalainen, S. & Yli-Kojola, H. 1987. Havupuiden elinvoimaisuus Suomessa vuosina 1985-1986. Metsäntutkimuslaitoksen tiedonantoja 256. 92 p.

–, Mikkola, K. & Salemaa, M. 1990. The vitality of conifers in Finland, 1986-1988. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer-Verlag, Berlin. p. 523-560.

Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). 1990. Acidification in Finland. Springer-Verlag, Berlin. 1237 p.

–, Kenttämies, K., Oikarinen, S. & Valli, R. 1987. Happamoituminen Suomessa. Maa- ja metsätalousministeriön Happamoitumisprojektin yleiskatsaus. Ympäristöministeriö. Ympäristön- ja luonnonsuojeluosasto. Sarja A 57. 97 p.

Kubin, E. 1990a. Sormipaisukarvejäkälän, Hypogymnia physodes, alkuainepitoisuudet Lapin ja Koillis-Suomen metsälautakuntien alueilla 1986. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 131-140.

– 1990b. A survey of element concentrations in the epiphytic lichen of Hypogymnia physodes in Finland in 1985-1986. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland, Springer Verlag, Berlin. p. 421-446.

Kuusinen, M., Mikkola, K. & Jukola-Sulonen, E.-L. 1990. Epiphytic lichens on conifers in the 1960's to 1980's in Finland. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin. p. 397-420.

Neuvonen, S. & Suomela, J. 1987. Keinotekoisen happosateen vaikutukset puiden tuholaisresistenssiin ja karikkeen hajoitukseen - kokemuksia Kevon kokeista. Aquilo Series Botanica 25 (I): 103-109.

–, Suomela, J., Haukioja, E., Lindgren, M. & Ruohomäki, K. 1990. Ecological effects of simulated acid rain in a subarctic area with low ambient sulphur deposition. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin. p. 477-493.

Räisänen, M.-L. 1990. Mineraalimaan happamoituminen eräillä koealoilla Itä-Lapissa. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 90-95.

Raitio, H. 1990. The foliar chemical composition of young pines (Pinus sylvestris L.) with or without decline. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin. p. 699-713.

– & Tikkanen, E. 1986. Nuorten mäntyjen kalsium- ja magnesiumtalouden häiriö kuivalla kankaalla. Metsäntutkimuslaitoksen tiedonantoja 225. 21 p.

– & Tikkanen, E. 1989. Nutritional disturbances of young pines in a dry heath forest. Plant and Soil 113: 229-235.

–, Tikkanen, E. & Nöjd, P. 1990a. Mäntyjen ravinnetalous Sallan puustovaurioalueella. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 23-31.

–, Tikkanen, E. & Nöjd, P. 1990b. The nutrient status of damaged Scots pine stands in northeastern Lapland. Manuscript. Finnish Forest Research Institute, Parkano Research Station.

Rühling, Å., Rasmussen, L., Pilegaard, K., Mäkinen, A. & Steinnes, E. 1987. Survey of atmospheric heavy metal deposition in Nordic countries in 1985. Nord 21. 44 p.

Sutinen, S. & Pesonen, R. 1990. Männyn ja kuusen neulasten soluvaurioista Lapissa. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 69-75.

Tikkanen, E. 1990. Root vitality and water status of young Scots pines (Pinus sylvestris) in a dry heath forest. Scandinavian Journal of Forest Research. In press.

– & Raitio, H. 1990a. On the occurrence and causes of needle loss observed in northern Finland in summer 1987. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17 - 19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2: 157-168.

– & Raitio, H. 1990b. Ilmastostressi ja ilmansaasteet - kesän 1987 neulaskadon syitä. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 34-42.

– & Raitio, H. 1990c. Nutrient stress in young Scots pines suffering from needle loss in a dry heath forest. Water, Air, and Soil Pollution. In press.

The Lapland Forest Damage Project: multidisciplinary cooperation in environmental sciences

Eero Tikkanen[1] & Kari Mikkola[2]
[1]Arctic Centre, University of Lapland
P.O.Box 122, SF-96101 Rovaniemi, Finland
[2]Finnish Forest Research Institute,
Rovaniemi Research Station
P.O.Box 16, SF-96301 Rovaniemi, Finland

Abstract

The Lapland Forest Damage Project was established in 1989 to intensify research into forest damage connected with air pollution in Finnish Lapland. The main objective of this 5-year project, coordinated by the Finnish Forest Research Institute and funded by the Ministry of Agriculture and Forestry, is to determine the effects of the Kola Peninsula pollutant emissions on Lapland's forests. The gradient study approach was selected for use in the project; i.e. sample plots along a pollution gradient have been established on lines, which originate from Nickel and Monchegorsk in the Kola Peninsula and go across Lapland. All field measurements and collection of material for laboratory analysis will be carried out on the plots or in close vicinity to them. The Lapland Forest Damage Project is a multidisciplinary cooperation project in which about 60 researchers from five Finnish research institutes and five universities are working together. In addition, concrete Finno-Soviet environmental cooperation in research has been initiated by the Lapland Forest Damage project; Russian scientists from the Kola Science Centre of the U.S.S.R's Academy of Sciences are working on the project, too.

Background

Research in Finnish Lapland on air pollutants and the damage they cause to forests is fragmented and just getting off the ground. This situation emerges from a long-established idea that the natural environment in Lapland was one of the least polluted in Europe. The massive pollution around big smelters in the Kola Peninsula revealed at the end of 1987, combined with serious needle loss in conifers, canker fungus of pines and high metal contents in some lichens and mosses (see Tikkanen 1991) prompted people to wonder what was happening in the forests, what the future would bring and what was behind the dam-

age and change observed. The concern over the state of the natural environment of Lapland was increased further when the first report on the state of the environment in the U.S.S.R. was published in 1989 (Report on the state of the environment in the USSR 1988). The most recent findings indicate that there are relatively few species of lichen in the eastern part of Lapland around Inari. Sensitive species have diminished, tolerant ones predominate. Varying interpretations and assumptions have divided researchers into different groups and schools of thought. Within a short time, the causes and consequences of forest damage in Lapland have become an issue of national importance.

To intensify research in Lapland into forest damage connected with air pollutants, the Finnish Forest Research Institute (FFRI) established the Lapland Forest Damage Project in May of 1989. The establishing of the project was influenced by the signs of damage observed in the forests of Lapland and by other changes in the environment as well as information made available during the past years on the pollutant emissions from the Kola Peninsula. The Lapland Forest Damage Project is part of FFRI's "Research programme for forest health."

The objectives

The main objective in the Lapland Forest Damage Project is to determine the effects of the Kola pollutant emissions on the vitality and health of the forests of Lapland. The second objective is to further the research dealing with the boreal environment. Third, the intention is to compare and categorise vegetation damage caused by air pollutants in the Kola region and in Finnish Lapland and to define the damage areas in Lapland. Research data is required, for instance, when deciding on the restrictions to be imposed on emission levels. Knowledge of the basic processes of the boreal environment, on the other hand, is needed to determine the environmental changes caused by human activity and their consequences when attempting to solve the ensuing problems.

Sample plots on gradient lines

A series of permanent sample plots has been established by FFRI for the project. These have been set out as clusters of three or four plots per sampled forest stand, a sample point, along three lines radiating SW, W and NW from Monchegorsk and another four lines from Nickel in the Kola Peninsula (Fig. 1). Any sample plots of the 7th and the 8th National Forest Inventories (VMI 7 and VMI 8) and the associated increment sample plots (INKA) and any other research plots which happen to be located along these lines have been used if they have fulfilled the requirements of this project. In the proximity of the frontier the investiga-



Figure 1. The Lapland Forest Damage Project sample plot lines.

tion points have been spaced out at intervals of 4 km, but as the distance from the border grows, the interval grows to 8, 16 and 32 km. The gradient line SW from Monchegorsk to the northern coastline of the Gulf of Bothnia differs from the others; the interval between investigation points is shortened at the SW end of the line in order to determine the effects of the local industrial emissions.

The prerequisites for establishing sample plots have been that each plot must be located in Scots pine dominated heath forests susceptible to acidification, the age of the Scots pines must be within the range 80-200 years and the topography must be flat or with an eastward slope. The majority of the sample plots have been established on state land.

The investigation points have been located by means of a sampling process using maps provided by the Finnish National Board of Forestry and private forest organizations. The investigation points were established at certain intervals in such stands nearest to the line as fulfilled the above project conditions. The sample plots were marked permanently. At each investigation point, the sample plots were located at random in various directions 40 m from the centre of the stand. Each sample plot is 300 m^2 in area. Altogether 430 sample plots have been established at 121 points along the gradient lines, from which 14 are so-called intensive sample plots (Fig. 2). On these plots the research work and sampling is more extensive and thorough (see Derome et al. 1991). The number of investigation points on a gradient line will vary from 20 to 25 depending on the length of the line. Various kinds of measurements will be carried out on the sample plots and some measurements and sampling will be conducted outside the sample plots. All material destined for laboratory analyses will be collected outside the sample plots.

Cooperation between research institutes and universities

The Lapland Forest Damage Project is a multidisciplinary diagnostic research project. FFRI has invited a number of leading Finnish researchers from various research institutes and universities to participate in this project which presupposes the utilisation of versatile expertise and research methods. In addition to researchers from FFRI, the current list of participating institutes includes the Arctic Centre, the Finnish Meteorological Institute, the Geological Survey of Finland, the National Board of Waters and the Environment and the universities of Helsinki, Joensuu, Kuopio, Oulu and Turku. Altogether, the Lapland Forest Damage Project consists of 14 subprojects led by researchers employed by the participating research institutes and universities (Appendix). About 60 scientists are engaged in the project.

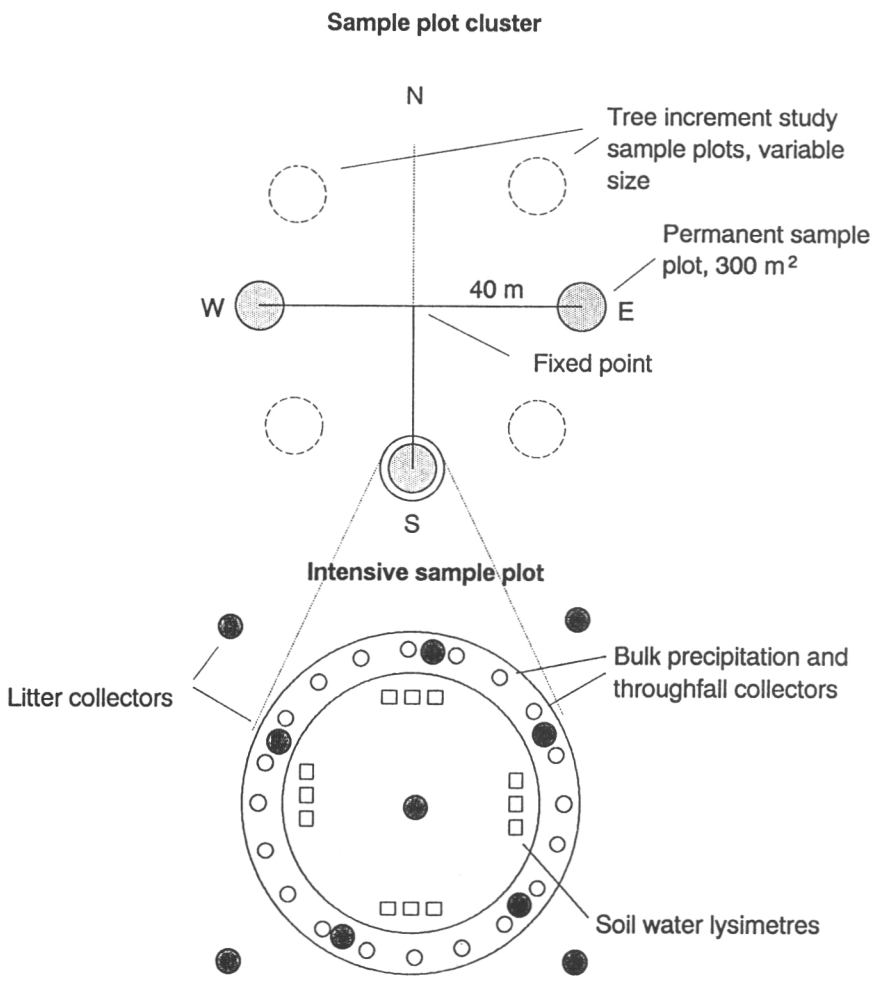


Figure 2. Sample plot layout in the Lapland Forest Damage Project.

Division of tasks

The podzol, stand throughfall, percolation water and soil studies conducted on the sample plots will be, in part, the responsibility solely of FFRI and in part FFRI will share this responsibility with the Geological Survey of Finland and the National Board of Waters and the Environment. FFRI will attend to tree increment studies. Research dealing with forest pathology, forest ecology, soil microbiology, plant physiology and plant ecology will be carried out by universities and research institutes both on their own and in collaboration with one another. The material to be studied will include needles from trees, litter, roots of trees, lichen and bryophytes. The methods used will mainly be those used in biochemistry, botany, environmental and forest sciences, geology, limnology, meteorology and zoology. The National Board of Waters and the Environment will study the water systems within the forest ecosystems and the Finnish Meteorological Institute will carry the main responsibility for measurements related to air quality. In addition to the above, the Lapland Forest Damage Project will include experimental research, and models describing the functioning of the forest ecosystem will be produced. All data will be gathered in a central data base at FFRI's Rovaniemi Research Station.

Planning and coordination

The Lapland Forest Damage Project is coordinated by FFRI's Rovaniemi Research Station. The first coordinator of the project was researcher Eero Tikkanen from 10 May 1989 to 31 August 1990. At the moment, the project is coordinated by Heikki Kauhanen who is employed as a researcher at FFRI's Rovaniemi Research Station. The coordinator acts, for example, as the chairman of the planning group and as the secretary of the leading group.

The planning group of the Lapland Forest Damage Project was chosen at the founding meeting of the project on 10 May 1989. During the first 15 months of the project, the planning group held six meetings. The group has made an overall research plan of the project including, for example, discussions about the gradient study method, objectives and funding of the project, division of tasks, Finno-Soviet cooperation and research methodology and plans of the subprojects.

The planning group has 17 members. These members are:

- researcher John Derome, FFRI, Department of Soil Science;
- Prof. Pertti Hari, University of Helsinki, Department of Silviculture;
- Prof. Erkki Haukioja, University of Turku, Department of Biology;

- Assist. Prof. Satu Huttunen, University of Oulu, Department of Botany;
- researcher Risto Jalkanen, FFRI, Department of Forest Protection;
- senior scientist Eeva-Liisa Jukola-Sulonen, FFRI, Department of Silviculture;
- researcher Sirkka Juntto, the Finnish Meteorological Institute;
- Prof. Seppo Kellomäki, University of Joensuu, Department of Silviculture;
- director Kari Kinnunen, the National Board of Waters and the Environment, Water and Environment District Office of Lapland;
- geochemist Matti Kontio, Geological Survey of Finland, Regional District Office of North Finland;
- researcher Seppo Neuvonen, University of Turku, Department of Biology;
- researcher Pekka Nöjd, FFRI, Department of Forest Inventory and Yield;
- researcher Jari Oksanen, University of Kuopio, Department of Environmental Sciences;
- researcher Hannu Raitio, FFRI, Department of Silviculture;
- researcher Aulis Ritari, FFRI, Department of Soil Science;
- director Martti Varmola, FFRI's Rovaniemi Research Station and
- researcher Henry Väre, University of Oulu, Department of Botany.

The leading group of the Lapland Forest Damage Project was appointed by the Ministry of Agriculture and Forestry in February 1990. The group consists of five members. The chairman is senior scientist Pekka Kauppi, FFRI, and the members Assist. Prof. Satu Huttunen, Department of Botany, University of Oulu, Prof. Veijo Ilmavirta, Arctic Centre, University of Lapland, secretary general Veikko Marttila, Ministry of Agriculture and Forestry and director Martti Varmola, FFRI's Rovaniemi Research Station.

The leading group met three times during the first 15 months of the project. The most important task of the group was to make a proposal to the Ministry of Agriculture and Forestry concerning the funding of the subprojects in 1990.

Finno-Soviet cooperation

An agreement concerning scientific cooperation has been made with researchers employed in Apatity in the Kola Science Centre of the U.S.S.R.'s Academy of Sciences. During the summer of 1990, the Soviets established 3 intensive sample plots and in autumn 4 more with the help of Finnish field workers. The investigation points lie between the border and the emission sources (Fig. 1). The work will continue in summer 1991. Soviet researchers will be involved in four subprojects.

In accordance with the agreement, material collected from the sample plots will be made available on both sides of the frontier. Research methodology will be made uniform; an instance of this is the analysis of plant and soil samples collected during the summer and autumn of 1989 from the Kola region. This material has been analysed during the winter of 1989-90 at the Kola Science Centre and at research laboratories in Finland (see Raitio 1991).

Uniformity in research methods will make it easier to compare and categorise the damage to vegetation caused by air pollutants in the Kola region and in Lapland. This Finno-Soviet cooperation in the field of environmental science, and the Lapland Forest Damage Project as such, have aroused the interest of scientists abroad as well.

Schedule and funding

FFRI commenced sample plots in early June 1989 starting from the Finno-Soviet border. The sample plot line west from Monchegorsk was completed as a pilot study. In addition, the first investigation points on three other lines were established in the proximity of the border. During the summer of 1989, FFRI's Department of Soil Science began to conduct stand throughfall and percolation water studies on some of the sample plots and collected soil samples from all plots for the purpose of searching signs of pollution-induced changes. FFRI's Department of Forest Inventory and Yield took measurements from the sample plots in the autumn of 1989.

The establishment of sample plots continued in spring 1990. By August, all sample plots in Finnish Lapland had been established. Field measurements were made and material for laboratory analysis was collected during summer and autumn 1990. Investigations are continuing in all subprojects, except number 2: "Meteorological recordings," because the Finnish Meteorological Institute acts as an expert unit and does not itself conduct research, and number 13: "Precipitation and acidification of water systems", where investigations will begin later.

The Lapland Forest Damage Project is planned to be a 5-year project starting in 1990 and ending in 1994. Preliminary work was carried out in 1989; sample plot establishing procedure was practised, research plans were drawn up, contacts were made with Soviet researchers, etc. The Ministry of Agriculture and Forestry allocated a sum of FIM 100 000 as a joint research appropriation for the purpose of commencing the project in 1989. In 1990 the sum was FIM 3.0 m which was allocated for the subprojects in accordance with the proposal of the leading group. The implementation of the Lapland Forest Damage Project requires about FIM 4.0 m annually from 1991 onwards.

Information and reporting

During the winter of each year the project organizers will arrange a joint information meeting during which the leaders of the various subprojects and researchers will have an opportunity to tell about the results of their work from the previous field period and of their research plans concerning the coming field period. On completion of each study, the researchers will publish the findings of their work and information on these will be provided separately. An interim project report is to be published at the end of 1992 to provide more information about the critical load of the northern forests. A final project report will be published when the project is completed. Research results will also be presented in conjunction with seminars and symposiums.

Environmental cooperation in technology

Environmental cooperation in the field of technology is also beginning between Finland, Norway and the Kola region. Finnish and Norwegian technology for nickel smelting will be delivered to the Kola Peninsula. The upgrading of the nickel smelters in Monchegorsk and Nickel will last four years from 1991 to 1994 at a cost of FIM 3000 m. Sulphur dioxide and heavy metal emissions by the smelters will diminish by about 80 % after the upgrading. At the moment, sulphur dioxide emission in the Kola Peninsula is approxim. 700 000 tons per year.

In conclusion

The Lapland Forest Damage Project is the largest joint project in Finland so far dealing with the effects of air pollutants on forests. The cornerstones of the project are cooperation and multidisciplinarity. Researchers from five universities and five research institutes are working together investigating the effects of Kola pollutant emissions on Lapland's forests. The disciplines represented are biochemistry, botany, environmental and forest sciences, geology, limnology, meteorology and zoology. In addition to Finnish cooperation, concrete Finno-Soviet environmental cooperation in research has been initiated for the first time by the Lapland Forest Damage Project.

Concrete environmental cooperation also in the field of technology between Finland, Norway and the Kola area has started. This kind of international environmental cooperation in research and technology is necessary and it will increase between scientists, politicians, state and public authorities, public organizations etc. in the arctic and subarctic regions.

References

Derome, J., Niska, K., Lindroos, A-J. & Välikangas, P. 1991. Ion-balance monitoring plots and bulk deposition in Lapland during July 1989 - June 1990. In: Tikkanen, E. & Varmola, M. (eds.). Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. A seminar in Kuusamo, Finland, 25-26 May 1990. The report of papers. Metsäntutkimuslaitoksen tiedonantoja 373. p. 49-76.

Raitio, H. 1991. A comparison of element analyses of pine needle samples. In: Tikkanen, E. & Varmola, M. (eds.). Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. A seminar in Kuusamo, Finland, 25-26 May 1990. The report of papers. Metsäntutkimuslaitoksen tiedonantoja 373. p. 77-80.

Report on the state of the environment in the USSR 1988. The USSR State Committee for the Protection of Nature. Moscow 1989. 184 p.

Tikkanen, E. 1991. A review of research into forest damage connected with air pollution in Finnish Lapland. In: Tikkanen, E. & Varmola, M. (eds.). Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. A seminar in Kuusamo, Finland, 25-26 May 1990. The report of papers. Metsäntutkimuslaitoksen tiedonantoja 373. p. 7-19.

The subprojects and respective project leaders, and the subproject objectives

1. Coordination of the Lapland Forest Damage Project: Heikki Kauhanen, MSc, Finnish Forest Research Institute, Rovaniemi Research Station, P.O.Box 16, 96301 Rovaniemi, ph. +358-60-15721

Coordination of the Lapland Forest Damage Project is in the hands of the coordination group stationed at the Rovaniemi Research Station of the Finnish Forest Research Institute (FFRI). The group is lead by project coordinator Heikki Kauhanen. The coordination group is responsible for e.g. establishing the sample plots along the gradient lines, organizing the collection of samples for the various subprojects, and matters related to the construction of a central data base for the project. Coordination of the subprojects and Finno-Soviet research collaboration with the Kola Science Centre of the U.S.S.R.'s Academy of Sciences, are also tasks allocated to the group.

2. Meteorological data: Sirkka Juntto, MSc, Finnish Meteorological Institute, P.O.Box 510, 00811 Helsinki, ph. +358-0-75811

The Department of Air Quality, FMI, acts as an advisory body, cooperating with all the organisations involved in the project.

3. Roots, mycorrhiza and soil microbiology: Henry Väre, PhLic, University of Oulu, Department of Botany, Linnanmaa, 90570 Oulu, ph. +358-81-353239

The objective is to determine the effects of emissions from the Kola Peninsula on the condition of Scots pine mycorrhizas, and the biological activity of soil in Lapland. The cooperating units are the Universities of Oulu and Kuopio, the Arctic Centre and the Rovaniemi Research Station, FFRI.

4. Lichens and bryophyte studies: Toini Holopainen, PhD, University of Kuopio, Department of Environmental Sciences, P.O.Box 6, 70211 Kuopio, ph. +358-71-163186

The objective is to gain an overall picture of the extent and biological effects of air pollutants in Lapland using lichens and bryophytes as biological indicators, and to clarify whether these pollutants have any effect on the productivity of reindeer pastures. The cooperating units are the Universities of Kuopio and Oulu, and the Rovaniemi and Muhos Research Stations, FFRI.

5. Remote sensing: Eero Mattila, DSc.For., Finnish Forest Research Institute, Rovaniemi Research Station, P.O.Box 16, 96301 Rovaniemi, ph. +358-60-15721

The objectives are to determine the degree of forest damage that can be mapped with the help of present-day satellite imagery, to consider the practicality of developing a forest damage monitoring system based on satellite imagery, and to produce an up-to-date map based on satellite imagery of the forest damage situation in eastern Lapland and the Kola Peninsula. The cooperating units are the Rovaniemi Research Station and Department of Forest Inventory and Yield, FFRI, the University of Joensuu and the National Board of Surveying.

6. Manipulative studies: Seppo Neuvonen, PhD, University of Turku, Department of Biology, 20500 Turku, ph. +358-21-6335780

This research comprises two sectors:

6.1. The effects of sulphuric acid and heavy metal treatments on the resistance of Scots pine to attack by insects and Scleroderris canker (*Ascocalyx abietina*) are studied by means of bioassays. The cooperating units are the University of Turku, and the Rovaniemi Research Station, FFRI.

6.2. The effect of needle removal on the growth of Scots pine: young pines are artificially defoliated in western and eastern Lapland, and their growth and recovery followed.

7. Soil research: John Derome, LicSc, Finnish Forest Research Institute, Department of Soil Science, P.O.Box 18, 01301 Vantaa, ph. +358-0-85705406

The cooperating units are the Department of Soil Science, FFRI, and the Regional Office for North Finland, Geological Survey of Finland.

This research comprises two sectors:

7.1. Effect of industrial pollution on soil acidification in eastern Lapland. Department of Soil Science, FFRI. The objective is to clarify the effects of the deposition of pollutants on the chemical properties (especially soil fertility and acidification, and the occurrence of heavy metals) of forest soils in eastern Lapland from the point of view of the maintenance of conditions suitable for tree growth.

7.2. Sensitivity to soil acidification. Regional Office for North Finland, Geological Survey of Finland. Regional information about nutrient and heavy element contents and the sensitivity to acidification of till and sorted mineral soils is being collated. Other geological soil data will be utilized. The results will be utilized for interpretation purposes and in modelling work by the other subprojects.

8. Modelling: Prof. Pertti Hari, University of Helsinki, Department of Silviculture, Unioninkatu 40 B, 00170 Helsinki, ph. +358-0-1911

The objective is to use the material collected in Lapland for developing models describing forest growth and its vitality, and to formulate development scenarios on the basis of alternative emission limitations. The cooperating units are the University of Helsinki and the Department of Forest Inventory and Yield, FFRI.

9. Forest pathology: Risto Jalkanen, DSc.For., Finnish Forest Research Institute, Rovaniemi Research Station, P.O.Box 16, 96301 Rovaniemi, ph. +358-60-15721

This research comprises two sectors:

9.1. Scleroderris canker in eastern Lapland. The occurrence, history and factors affecting the abundance of Scleroderris canker caused by *Ascocalyx abietina* in Salla, eastern Lapland, and surrounding areas including the Soviet Union, are being studied.

9.2. Biochemical resistance of Scots pine to *Ascocalyx abietina*. The objective is to determine whether pollutants alter the biochemical properties of Scots pine shoots and affect the tree's susceptibility to Scleroderris canker infection.

10. Element composition of Scots pine needles: Hannu Raitio, PhD, Finnish Forest Research Institute, Parkano Research Station, 39700 Parkano, ph. +358-33-82912

The objective is to determine the nutrient status of Scots pines along the sample plot lines, and to make a survey of the occurrence of air pollutants in pine needles. The cooperating units are the Parkano and Suonenjoki Research Stations, FFRI, the Arctic Centre and the University of Oulu.

11. Tree vitality, ground vegetation and forest litter: Eeva-Liisa Jukola-Sulonen, PhD, Finnish Forest Research Institute, Department of Silviculture, P.O.Box 18, 01301 Vantaa, ph. +358-0-85705568

The objective is to determine whether the distance to the source of emissions is reflected in forest vitality, the ground vegetation and the composition of forest litter, and whether changes have occurred in these parameters during the past few decades. The cooperating units are the Department of Silviculture and the Rovaniemi Research Station, FFRI.

12. Tree growth: Pekka Nöjd, MSc, Finnish Forest Research Institute, Department of Forest Inventory and Yield, Unioninkatu 40 A, 00170 Helsinki, ph. +358-0-85705325

The objective is to determine and model the increment development of forests subjected to atmospheric pollution. The cooperating units are the Department of Forest Inventory and Yield, FFRI, and the University of Helsinki.

13. Acidification of water systems: Kari Kinnunen, DSc.For., National Board of Waters and Environment, Water and the Environment District Office of Lapland, P.O.Box 8060, 96101 Rovaniemi, ph. +358-60-2941

A survey of water-system acidification will be carried out in lakes within the watersheds of the sample plots.

14. Stress and damage symptoms: Satu Huttunen, Assist. Prof., University of Oulu, Department of Botany, Linnanmaa, 90570 Oulu, ph. +358-81-353216

This research comprises three sectors:

14.1. Stress and damage symptom studies. The objective is to identify the stress symptoms caused by air pollutants. The cooperating units are the Universities of Oulu and Kuopio, and the Arctic Centre.

14.2. Freezing stress resistance and air pollutants. The objective is to identify the effect of air pollutants on seasonal changes in freezing stress resistance of adult pine trees and transplanted seedlings of different provenances. The biochemical mechanisms involved in freezing injury will be studied at the membrane level. Digital image processing will be used to estimate the biomass of the damaged needles. The cooperating units are the Rovaniemi Research Station, FFRI, and the Regional Office for North Finland, Geological Survey of Finland.

14.3. The effects of air pollutants and other abiotic and biotic factors on trees in Finnish Lapland. The study will be carried out at the light microscope and transmission electronmicroscope levels. The conclusions will be based on known cell and cellular symptoms induced by different stress factors, as well as on other information available from the study areas. The cooperation units of this sector are the Suonenjoki and Parkano Research Stations, FFRI.

Evaluation of the research plan of the Lapland Forest Damage Project

John A. Witter
The University of Michigan
School of Natural Resources
Ann Arbor, MI 48109-1115, U.S.A.

Introduction

The objective of this presentation is to evaluate the overall research plan of the Lapland Forest Damage Project. My evaluation is based on: (1) careful review of the research plan and reading research articles on air pollution in Lapland, (2) four days of visiting with investigators at various field sites, (3) two days of visiting with investigators at the Rovaniemi Research Station and at the Finnish Forest Research Institute at Vantaa, and (4) participating in the Lapland Forest Project Damage Seminar at the Oulanka Biological Station of the University of Oulu.

It is important that Finnish researchers and administrators are familiar with my training and credentials. I have B.S. and M.S. degrees in forest management and entomology from Virginia Polytechnic Institute. I received my PhD from the University of Minnesota; my training was in forest entomology with a major in entomology and minor in forest biology. I have been conducting research on forest insects for over 25 years and have published over 140 papers. My research emphases have been on forest/insect interactions, forest pest management, and the effects of multiple interactions on forests. Specifically, I have concentrated my research efforts on the effects of lepidopterous defoliators (e.g., forest tent caterpillar, spruce budworm, and gypsy moth) on various forest ecosystems. During the last five years, I have been conducting research on the effects on air pollutants on the health of forests in the Great Lakes Region, USA. I am project coordinator of the Michigan Air Pollution Gradient Study. I have been a professor of forestry at The University of Michigan, School of Natural Resources since 1972. I also am Adjunct Professor of Forestry at Michigan Technological University.

The review is divided into the following sections:

(1) Organization/coordination of the Lapland Forest Damage Project,
(2) Objectives of the Lapland Forest Damage Project,
(3) Multidisciplinary research,
(4) Cooperative research between Finnish Forest Research Institute and Finnish universities,
(5) Cooperative research between countries,

(6) Gradient approach,
(7) Sampling method used in the Lapland Forest Damage Project,
(8) Monitoring changes in temperature and precipitation along gradient,
(9) Growth of Scots pine saplings along the pollution gradients,
(10) Additional information to obtain at the intensive study site locations,
(11) Innovative studies,
(12) Integrity of sites,
(13) Data quality and control, and
(14) Public relations and technology transfer.

Organization/Coordination of the Lapland Forest Damage Project

The overall organization of the project is very good. The coordinator of the project, Eero Tikkanen, is extremely well-trained, has a broad background in biology and ecology, and has excellent organization and communication skills. I was extremely impressed with Eero's contacts with the press and legislators in Finland. He also has excellent rapport with the researchers from both universities and the Finnish Forest Research Institute. The use of the Leading Group and Planning Group to determine priorities in developing overall policy and to approve the overall research plan is an extremely wise decision. It is important that the various participating research organizations have a forum where overall project plans and policies can be discussed, approved, and/or modified on a regular basis.

The success of this project will depend to a large degree on continued outstanding organization and communication skills that has been provided to date by Eero Tikkanen. The coordinator's position is an extremely difficult one because he is dealing with numerous disciplines (e.g., botany, chemistry, ecology, forestry, geology, physiology, remote sensing, soils), many different organizations (i.e., 5 research institutes and 5 universities), and several different countries. There is never enough time or money to complete all tasks. Sometime a phone call is not returned or a letter goes unanswered. Individual researchers are not always happy with the priorities set by the group making administrative decisions. The message is for all participants in the Lapland Forest Damage Project to have patience.

The project is of sufficient size that the coordinator needs additional help if all tasks are to be completed in a timely manner. This is already starting to happen. Martti Varmola has played a major role in increasing cooperation between Finland and the Soviet Union. Kari Mikkola has become heavily involved with sampling methodology, site selection, and data management. Marja-Liisa Sutinen is now helping with numerous technical details relating to several subprojects. I encourage the

project coordinator to continue to delegate responsibility whenever possible and to find a small group of individuals (about five persons) who understand the entire project, who can help share responsibilities, and who can represent the overall project at various functions. It is important to have university personnel share in this function as well and not have this group completely composed of scientists from the Finnish Forest Research Institute.

Objectives of the Lapland Forest Damage Project

In my opinion, the three objectives of the project are reasonably clear. They are: (1) to determine the effects of pollutant emissions from the Kola Peninsula on the productivity and health of Lapland forests, (2) to increase the knowledge base on the biology and ecology of northern boreal forests so that we can better understand interactions and interactive effects that are occurring in these forests, and (3) to categorize and compare the damage to plants caused by air-borne pollutants in the Kola Region and in Lapland and to determine the extent of damage in Lapland (Tikkanen & Mikkola 1991). My only recommendation on the objectives is to make it perfectly clear to the public and the politicians that the study is not a survey of all forested landscapes in Finland. Instead, it is concentrating on the Scots pine heath forests most susceptible to acidification (Tikkanen & Raitio 1990, Kinnunen & Varmola 1990). These are the dry and sub-dry heath forests on east-facing slopes. The decision to concentrate on the most susceptible forested ecosystem was correct since it is impossible to conduct any kind of serious scientific research on all forested landscapes in Lapland.

Multidisciplinary Research

There are many abiotic and biotic factors that can cause stress, injury, or mortality to forest trees and stands. Temperature extremes, pollutants, wind, high water tables, fire, drought, and mechanical damage are common examples of abiotic factors that have been associated with trees and forests under stress (Coulson & Witter 1984, Smith 1985, Sinclair et al. 1987, Skelly et al. 1987, Krahl-Urban et al. 1988, Millers et al. 1989). Insects, diseases, hares, reindeer, and moose are common examples of biotic agents that can damage trees and cause stress at the tree and ecosystem level (Spurr & Barnes 1980, Heliövaara & Väisänen 1988, Waring & Schlesinger 1985, Tikkanen & Raitio 1990, Kinnunen & Varmola 1990, Kullman 1990). Agents causing stress can act alone, in combination, or in a stepwise pattern. The interactions of several abiotic and biotic factors may cause additional stress and ultimately lead to tree decline, growth reduction, tree mortality, stand mortality, and

changes in stand composition (Houston 1981, Millers et al. 1989, Mattson & Witter 1990). Deposition of large amounts of air pollutants from industrial point sources has occurred on several continents for over one hundred years (Krahl-Urban et al. 1988). High dosages of sulfur dioxide, fluoride, or heavy metals from local point sources such as smelters or aluminum plants have caused documented destruction of nearby forests (Kriuchkov 1990, Miller & McBride 1975, Hutchinson & Whitby 1976, Freedman & Hutchinson 1980, Smith 1985, Heck et al. 1986). These areas nearest to the emission source are often referred to as "biological deserts." Common impacts of acute pollution exposure include mortality of trees and stands; changes in stand composition, structure, and genetic diversity; ecosystem simplification; nutrient loss and soil erosion; and alteration of microclimates and hydrologic patterns (Smith 1981, 1985).

There is very little information available for forested stands in Finland or anywhere in the world that quantifies the interactive effects of pollutants, other abiotic factors, and biotic stresses on forests over large areas replicated in time and space. Studies such as the Lapland Forest Damage Project (Tikkanen & Mikkola 1991), Michigan Gradient Study (Witter 1988a,b, 1989, 1990) Pennsylvania Gradient Study (Davis & Skelly 1989), and the Ohio Corridor Study (Loucks 1990) are absolutely necessary if we are to (1) examine ecological changes over large areas, (2) understand the factors regulating changes, and (3) make decisions on allowable emission levels for various pollutants. A body of knowledge is now being developed that is helping us to better understand biological and ecological processes (Waring & Schlesinger 1985, Johnson & Van Hook 1989). These kinds of detailed studies on ecosystem processes and the affects of multiple stresses on ecosystems can only be conducted by multidisciplinary research teams.

Cooperative Research Between Finnish Forest Research Institute and Finnish Universities

Research institutes and universities must work together on these multidisciplinary kinds of projects. Old barriers must be broken at both the university and research institute levels if these multidisciplinary projects are to be successful. Each group has different types of strengths. In Finland, the research institutes have permanent facilities located throughout Finland, are familiar with all parts of country, have technicians and research assistants that know the local countryside, and have various support services available throughout Finland. They also have a well established pool of research scientists that have studied almost all areas of applied forestry. The universities in Finland are known throughout the world. Their professors and graduate students are very knowledge and well trained in basic biology and ecology. They are famil-

iar with current literature and have a strong background in biological and ecological theory, a long history of conducting basic research, and a pool of bright young students eager to work on complex environmental problems. There are several factors that must be improved upon if universities and research institutes are to work successfully together to solve complex environmental problems. They are:

(1) universities must encourage professors and their students to work on applied problems,
(2) universities must breakdown the barrier that applied research can not be "leading edge" work,
(3) universities and research institutes must do a better job of evaluating "quality" research and not just count publications,
(4) universities and research institutes must do a better job of evaluating the efforts of scientists who publish multiple-authored manuscripts,
(5) universities and research institutes must be more tolerant of different viewpoints and different approaches, and
(6) universities and research institutes must break down the barriers so that it is easy for researchers to work with colleagues in different departments, colleges, universities, and agencies.

There are certain risks that are taken when scientists start working on multidisciplinary studies. Administrators in universities and research institutes must encourage and support researchers who work on multidisciplinary studies. I applaud the efforts of the Finnish Forest Research Institute that have been made to date in allowing this multidisciplinary project to become a reality. I am very encouraged that four other Finnish research institutes and five universities have become heavily involved in this project. However, this kind of cooperation is not easy because of the number of individuals and agencies involved, different personalities of the investigators, institutional barriers, and different methodologies and thought-processes used by different disciplines. Therefore, each of the participants will have to give considerable encouragement from time to time to other colleagues who are working on this project.

Cooperative Research Between Countries

For this project to be successful, there must be very close cooperation between Finland and the Soviet Union. Collaboration between scientists from both countries is essential for extension of the sample lines from the Finno-Soviet borders to the emission source. The efforts of Martti Varmola and others in developing the research collaboration between the two countries is starting to produce good results. Scientists from

both countries have visited in each other's country. Cooperative agreements concerning scientific collaboration has been signed by both countries. Areas of cooperation agreed on to date include:

(1) Kola Science Centre will establish 25 research locations along the pollution gradient line in 1990 using sampling methods identical to those used in the Lapland Forest Damage Project,
(2) Soviet scientists will visit Finnish Forest Research Institute during summer 1990 to learn how to establish research sites,
(3) Finnish scientists will visit Kola Science Centre during summer 1990,
(4) Finnish research institutes and universities will analyze part of the plant and soil samples collected in the Kola area,
(5) the Lapland Forest Damage Project will provide some of the supplies necessary to establish the sample plots, and
(6) Soviet scientists will be involved in the following subprojects: lichens and bryophyte studies, element composition of Scots pine needles, soil research and tree vitality, ground vegetation and forest litter (Varmola 1990).

Continued cooperation for the next five years between the two countries is essential for this project to be extremely successful. I have been communicating and cooperating with Russian forest entomologists since 1981. I am willing to help in any way necessary to improve the cooperative studies between scientists from Finland and the Soviet Union.

I also am encouraged about the cooperative research ventures being discussed between Finland and Norway and research seminars on pollution issues that are being planned by all of the Scandinavian countries.

Gradient Approach

There are numerous ways to investigate the effects of an environmental stress factor such as sulphate or nickel on plants and ecosystems. Approaches that can be used include: (1) dose-response studies using seedlings in greenhouses, open-top chambers, or experimental plots (Shriner et al. 1990, Jager et al. 1988), (2) branch chamber studies where a certain dosage of a pollutant is administered to branches on mature trees (Amundson et al. 1986), (3) ecosystem-level studies where a known amount of a pollutant is released onto a portion of a forest, and (4) gradient studies (Reed et al. 1988).

A dosage-response study on one or two year old Scots pine is a nice design because one can look at cause-effect relationships, but the major weakness of this approach is the scale problems (Morris 1987); it is

difficult to try to determine what results on one or two year old seedlings means when the mature Scots pine trees are 200 years old or older. Branch chamber studies get around the problem of working with seedlings, but you still have the problem of scaling from a branch on a mature tree to the entire tree and then to the ecosystem. Ideally, to investigate an environmental stress such as air pollution, I would conduct a controlled experiment at the ecosystem level where different levels of the factor can be applied to homogenous experimental units. This is impossible to achieve under field conditions. First, only a limited amount of homogeneity can be achieved in experimental ecosystems. Second, it is impossible to apply different levels of pollutants in a realistic fashion on large plots in mature forests. The timing and methods of treatment in such experimental field studies are inevitably artificial and can only mimic actual field situations to a limited extent.

Therefore, I feel that the only reasonable method to study the effects of pollutants on forests is to establish plots along a pollution gradient with historically different deposition levels. One then can study impact along the gradient and also conduct various experimental studies on plots along the gradient.

I highly support the gradient approach that was selected for use in the Lapland Forest Damage Project. However, since this is not truly a controlled experiment, it is necessary to monitor environmental and biotic factors such as temperature, moisture, and insect defoliation which can affect certain ecosystem processes such as growth or nutrient cycling. You need to account, in some way, at least for a subset of locations along the gradient, for annual and site differences which are not directly attributed to pollutants.

Sampling Method Used in the Lapland Forest Damage Project

I am in general agreement with the sampling method (Tikkanen & Mikkola 1991) being used in this study. The use of a pollution source-centered gradient line with sample plot clusters placed on the lines according to approximately quadratic rule (distance between cluster differences in km follow order of 4-8-16-32) is a sound and appropriate method for this study. I am not concerned about the fact that all stands are not located exactly on the gradient line. It is not always possible to locate appropriate Scots pine stands at a specific point along the gradient line because the landscape is composed of different forest ecosystems and some areas are not accessible due to lack of roads. The most important factors is to locate homogenous forest stands that meet the sampling criteria (Turner 1987, O'Neill et al. 1986, Barnes et al. 1982). In other words, at a sampling location, select the nearest Scots pine stand along the gradient line that fulfills the sampling criteria.

I do have some serious concerns about the homogenity of certain independent variables (i.e., overstory stand density, stand age, variations in soil types within stand) associated with the selected forest stands. As mentioned previously, it is very important in a gradient type study to minimize variation in the independent variables between plots within stands and between plots in different stands. There are some logistic, timing, and cost problems associated with the following recommendation. However, please seriously consider the recommendation and discuss the advantages and disadvantages of implementing it. I recommend that four plots be established in each stand. After the data is collected in 1990, the one plot that is most different from the other plots is deleted and the three remaining plots in that stand are used to represent the stand. The coordinator of the Lapland Forest Damage Project would determine which stand and plot parameters are the most important and need to be most similar. I am concerned about the following three parameters: (1) variation in number of trees per plot (i.e., overstory basal area), (2) tree age, and (3) soil and physiographic characteristics.

Monitoring Changes in Temperature and Precipitation Along Gradient

As mentioned previously, I am concerned about the homogenity of the independent variables. Weather conditions are never identical at the various sites located along the gradient. The investigators responsible for determining stand and plot locations have done their best to reduce elevation, temperature, and moisture differences at the stand and plot level. The major problem is the lack of weather stations in the Lapland Forest Damage Project; it is difficult to correct for temperature differences along the pollution gradient when there are so few weather monitoring stations. I recommend the following two solutions: (1) use of sucrose inversion method at all study sites to delineate region-wide temperature patterns (Denton & Barnes 1987), and (2) installation of hydrothermographs or mini weather stations at all intensive study site locations (i.e., all locations where water collection plots are located and where detailed basic experiments are being conducted).

Growth of Scots Pine Saplings Along the Pollution Gradients

The study plots were established to monitor the impact of pollutants on mature trees. There are no studies designed to look at the impact of pollutants on the young saplings and pole size Scots pine that are often present in these mature Scots pine stands. In the visiting the study locations, two impressions stood out: (1) mature Scots pine trees are often

dispersed widely, and (2) young Scots pine are often present, often clumped in distribution, and often growing quite rapidly. I recommend establishing plots outside of the permanent plots to measure growth rate of younger pine trees. Information should be obtained in 1991 and 1994 or 1995 on about 25 young Scots pine trees at each location.

Additional Information to Obtain at the Intensive Study Site Locations

The sampling strategy of collecting data extensively at about 400 permanent sample plots, located at over 100 sites along the gradient, is very good. I also agree with the Planning Group that most of the detailed basic studies can only be conducted at a few locations (i.e., intensive sites). It is extremely important that each subproject leader seriously consider what additional one or two parameters would be most helpful to their scientists. I recommend that the Leading Group discussed these very carefully and then the Project Coordinator selects several additional parameters to measure at the intensive site locations. Parameters to seriously consider are air temperature, relative humidity, beginning bud and leaf development, and survival and growth of seedlings and saplings.

Innovative Studies

It is extremely important that the Planning and Leading Groups continue to realize the importance of the basic studies being conducted by the various scientists at the subproject level. These studies are crucial for the success of the Lapland Forest Damage Project. Experimental studies, such as investigations of the effects of pollutants and other abiotic factors on needle structure and specific dosage-response studies, are extremely important. They will help us better understand the effect of a specific pollutant or combination of pollutants on plant structure at the cellular level and aid in solidifing cause-effect relationships. Such studies are currently being carried out at an appropriate scale (one or two sites). Costs and logistic problems prohibit them from being conducted at all intensive sites. I have not evaluated the study plans for each subproject since this was not the objective of this report.

I challenge the group to be even more innovative, especially when conducting basic experimental studies at the intensive sites. I suggest that the Lapland Forest Damage Project seriously consider three ideas. These include three different types of placement studies that would be conducted on the intensive sites. The first involves designing a study that places soil cores from the pristine non-polluted areas in central and western Lapland into all intensive sites along the gradient. The sec-

ond study involves collecting sensitive epiphytic lichens species from pristine sites and placing these organisms into all intensive sites. The third study would involve planting Scots pine seedlings (one or two year stock) from four different provenances (two from the South and two from the North) at all intensive sites. The objective of all three placement studies is to evaluate the effects of the pollutant gradient on soil, lichens, and seedlings under a fairly controlled situation.

Two observations were made while discussing specialized studies with individual researchers. The tree growth/increment core study is very well designed; it includes over 2500 mature trees. Present methodology involves taking one tree core per tree. After examining the increment cores very closely, one core per tree is probably sufficient since there is no overstocking problems in these stands. However, the study can be strengthened considerably by taking two cores per tree for a subsample of trees at three or four locations so within tree variation can be documented. The second observation involves the studies on nutrient status of Scots pine needles along the pollution gradient. Many different Scots pine provenances are found along the pollution gradient. To what extent are the differences in elemental composition of the Scots pine needles due to genetic difference between Scots pine populations? I recommend that a simple experiment be conducted in two areas in Finland where numerous Scots pine provenances are already planted at several research stations. The nutrient status of the needles of these different provenances should be determined at two sites; the two sites should be located in a prestine area and a semi-polluted area.

Integrity of Sites

It is extremely important that all personnel working at the various site locations use all precautionary methods necessary to preserve the natural conditions of the site and to cause as little impact as possible on the study plots and area surrounding the study plots. This must happen at all study sites, but investigators must be particularly careful at the intensive sites because personnel enter these sites much more often.

Data Quality and Control

It is extremely important that the Lapland Forest Damage Project develops guidelines that all investigators follow relating to data quality and data control. An example of a detailed quality assurance project plan can be found in the publication on the Michigan Gradient Study (Witter 1988b). Specifically, there needs to be a documented table that contains all variables being measured along with appropriate techniques, measuring units, reporting units, repeated measurement error, and mea-

surement accuracy; see Table 4 of Witter (1988b) for an example of data quality estimates for different variables being measured in the Michigan Gradient Study. It is very important that the water collection studies have proper quality assurance and quality control tests which include external standards for accuracy and internal schemes for precision testing (i.e., 10 % of total sample size is duplicated at convenient stages of analysis) (Robarge & Fernandez 1986). Similar information is needed for the various field measurements (Zedaker & Nicholas 1990). Someone needs to be responsible for examining data quality on an annual basis. I have no reasons to believe that the Lapland Forest Damage Project has any major problems with data quality and control. However, it is wise to document the data quality and control procedures at the beginning of the study.

Public Relations and Technology Transfer

The Lapland Forest Damage Project currently is well aware of the importance of transferring their information to the public. They appear to have an extremely good working relationship with the press. The Leading Group needs to develop more detailed plans that specify the exact responsibilities of the various individuals on the project regarding press releases and the development of specific technology transfer materials such as leaflets and video tapes. My experience has shown that it is much better to develop your technology transfer plan at the beginning of the project instead of waiting to the last year of the project (Montgomery et al. 1984).

Acknowledgements

I really appreciated the cooperation that I received from all scientists while I was evaluating this program in Lapland on May 18-24, 1990. My special thanks goes to John Derome, Kari Mikkola, Pekka Nöjd, Marja-Liisa Sutinen, Eero Tikkanen, and Martti Varmola who spent considerable time answering my questions and who accompanied me on parts or all of my extended field trips to various sites along the gradient.

Again, many thanks for your hospitality and I will always remember the new friends and contacts made on my first trip to Finland.

References

Amundson, R. G., Walker, R. B. & Legge, A. H. 1986. Sulphur gas emissions in the boreal forest: The West Whitecourt Case Study. VII. Pine tree physiology. Water, Air, and Soil Pollution 29: 129-147.

Barnes, B. V., Pregitzer, K. S., Spies, T. A. & Sponner, V. A. 1982. Ecological forest site classification. Journal of Forestry 80: 493-498.

Coulson, R. N. & Witter, J. A. 1984. Forest Entomology: Ecology and Management. John Wiley and Sons, New York. 669 p.

Davis, D. D. & Skelly, J. M. 1989. Measurement of forest condition and response along an atmospheric deposition gradient. In: Eastern Hardwoods Research Cooperative: A Program Description. USDA Forest Service, Broomall, PA. p. 23-28.

Denton, S. R. & Barnes, B. V. 1987. Application of the sucrose inversion method to delineation of region-wide temperature patterns. Canadian Journal of Botany 65: 779-786.

Freedman, B. & Hutchinson, T. C. 1980. Long-term effects of smelter pollution at Sudbury, Ontario, on forest community composition. Canadian Journal of Botany 58: 2123-2140.

Heck, W. W., Heagle, A.S. & Shriner, D. S. 1986. Effects on vegetation: native, crops, forests. In: Stern, A. S. (ed.). Air Pollution, Vol. 6. Academic Press, New York. p. 247-350.

Heliövaara, K. & Väisänen, R. 1988. Interaction among herbivores in three polluted pine stands. Silva Fennica 22(4): 283-292.

Houston, D. R. 1981. Stress triggered tree diseases - the diebacks and declines. NE-INF 41-81 USDA Forest Service, Northeastern Forest Experiment Station, Hamden, CT. 36 p.

Hutchinson, T. C. & Whitby, L. M. 1976. The effects of acid rainfall and heavy metal particulates on a boreal forest ecosystem near the Sudbury smelting region of Canada. In: Dochinger, L. S. & Seliga, T. A. (eds.). Proceedings 1st International Symposium Acid Precipitation and the Forest Ecosystem, USDA Forest Service, General Technical Report, NE-23, Upper Darby, PA. p. 745-765.

Jager, H. J., Weigel, H. J., Guderian, R., Arndt, V. & Seufest, G. 1988. Methodological approaches. Part I. Experiments with open-top chambers: results, advantages, and limitations. In: Mathey, P. (ed.). Air Pollution and Ecosystems. Reidel Publishing Co., Boston. p. 327-337.

Johnson, D. W. & Van Hook, R. I. (eds.). 1989. Analysis of Biogeochemical Cycling Processes in Water Branch Watershed. Springer-Verlag, New York. 401 p.

Kinnunen, K. & Varmola, M. (eds.). 1990. Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17-19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2. 240 p.

Krahl-Urban, B., Brandt, C. J., Schimansky, C., Peters, K., Peninston-Bird, R., Benz, A., Anderer, J. & Stocker, V. (eds.). 1988. Forest decline: cause-effect research in the United States of North America and Federal Republic of Germany. Julich Nuclear Research Center, Julich, Federal Republic of Germany. 137 p.

Kriuchkov, V. 1990. Extreme anthropogenic load and the state of the North taiga ecosystem. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17-19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2: 197-205.

Kullman, L. 1990. Recent natural decline of Swedish montane forests - a review. In: Kinnunen, K. & Varmola, M. (eds.). Effects of air pollutants and acidification in combination with climatic factors on forests, soils, and waters in northern Fennoscandia. A workshop in Rovaniemi, Finland, 17-19 October 1988. The report of papers and recommendations. Nord. Miljörapport 2: 146-156.

Loucks, O. (ed.). 1990. Air pollutants and forest response: The Ohio Corridor Study. Holcomb Research Institute Working Paper 134. Butler University, Indianapolis, IN. 340 p.

Mattson, W. J. & Witter, J. A. 1990. Pollution induced changes in forest-insect relationships. In: XIX IUFRO World Congress Proc. (Montreal, Canada). In press.

Miller, P. R. & McBride, J. R. 1975. Effects of air pollutants on forests. In: Mudd, J. B. & Kozlowski, T. T. (eds.). Response of Plants to Air Pollution. Academic Press, New York. p.196-236.

Millers, I., Shriner, D. S. & Rizzo, D. 1989. History of hardwood decline in the Eastern United States. Gen. Tech. Rep. NE-126, USDA Forest Service, Northeastern Forest Experiment Station. 75 p.

Montgomery, B. A., Rogan, R. G., Witter, J. A. & Simmons, G. A. 1984. Spruce budworm technology transfer program for the Lake States Region: a case study. Environmental Entomology 13:1-6.

Morris, D. W. 1987. Ecological scale and habitat use. Ecology 63:362-369.

O'Neill, R. V., DeAngelis, D. L., Waide, J. B. & Allen, T. F. H. 1986. A Hierarchical Concept of Ecosystems. Princeton University Press, New Jersey. 253 p.

Reed, D. G., Morz, D.G., Pregitzer, K.S. & Witter, J. A. 1988. Site selection procedures in the Michigan Gradient Study. In: Witter, J. A. (Tech. Coord.). Effects of an air pollution gradient on northern hardwood forests in the Northern Great Lakes Region. Annual Report Eastern Hardwood Research Coop. p. 21-48.

Robarge, W. P. & Fernandez, I. 1986. Quality assurance methods manual for laboratory analytical techniques. U.S. EPA and USDA Forest Service, Forest Response Program, Corvallis Environmental Research Laboratory, Corvallis, OR. 204 p.

Shriner, D. S., Heck, W. W., McLaughlin, S. B., Johnson, D. W., Joslin, J. D. & Peterson, C. E. 1990. Responses of vegetation to atmospheric deposition and air pollution. State of Science and Technology Report 18. National Acid Precipitation Assessment Program. In press.

Sinclair, W. A., Lyon, H. H. & Johnson, W. J. 1987. Diseases of Trees and Shrubs. Cornell University Press. 574 p.

Skelly, J. M., Davis, D. D., Merill, W., Cameron, E. A., Brown, H. D., Drummond, D. B. & Dochinger, L. S. (eds.). 1987. Diagnosing injury to Eastern Forest Trees. USDA Forest Service, Atlanta, GA and Penn State University, University Park, PA. 122 p.

Smith, W. H. 1981. Air Pollution and Forests. Springer-Verlag, New York. 379 p.

- 1985. Forest and air quality. Journal of Forestry 83:84-92.

Spurr, S. H. & Barnes, B. V. 1980. Forest ecology. Wiley, New York. 687 p.

Tikkanen, E. & Raitio, H. 1990. Nutrient stress in young Scots pines suffering from needle loss in a dry heath forest. Water, Air, and Soil Pollution. In press.

- & Mikkola, K. 1991. The Lapland Forest Damage Project: multidisciplinary cooperation in environmental sciences. In: Tikkanen, E. & Varmola, M. (eds.). Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. A seminar in Kuusamo, Finland, 25-26 May 1990. The report of papers. Metsäntutkimuslaitoksen tiedonantoja 373. p. 20-34.

Turner, M. G. 1987. Landscape Heterogeneity and Disturbance. Springer-Verlag, New York. 239 p.

Varmola, M. 1990. Lapland cooperation with researchers from the Kola Peninsula. Aquilo. In press.

Waring, R. H. & Schlesinger, W. H. 1985. Forest Ecosystems - Concepts and Management. Academic Press, Orlando. 340 p.

Witter, J. A. (Tech. Coord.). 1988a. Effects of an air pollution gradient on northern hardwood forests in the Northern Great Lakes Region. Annual Report Eastern Hardwood Res. Cooperative. 268 p.

- (Tech. Coord.). 1988b. Effects of an air pollution gradient on northern hardwood forests in the Northern Great Lakes Region. Quality Assurance Project Plan Eastern Hardwood Research Cooperative Agreement No. 23-849. 230 p.

- (Tech. Coord.). 1989. Michigan Gradient Case History Study for NAPAP Assessment Plan. Tech. Rep. to EPA (Corvallis, OR) and USDA Forest Service, Eastern Hardwoods Research Cooperative, Broomall, PA. 133 p.

- (Tech. Coord.). 1990. Effects of an air pollution gradient on northern hardwood forests in the Northern Great Lakes Region. 1989 Annual Report Eastern Hardwoods Research Coop. 266 p.

Zedaker, S. M. & Nicholas, N. S. 1990. Quality assurance methods manual for Forest site classification and field measurements. U.S. EPA and USDA Forest Service, Forest Response Program, Corvallis Environmental Research Laboratory, Corvallis, OR. 46 p.

Ion-balance monitoring plots and bulk deposition in Lapland during July 1989 - June 1990

John Derome[1], Kaarina Niska[2], Antti-Jussi Lindroos[1], Pekka Välikangas[2]
[1]Finnish Forest Research Institute, Department of Soil Science P.O.Box 18, SF-01301 Vantaa
[2]Finnish Forest Research Institute, Rovaniemi Research Station P.O.Box 16, SF-96301 Rovaniemi

Abstract

The results presented in this paper represent bulk deposition data collected during the first full year of operations (July 1989 - June 1990) on 7 of the ion-balance monitoring plots established as part of the Lapland Forest Decline Project. The results are compared with 20-year average (1971-1988) deposition values recorded by the National Board of Waters and the Environment, and data collected by the Finnish Meteorological Institute during July 1989 - June 1990. The following components of bulk deposition were determined: annual precipitation (mm), pH, H^+, total S and N, Ca, Mg and Na, as well as the relative proportions of the different cations.

No signs of elevated H^+ or S deposition levels were found in bulk precipitation in eastern Lapland during the monitoring period. As expected, N deposition throughout the whole of Lapland was very low, and can be considered to represent the background level. The proximity of the Arctic Ocean had a marked effect on the deposition of Mg and Na, and probably also S, in northern and central Lapland. The proportion of H^+ out of the major cations in bulk precipitation was very low (about 30%). NH_4^+ was the predominant cation in bulk precipitation at almost all the collection sites.

Preface

The purpose of this interim report is to provide the institutes and universities participating in the Lapland Forest Damage Project with information about the experimental setup and the sampling and analysis procedures for the ion-balance monitoring plots. Deposition data for the first, one-year period are also included.

The ion-balance plot network

A total of 14, ion-balance monitoring plots have been established along the five gradient lines, 7 during summer 1989 and the remaining 7 in spring 1990 (Fig. 1).

Plot design and equipment

The purpose of the plots is to provide continuous data about litterfall, bulk precipitation, stand throughfall, surface runoff and percolation water quantity and quality. The experimental setup is shown in Figs. 2 and 3. In order to cause minimal disturbance to the permanent sample plot proper (300 m^2), the ion-flux monitoring work is carried out on a surrounding "doughnut-shaped" plot, 300 m^2 in area.

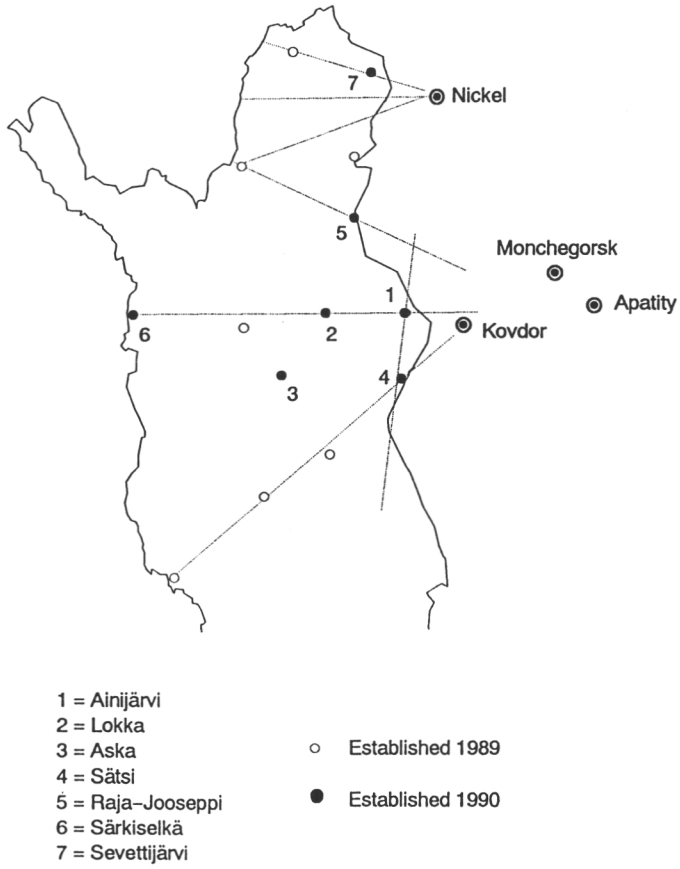


Figure 1. Location of the ion-balance plots and gradient lines. The plots are numbered in the same way as in the tables.

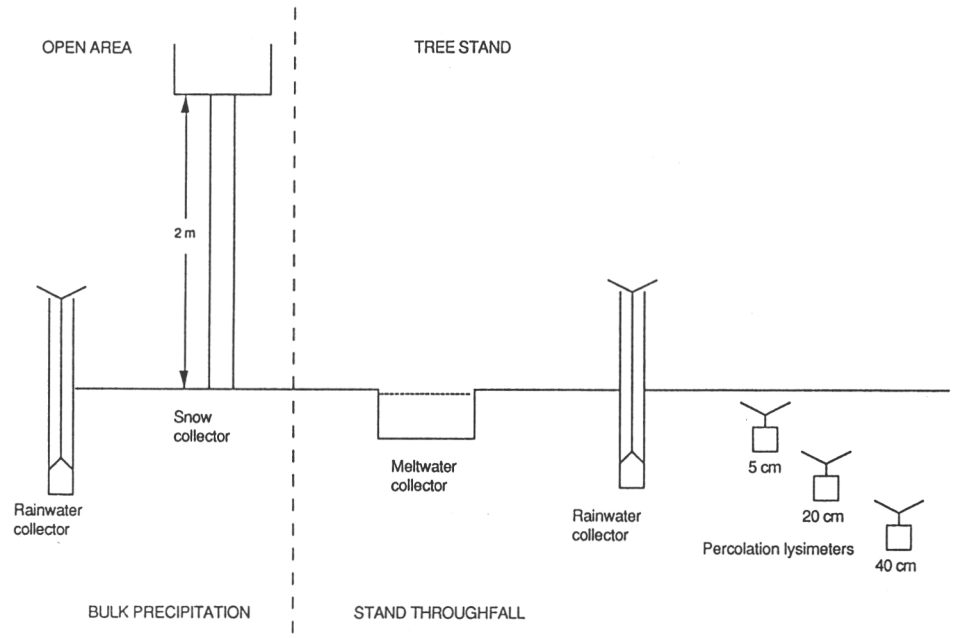


Figure 2. Ion-balance plot, experimental design.

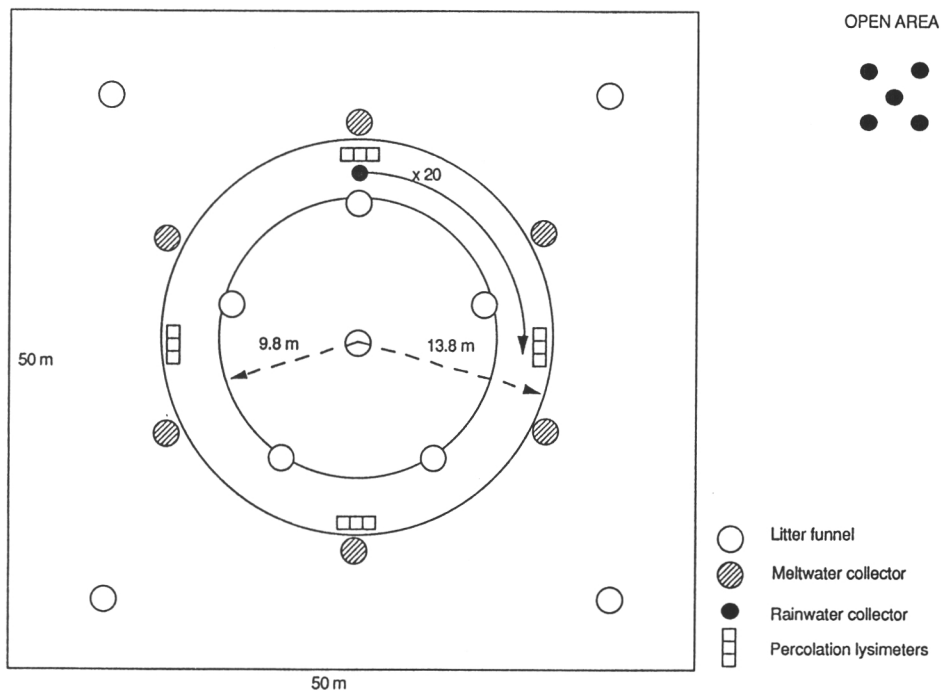


Figure 3. Position of the sampling equipment on the ion-balance plots.

Bulk precipitation is collected at a suitable point in an open area using five rainwater collectors (Fig. 4a). An open area is considered to be a point where the nearest trees are situated at a distance exceeding the maximum height of the same trees. Snowfall in the open is collected using two plastic containers (diam. 43.6 cm) fixed at a height of 2 m above the ground to eliminate ground-eddy effects. The total surface area of the five rainwater collectors is 0.157 m^2, and of the snow collectors 0.299 m^2.

Stand throughfall is collected using 20 rainwater collectors located systematically on the sample plot. Snowfall within the stand is collected as snowmelt late in the autumn and in the spring using 6 snowmelt collectors sunk into the ground at points immediately outside the sample plot (Fig. 4b). The rim of the collectors projects about 3 cm above the ground surface to prevent the inflow of water from the surrounding area. Although the collectors are situated as far as possible in a systematic fashion, depressions have been avoided to reduce the risk of accumulated surface runoff running into the collectors during snowmelt. The total surface area of the twenty rainwater collectors is 0.628 m^2, and of the six snow collectors 0.611 m^2.

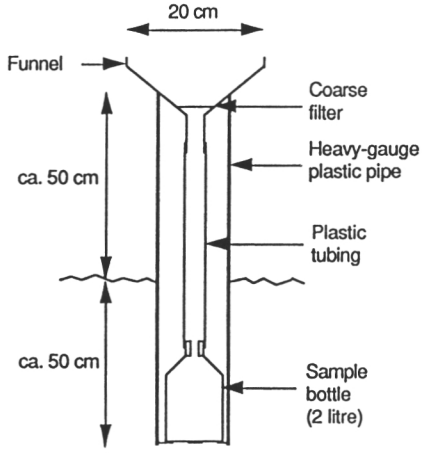


Figure 4a. Rainwater collector.

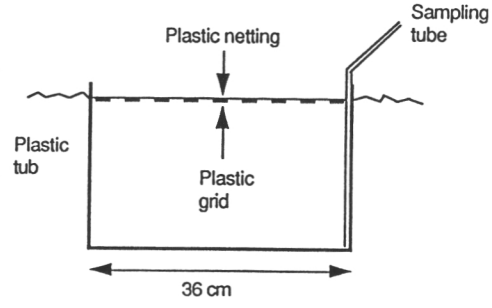


Figure 4b. Meltwater collector.

Percolation water is collected at three depths (5, 20 and 40 cm) using a total of 12 gravity lysimeters (Fig. 5a) installed in banks of three at four points around the sample plot. The lysimeters have been installed by first removing an intact soil core (diam. 30 cm) down to the required depth, and then inserting the lysimeters in a shaft sunk below the removed soil core. After inserting the percolation lysimeters, the soil core was carefully replaced. Percolation water is removed from the lysimeters by means of a nylon tube leading down into the collection bottle.

Litterfall is being investigated using 10 litter funnels (Fig. 5b) systematically located over an area of 2500 m2. The design and positioning of the funnels are the same as those used earlier in long-term, litter-monitoring studies carried out by the Department of Silviculture, FFRI.

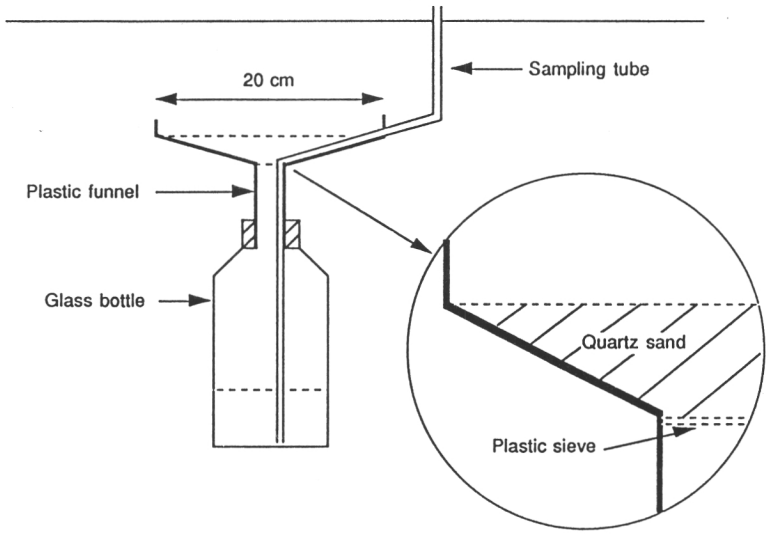


Figure 5a. Percolation lysimeter.

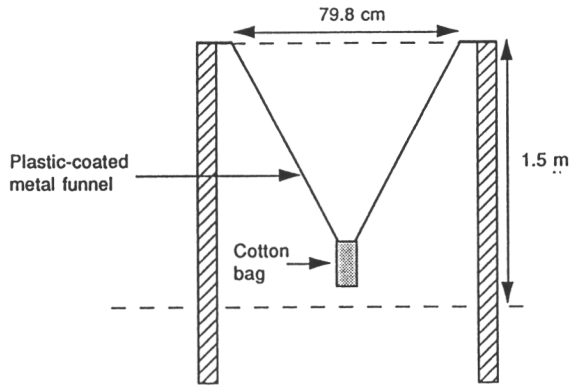


Figure 5b. Litter collector.

Sampling timetable

The rainwater and percolation water collectors are emptied at 2-3 week intervals. However, collection periods of varying length have occasionally to be used to prevent the rain collectors either overflowing, or to ensure that sufficient sample is obtained for the analyses. The snow collectors located in the open are emptied at suitable intervals throughout the winter depending on the amount of snowfall. Sampling with the snow and snowmelt collectors is started at the same time as rainwater collection ceases, and vice versa. The snowmelt collectors installed in the ground within the stand are emptied at the end of the winter following the onset of snowmelt. The samples are taken as meltwater and not snow. If snow that has fallen during the autumn subsequently melts during mild periods before the onset of winter proper, the melted snow water is collected when precipitation again starts falling as snow.

Litter samples are taken at one-monthly periods throughout the year. Collection and analysis of the litter samples are carried out by the Department of Silviculture, FFRI.

Sample pretreatment and chemical analyses

Extreme care is taken to avoid contamination during erection and replacement of the rainwater and snow collectors, as well as during water sampling, e.g. by wearing disposable gloves to prevent K and Na contamination from the hands. All the above-ground collectors are acid-washed prior to erection in the forest, and the funnels and tubing replaced when necessary - at the latest after every second collection period.

The sample bottles of the rainwater collectors are replaced at the end of each sampling period, and the sample transported as quickly as possible to the laboratory in the sample bottle. The percolation water lysimeters are emptied using a 50 ml disposable syringe and 3-way valve, the water being transferred into acid-washed, plastic sample bottles for immediate transport to the laboratory. The snow samplers in the open area are lined with clean plastic bags. At each snow sampling time the plastic bags are removed and replaced with empty ones. The bags containing the snow samples are placed in heavy-gauge, watertight bags for transport to the laboratory.

Snow meltwater that accumulates in late autumn, and all the water present in the collectors after the end of snowmelt in the spring are collected. If the snow cover is very thick, the collectors are also emptied earlier soon after the onset of snowmelt to prevent overflowing.

The volume of all the water samples is determined by weighing on arrival at the laboratory, and aliquots removed for pH measurement.

The samples from the 5 rainwater collectors in the open (representing bulk precipitation) are combined, mixed well, and a 250 ml aliquot

filtered through filter paper. 200 ml of the filtrate are stored in a deep freeze for subsequent determination of SO_4, NH_4, NO_3 and total N by flow injection analysis (FIA). The remaining 50 ml are treated with 65% suprapure nitric acid (0.25 ml) to prevent adsorption or precipitation of heavy metals during storage. Ca, Mg, K, Na, S, P and heavy metals are determined from the samples by inductively coupled plasma atomic emission spectrometry (ICP/AES).

The samples from the 20 rainwater collectors located within the stand (throughfall) are divided into two groups according to the position of the collectors: A) Collectors lying below the crown canopy, and B) collectors lying between the crown canopy. The samples are combined to give one sample per group. The subsequent pretreatment and analyses are the same as for bulk precipitation samples.

The snow samples from the collectors in the open (bulk precipitation) are weighed and then thawed. After pH measurement, the two samples, as well as the 6 meltwater samples, are filtered and analysed in the same way as for the bulk precipitation samples.

The percolation water samples are pretreated and analysed in the same way as for the bulk precipitation samples except that the 50 ml sample for ICP/AES analysis is first passed through a 0.45 µ membrane filter to remove the finest particulate material.

Organic matter is determined in all samples by titration with potassium permanganate in accordance with the Finnish standard SFS 3036.

Annual bulk deposition

The data presented here are for the 7 ion-balance plots established in summer 1989, and represent bulk precipitation collected in the open areas. The measurement period was approximately July 1989 - June 1990 (Table 1). Long-term (1971-1988) deposition data collected by the National Board of Waters and the Environment (NBWE) (Järvinen & Vänni 1990), as well as data collected by the Finnish Meteorological Institute (FMI) at four weather stations during the period July 1989 - June 1990, are used for comparison in the figures. The FMI data for the period July-December 1989 have been obtained from published results (Leinonen & Juntto 1990), and the data for the period January-June 1990 are preliminary results supplied directly by the FMI.

Annual precipitation (Fig. 6) in Lapland was about 3/4 of the 20-year average. Our values are slightly lower than those of the FMI, undoubtedly due to evaporation of water from the snow in the collectors, especially during the spring. However, this does not have any effect on the annual deposition values for the chemical components. The amount of bulk precipitation (mm) collected as rain or snow in open areas near the plots is given in Table 1.

Table 1. Amount of bulk precipitation (mm) as rainfall or snow during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	mm	Date	mm	Date	mm	Date	mm	Date	mm	Date	mm	Date	mm
130689		210689		280689		150689		200689		210789		100889	
280689	19.3	180789	69.6	240789	63.6	050789	26.4	060789	11.3	150889	35.8	240889	39.6
190789	66.3	110889	25.3	280889	54.7	200789	65.0	260789	66.7	130989	56.0	140989	11.6
140889	8.6	040989	37.8	210989	40.9	170889	10.4	220889	57.4	280989	39.6	260989	31.5
310889	61.6	250989	57.2	251089	25.6	110989	53.2	150989	13.9	231089	24.8	231089	23.2
210989	62.5	251089	27.7	160190	32.8*	220989	45.5	270989	27.3	250190	54.3*	120190	58.3*
191089	20.7	160190	28.8*	220290	37.8*	191089	15.2	191089	9.3	210290	49.9*	080290	22.9*
160190	44.2*	220290	33.8*	170490	4.4*	160190	72.3*	110190	41.5*	240490	5.5*	080390	17.1*
220290	31.8*	170490	13.0*	040690	39.5	220290	64.3*	070290	10.5*	050690	21.0	250490	3.1*
260490	1.2*	040690	48.3	020790	57.5	200490	14.4*	090390	28.1*	100790	42.1	170590	13.2*
070590	0.4*	020790	44.4			040590	13.3*	210590	6.0*	240790	57.9	120790	22.7
050690	38.6					040690	44.8	070690	34.7			260790	35.8
020790	41.8					050790	46.7	110790	26.4				
Rain-fall	319.5		310.2		281.9		307.2		247.0		277.0		164.3
Snow	77.6		75.6		75.1		164.4		86.2		109.8		114.6
Total	397.1		385.8		357.0		471.5		333.1		386.8		278.9
Days (No.)	384		376		369		385		386		367		350
Annual precip. (mm)	377		375		353		447		315		384		291

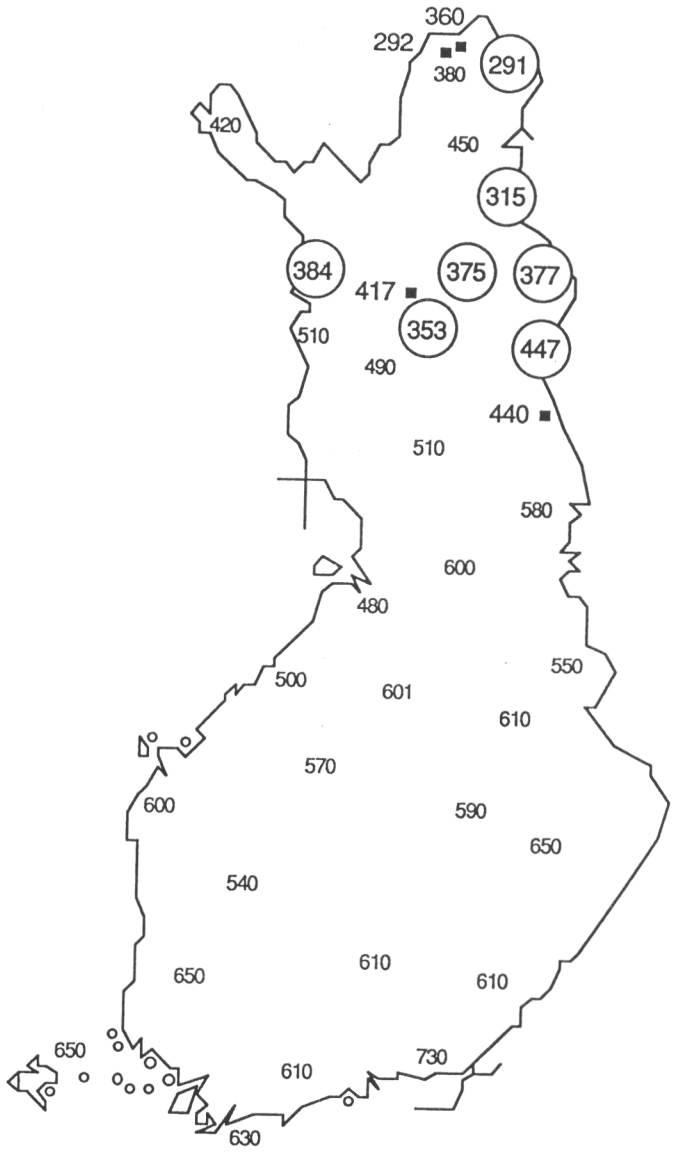


Figure 6. Annual precipitation (mm) in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Average pH during the period was in good agreement with the long-term means (Fig. 7). The values did not show any decreasing pH gradient running through Lapland from east to west. The lowest value (pH 3.56) was recorded at Ainijärvi in early spring 1990 (Table 2). The mean pH of rainwater was considerably higher (0.22 - 0.82 pH-units) than that of snow at all the plots. However, this may be due to "concentration" of the snow samples through evaporation. The lowest snow pH values occurred, almost without exception, in early spring when evaporation will be higher due to the longer daylength. Minimum evaporation can be expected from the rainwater samples because they were stored underground. Although pH would be a good measure for determining whether acidic material derived from emissions in the Kola Peninsula is deposited in Lapland, the inclusion of pH values from "concentrated" snow samples, the low density of the monitoring network (7 plots only) and the rather small number of observations from each plot means that no far-reaching conclusions can yet be drawn. Although the range of pH values was fairly large and some fairly low values were recorded (Table 2), pH alone is not sufficient for estimating the impact of acidic deposition on soil because both the concentration and amount of hydrogen ions have an effect on soil acidification.

Annual hydrogen ion deposition (Fig. 8) at most sites was well below the long-term mean. The variation between collection dates was very high (Table 3), mainly due to differences in the amount of precipitation and the duration of the collection periods. If the two plots in the centre of Lapland are excluded, the values for the other plots appear to be in fairly good agreement with the FMI data, and to follow the national, N-S gradient of increasing hydrogen ion deposition.

The distribution of annual bulk deposition of sulphur (Fig. 9, Table 4) followed a similar trend to that for hydrogen ion deposition, and the levels at most plots were around half the long-term average. Apart from the results for Sevettijärvi, the S deposition values are in good agreement with those of the FMI. The correlation between hydrogen ion and sulphur deposition values for the whole material was non-significant ($R^2 = 0.112$, $n = 75$). Correcting the data in order to remove the possible interfering effect of marine sulphate did not improve the correlation ($R^2 = 0.110$, $n = 75$). Thus although the overall trends in H^+ and S deposition at the different plots were somewhat similar, it would appear that bulk deposition of H^+ in Lapland during the period in question was not primarily due to the formation of sulphuric acid in the atmosphere as a result of SO_2 emissions. The high level of S deposition at Sevettijärvi is probably caused by the high proportion of marine-derived sulphate in bulk precipitation (cf. data for Mg and Na later in text), the distance to the Arctic Ocean being only about 50 km.

Annual nitrogen deposition (Fig. 10, Table 5) was in very good agreement with the long-term mean, and showed a clear N-S gradient. Nitrogen deposition in Lapland was about one quarter that in southern Finland.

Annual calcium deposition (Fig. 11, Table 6) recorded at most of the plots was only about one tenth of the NBWE long-term mean. The FMI values in northernmost and SE Lapland were, however, very similar. Analytical errors were ruled out because Ca and S were determined simultaneously on the same analyser (ICP/AES), and the Institute's laboratory has obtained excellent results in national, laboratory intercalibration exercises (Reissell 1989). According to Järvinen & Vänni (1990) there has been a clear decreasing trend in Ca deposition in northern Lapland over the past 20 years. However, this could not account for the very high discrepancy between our values and those of the NBWE. The most likely explanation lies in the siting of the precipitation collectors. All of the bulk precipitation collectors in our network are located in openings surrounded by large tracts of forest. If a high proportion of Ca deposition is air-borne particulate material (e.g. from fields and roads), then the surrounding forest will undoubtedly filter out dry deposition rather effectively from air moving in a transverse direction. The precipitation collectors of the NBWE are mostly situated in larger open areas closer to populated areas.

Annual magnesium deposition (Fig. 12, Table 7) was also much smaller than the NBWE long-term mean, but similar to the FMI values. There appeared to be a clear N-S, decreasing trend in Mg deposition in Lapland. Oceans are known to be a major source of Mg and Na (together with sulphate and chloride) in precipitation in coastal regions. Thus the pattern of Mg deposition in bulk precipitation in Lapland appears to be mainly determined by the distance to the Arctic Ocean. The explanation presented for the lower Ca levels recorded at the plots (apart from Sevettijärvi) compared to the long-term mean of the NBWE undoubtedly holds good for Mg, too.

No separate data have been presented for potassium because the concentrations of this element in bulk precipitation were in most cases well below the detection limit for ICP/AES analysis.

Annual sodium deposition (Fig. 13, Table 8) showed a similar N-S decreasing trend to Mg, which lends further support to the hypothesis concerning the role of the Arctic Ocean in determining Mg and Na deposition patterns in Lapland. Deposition of Na during a 3-month period in early winter at Sevettijärvi was greater than deposition for the whole year at any of the other plots. The fact that our annual deposition values for Na are in fairly good agreement with the long-term means of the NBWE, also supports the dry deposition hypothesis presented as an explanation for our lower values for Ca and Mg.

Table 2. Average pH of bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	pH	Date	pH	Date	pH	Date	pH	Date	pH	Date	pH	Date	pH
130689		210689		280689		150689		200689		210789		100889	
280689	4.48	180789	5.02	240789	5.23	050789	4.73	060789	5.80	150889	6.05	240889	4.85
190789	4.96	110889	4.78	280889	5.10	200789	5.06	260789	5.28	130989	4.88	140989	5.72
140889	4.97	040989	4.96	210989	6.13	170889	5.43	220889	4.91	280989	4.67	260989	5.94
310889	4.73	250989	4.81	251089	4.29	110989	5.10	150989	5.03	231089	4.70	231089	4.83
210989	4.85	251089	4.68	160190	4.84*	220989	4.51	270989	4.68	250190	4.52*	120190	4.55*
191089	4.36	160190	4.94*	220290	4.70*	191089	4.23	191089	4.78	210290	4.64*	080290	4.33*
160190	4.68*	220290	4.52*	170490	3.79*	160190	4.78*	110190	4.54*	240490	4.04*	080390	4.50*
220290	4.64*	170490	4.35*	040690	5.14	220290	4.57*	070290	4.25*	050690	5.26	250490	4.00*
260490	3.32*	040690	6.23	020790	4.96	200490	4.64*	090390	4.58*	100790	4.64	170590	4.75*
070590	3.56*	020790	4.89			040590	4.51*	210590	4.12*	240790	4.40	120790	5.65
050690	5.05					040690	5.03	070690	5.03			260790	4.52
020790	4.94					050790	4.67	110790	4.54				
Average	4.55		4.92		4.91		4.77		4.80		4.78		4.88
Rain-water	4.79		5.05		5.14		4.85		5.01		4.94		5.25
Snow	4.05		4.60		4.44		4.63		4.37		4.40		4.43
Samples (No.)	12		10		9		12		12		10		11

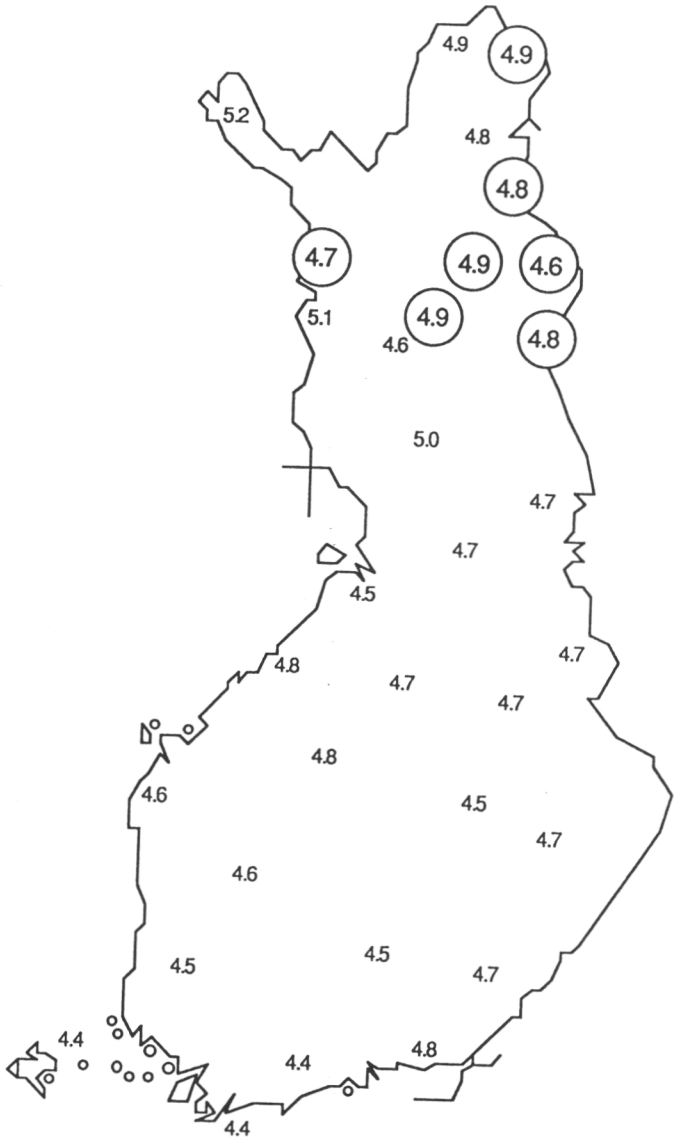


Figure 7. Average pH of bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 3. H+ deposition in bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	H+ (µg/m²)	Date	H+ (µg/m²)	Date	H+ (µg/m²)	Date	H+ (µg/m²)	Date	H+ (µg/m²)	Date	H+ (µg/m²)	Date	H+ (µg/m²)
130689		210689		280689		150689		200689		210789		100889	
280689	639	180789	664	240789	374	050789	492	060789	18	150889	32	240889	560
190789	727	110889	420	280889	435	200789	566	260789	350	130989	738	140989	22
140889	92	040989	415	210989	30	170889	38	220889	706	280989	847	260989	36
310889	1146	250989	885	251089	1313	110989	423	150989	130	231089	494	231089	343
210989	884	251089	578	160190	480*	220989	1407	270989	570	250190	1639*	120190	1605*
191089	903	160190	335*	220290	747*	191089	896	191089	155	210290	1144*	080290	1065*
160190	916*	220290	1011*	170490	709*	160190	1208*	110190	1200*	240490	501*	080390	535*
220290	727*	170490	583*	040690	286	220290	1722*	070290	584*	050690	115	250490	208*
260490	554*	040690	28	020790	631	200490	332*	090390	739*	100790	964	170590	235*
070590	114*	020790	572			040590	398*	210590	458*	240790	2304	120790	51
050690	344					040690	418	070690	324			260790	1080
020790	480					050790	998	110790	762				
Total	7526		5491		5005		8898		5996		8778		5740
Days (No.)	384		376		369		385		386		367		350
Annual deposit. (meq/m²)	7.1		5.3		5.0		8.4		5.7		8.8		6.0

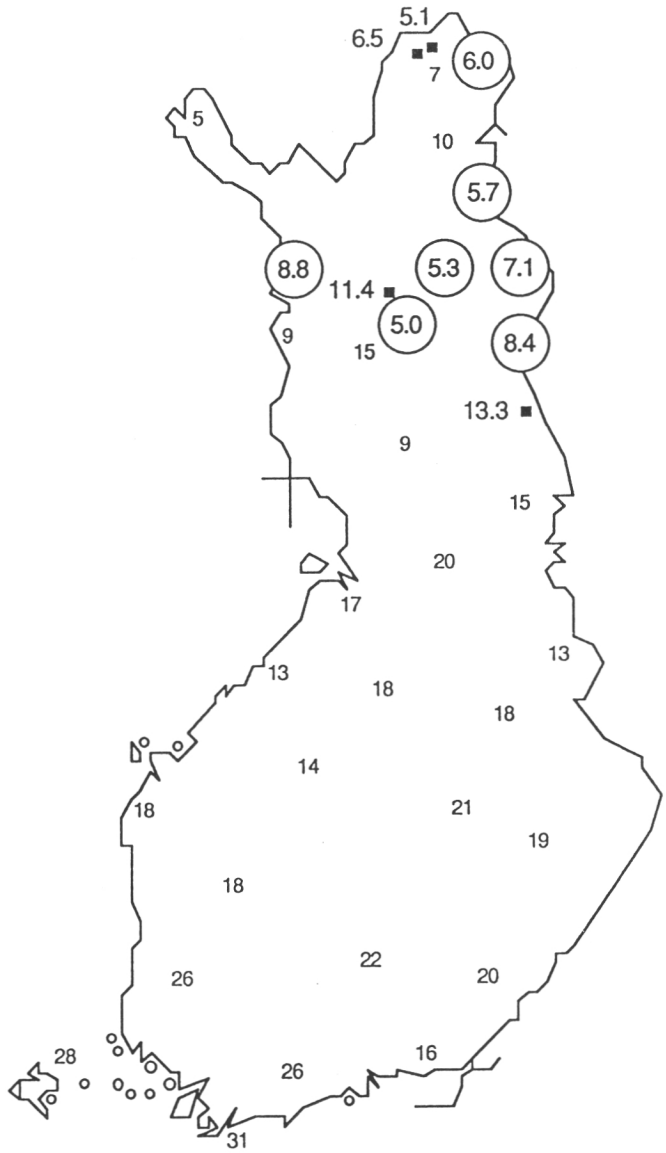


Figure 8. H^+ deposition (meq /m^2/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 4. Total S deposition in bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	S (mg/m²)	Date	S (mg/m²)	Date	S (mg/m²)	Date	S (mg/m²)	Date	S (mg/m²)	Date	S (mg/m²)	Date	S (mg/m²)
130689		210689		280689		150689		200689		210789		100889	
280689	9.49	180789	24.58	240789	19.86	050789	15.30	060789	8.88	150889	44.54	240889	16.05
190789	28.21	110889	16.15	280889	23.23	200789	26.10	260789	14.96	130989	30.32	140989	2.41
140889	8.00	040989	16.02	210989	27.04	170889	13.35	220889	23.78	280989	21.10	260989	12.14
310889	32.71	250989	30.70	251089	18.72	110989	10.06	150989	4.34	231089	12.58	231089	81.11
210989	22.59	251089	13.21	160190	7.61*	220989	34.76	270989	10.21	250190	11.95*	120190	17.84*
191089	15.38	160190	6.78*	220290	13.90*	191089	14.49	191089	3.18	210290	20.98*	080290	10.30*
160190	10.39*	220290	16.75*	170490	17.83*	160190	16.78*	110190	10.87*	240490	14.94*	080390	6.15*
220290	14.76*	170490	12.65*	040690	11.09	220290	33.04*	070290	6.13*	050690	3.67	250490	7.97*
260490	19.75*	040690	15.33	020790	19.69	200490	9.45*	090390	7.20*	100790	22.90	170590	6.35*
070590	6.48*	020790	16.90			040590	15.77*	210590	20.46*	240790	17.32	120790	13.75
050690	11.56					040690	13.54	070690	5.52			260790	17.33
020790	14.47					050790	22.50	110790	27.26				
Total	193.79		169.07		158.97		225.14		142.79		200.30		191.40
Days (No.)	384		376		369		385		386		367		350
Annual deposit. (mg/m²)	184		164		157		213		135		199		200

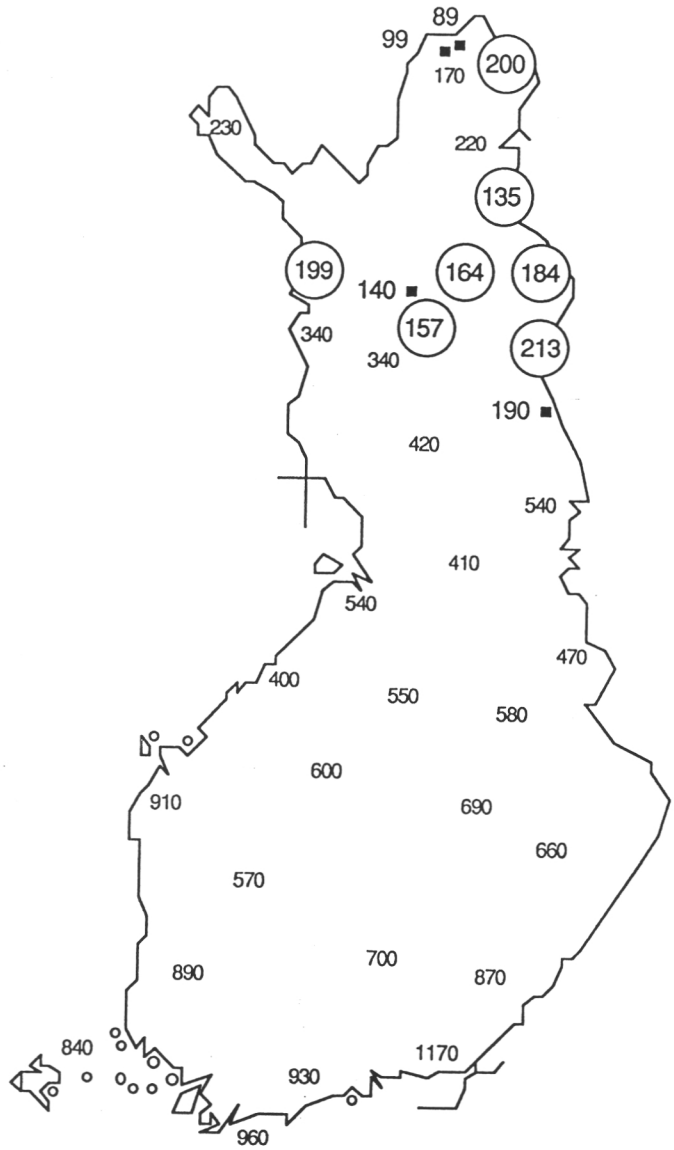


Figure 9. Total S deposition (mg /m2/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 5. Total N deposition in bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	N (mg/m^2)	Date	N (mg/m^2)	Date	N (mg/m^2)	Date	N (mg/m^2)	Date	N (mg/m^2)	Date	N (mg/m^2)	Date	N (mg/m^2)
130689		210689		280689		150689		200689		210789		100889	
280689	7.91	180789	37.56	240789	22.26	050789	20.87	060789	13.07	150889	95.53	240889	13.47
190789	27.17	110889	28.12	280889	39.69	200789	31.18	260789	21.33	130989	50.70	140989	6.55
140889	12.03	040989	20.99	210989	30.19	170889	30.31	220889	27.28	280989	23.32	260989	8.64
310889	31.40	250989	36.59	251089	23.42	110989	17.29	150989	6.20	231089	16.96	231089	9.27
210989	20.20	251089	17.15	160190	17.41*	220989	39.15	270989	10.15	250190	32.55*	120190	23.13*
191089	14.07	160190	14.30*	220290	36.43*	191089	15.60	191089	3.82	210290	48.68*	080290	21.18*
160190	22.67*	220290	36.11*	170490	15.56*	160190	40.13*	110190	21.39*	240490	15.57*	080390	12.73*
220290	34.81*	170490	14.94*			220290	65.76*	070290	12.23*			250490	6.24*
260490	15.78*					200490	14.50*	090390	19.33*				
Total	186		206		185		275		135		283		101
Days (No.)	317		300		293		309		262		277		258
Annual deposit. (mg/m^2)	214		250		230		325		188		373		143

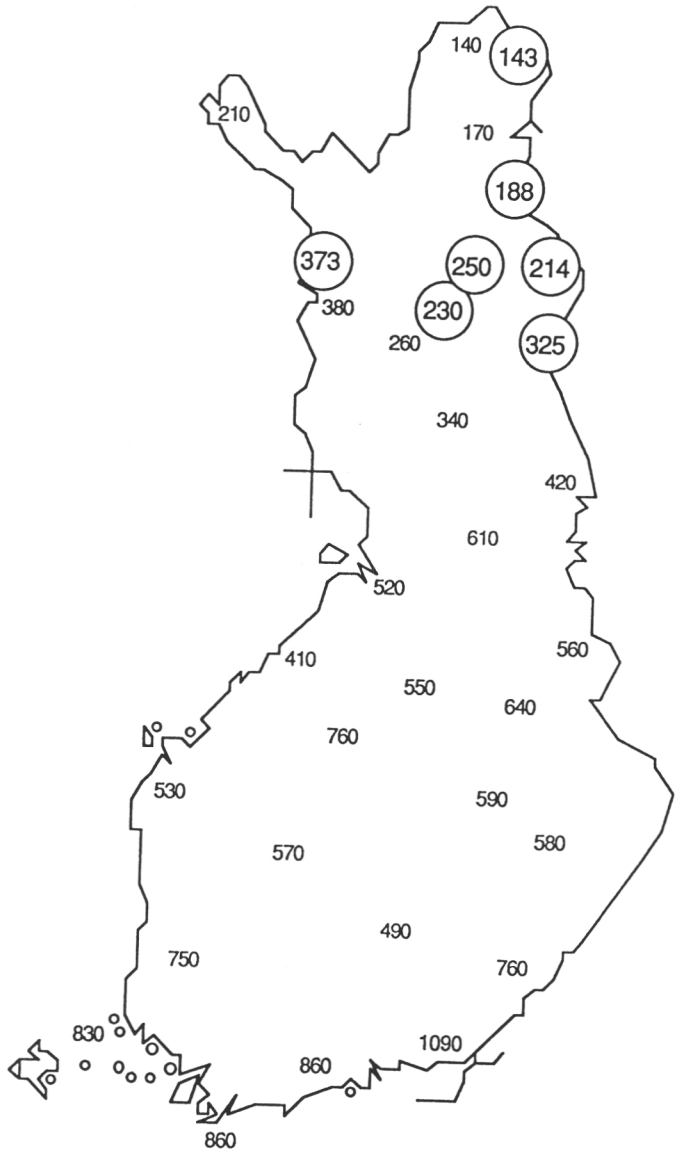


Figure 10. Total N deposition (mg /m²/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 6. Ca deposition in bulk precipitation during the period July 1989 to June 1990.* indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	Ca (mg/m²)	Date	Ca (mg/m²)	Date	Ca (mg/m²)	Date	Ca (mg/m²)	Date	Ca (mg/m²)	Date	Ca (mg/m²)	Date	Ca (mg/m²)
130689		210689		280689		150689		200689		210789		100889	
280689	1.22	180789	2.04	240789	1.11	050789	1.55	060789	0.36	150889	0.69	240889	2.09
190789	0.93	110889	0.40	280889	2.08	200789	0.96	260789	0.38	130989	2.38	140989	0.26
140889	0.30	040989	2.28	210989	1.14	170889	0.23	220889	1.50	280989	1.30	260989	0.72
310889	1.30	250989	3.53	251089	1.14	110989	1.42	150989	0.33	231089	2.69	231089	0.77
210989	1.46	251089	1.58	160190	0.90*	220989	2.09	270989	0.50	250190	1.13*	120190	4.46*
191089	0.92	160190	0.73*	220290	1.21*	191089	0.85	191089	0.86	210290	1.21*	080290	1.13*
160190	1.19*	220290	0.73*	170490	2.20*	160190	1.80*	110190	1.87*	240490	1.69*	080390	0.86*
220290	0.80*	170490	1.49*	040690	0.55	220290	2.14*	070290	0.96*	050690	1.38	250490	2.27*
260490	4.43*	040690	1.32	020790	1.73	200490	0.87*	090390	0.67*	100790	3.21	170590	0.88*
070590	2.32*	020790	1.95			040590	2.53*	210590	5.25*	240790	1.00	120790	1.69
050690	1.05					040690	0.69	070690	0.91			260790	1.16
020790	1.82					050790	2.88	110790	1.93				
Total	17.74		16.05		12.06		18.01		15.52		16.68		16.29
Days (No.)	384		376		369		385		386		367		350
Annual deposit. (mg/m²)	16.9		15.6		11.9		17.1		14.7		16.5		17.0

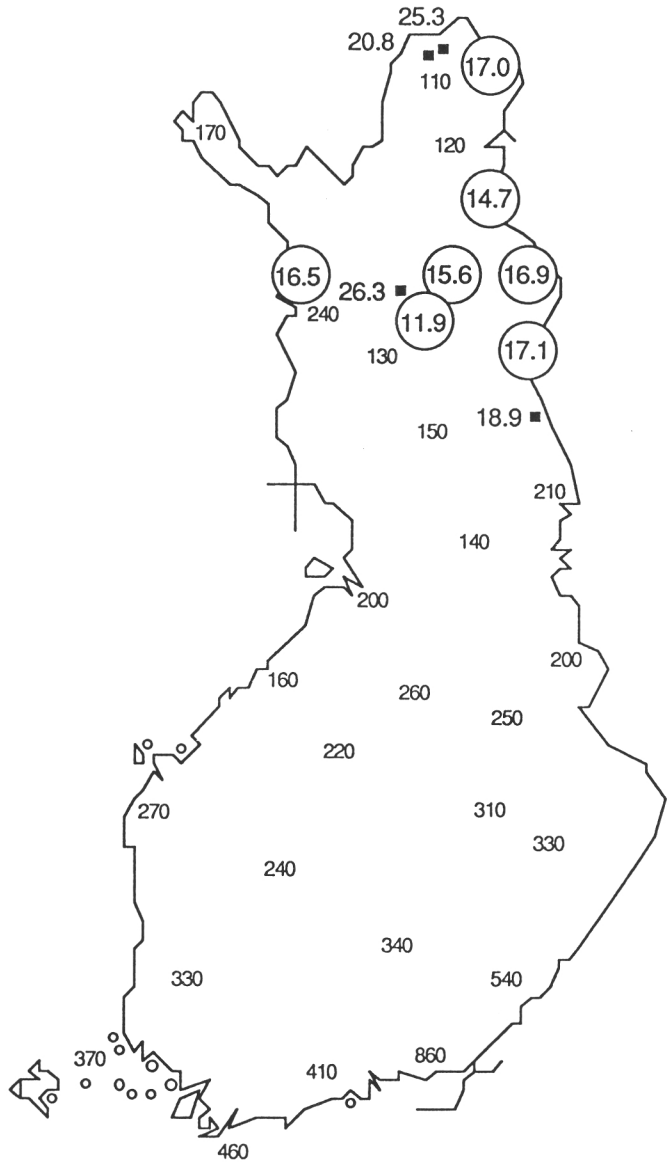


Figure 11. Ca deposition (mg /m^2/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 7. Mg deposition in bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	Mg (mg/m²)	Date	Mg (mg/m²)	Date	Mg (mg/m²)	Date	Mg (mg/m²)	Date	Mg (mg/m²)	Date	Mg (mg/m²)	Date	Mg (mg/m²)
130689		210689		280689		150689		200689		210789		100889	
280689	0.58	180789	0.40	240789	0.28	050789	0.53	060789	0.18	150889	0.13	240889	0.33
190789	0.31	110889	0.07	280889	0.52	200789	0.27	260789	0.17	130989	0.66	140989	0.22
140889	0.05	040989	0.51	210989	0.27	170889	0.07	220889	0.36	280989	0.39	260989	0.77
310889	0.54	250989	1.49	251089	0.33	110989	0.19	150989	0.16	231089	0.39	231089	0.65
210989	0.68	251089	0.71	160190	0.80*	220989	0.50	270989	0.13	250190	0.65*	120190	9.70*
191089	0.63	160190	0.66*	220290	0.29*	191089	0.53	191089	1.75	210290	0.42*	080290	1.95*
160190	1.44*	220290	0.67*	170490	0.87*	160190	1.30*	110190	2.40*	240490	0.81*	080390	1.55*
220290	0.36*	170490	0.77*	040690	0.16	220290	0.88*	070290	0.68*	050690	0.25	250490	2.08*
260490	1.35*	040690	0.63	020790	0.17	200490	0.42*	090390	0.42*	100790	0.71	170590	1.30*
070590	0.59*	020790	0.34			040590	0.69*	210590	3.59*	240790	0.20	120790	1.2
050690	0.35					040690	0.25	070690	0.19			260790	0.66
020790	0.33					050790	0.42	110790	0.67				
Total	7.21		6.25		3.69		6.05		10.70		4.61		20.48
Days (No.)	384		376		369		385		386		367		350
Annual deposit. (mg/m²)	6.9		6.1		3.6		5.7		10.1		4.6		21.4

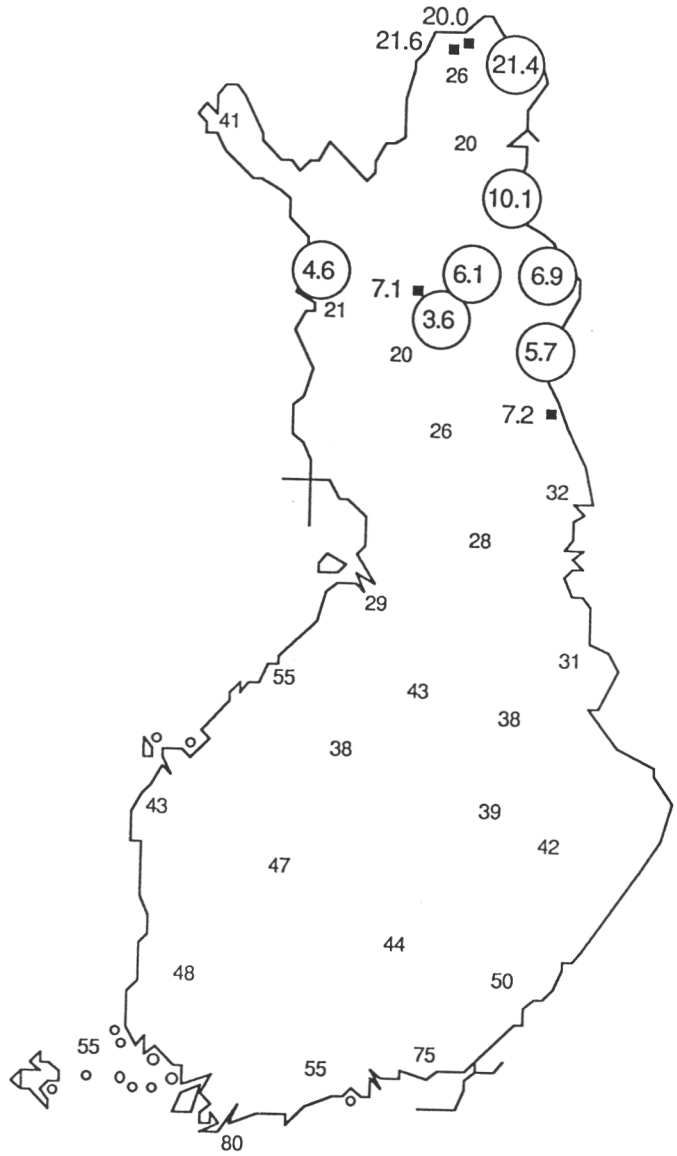


Figure 12. Mg deposition (mg /m²/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

Table 8. Na deposition in bulk precipitation during the period July 1989 to June 1990. * indicates that precipitation has been collected with the snow collectors.

AINIJÄRVI (01)		LOKKA (02)		ASKA (03)		SÄTSI (04)		RAJA-JOOSEPPI (05)		SÄRKISELKÄ (06)		SEVETTI (07)	
Date	Na (mg/m²)	Date	Na (mg/m²)	Date	Na (mg/m²)	Date	Na (mg/m²)	Date	Na (mg/m²)	Date	Na (mg/m²)	Date	Na (mg/m²)
130689		210689		280689		150689		200689		210789		100889	
280689	0.82	180789	0.00	240789	3.72	050789	2.33	060789	1.66	150889	0.00	240889	0.00
190789	5.30	110889	0.00	280889	0.00	200789	0.00	260789	3.63	130989	5.92	140989	3.31
140889	0.83	040989	0.00	210989	0.00	170889	1.66	220889	0.00	280989	4.66	260989	4.07
310889	0.00	250989	0.00	251089	4.14	110989	0.00	150989	1.24	231089	4.38	231089	8.42
210989	0.00	251089	4.18	160190	7.01*	220989	0.00	270989	0.00	250190	3.81*	120190	90.62*
191089	5.28	160190	7.64*	220290	0.00*	191089	4.79	191089	16.94	210290	4.09*	080290	17.22*
160190	15.93*	220290	2.63*	170490	6.28*	160190	10.10*	110190	21.85*	240490	6.59*	080390	15.97*
220290	2.67*	170490	8.55*	040690	1.73	220290	3.11*	070290	5.35*	050690	1.67	250490	16.86*
260490	9.54*	040690	8.59	020790	0.00	200490	3.84*	090390	2.91*	100790	5.55	170590	14.18*
070590	3.28*	020790	0.00			040590	6.43*	210590	23.26*	240790	3.55	120790	19.03
050690	6.38					040690	4.48	070690	3.11			260790	9.90
020790	2.64					050790	2.95	110790	4.60				
Total	52.67		31.59		22.88		39.69		84.55		40.22		199.58
Days (No.)	384		376		369		385		386		367		350
Annual deposit. (mg/m²)	50.1		30.7		22.6		37.6		80.0		40.0		208.1

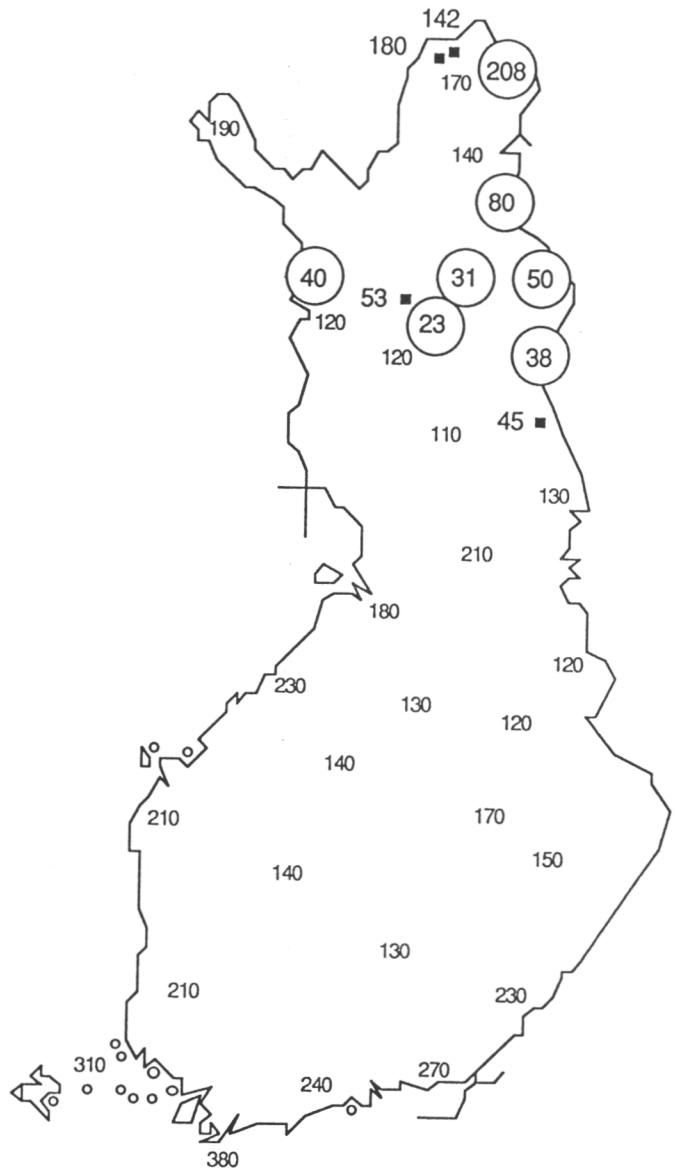


Figure 13. Na deposition (mg /m²/a) in bulk precipitation in Finland. Ringed values refer to data from the ion balance plots (July 1989 - June 1990), unringed values adjacent to black squares to data collected by the Finnish Meteorological Institute (July 1989 - June 1990), and the smaller-type unringed values are long term means (1971-1988) recorded by the National Board of Waters and the Environment.

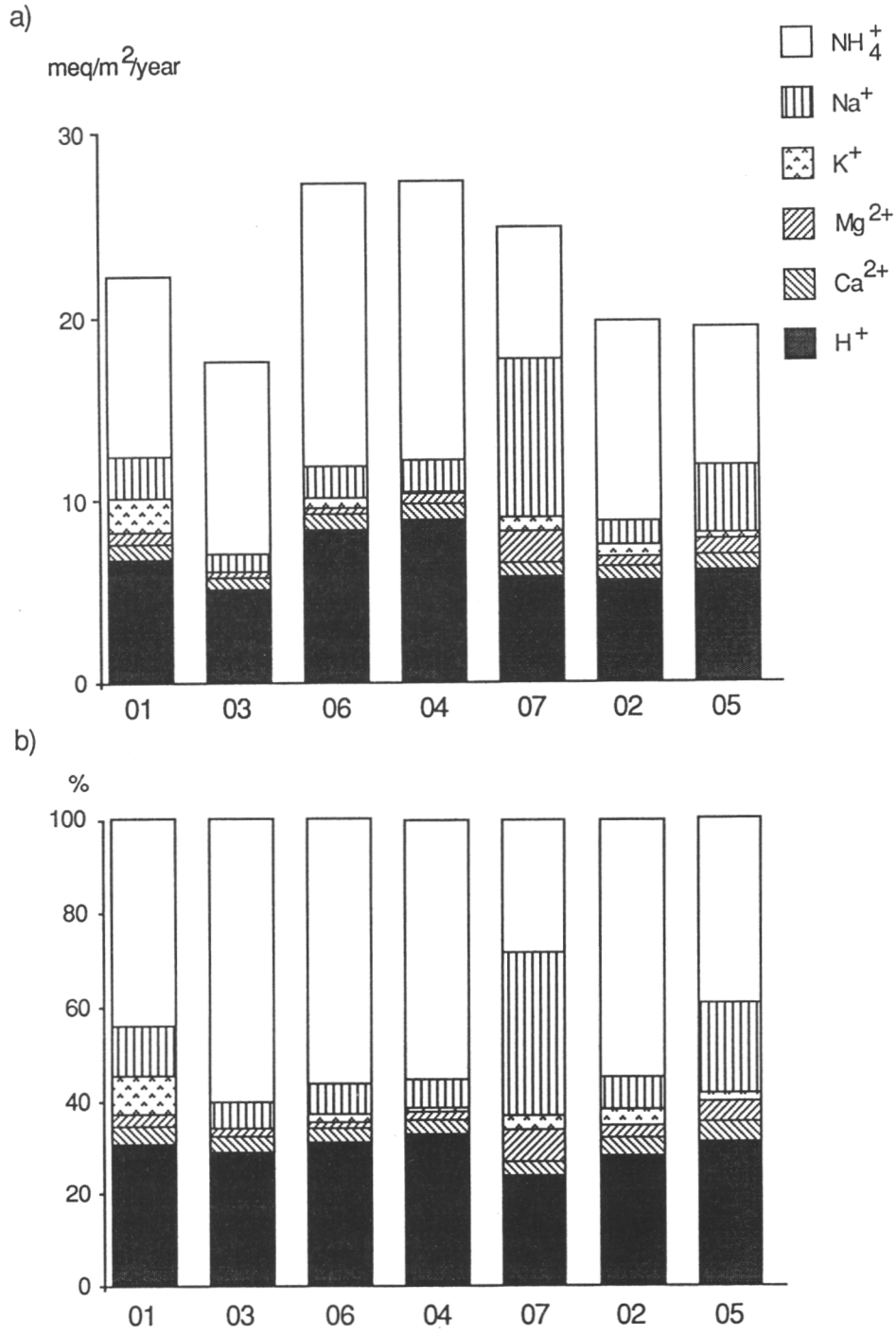


Figure 14. a) The cationic composition of bulk precipitation at the seven ion-balance plots during July 1989 - June 1990. b) The relative proportions (%) of the individual cations.

Cation ratios in bulk deposition

Three factors have to be taken into account when considering the possible effects of acidic deposition on soil acidification and associated processes: (1) the hydrogen ion concentration of rainwater or snowmelt (i.e. pH), (2) the amount of hydrogen ions deposited on a unit area over a specific time period, and (3) the ratio between the amount of H^+ and that of the other cations in deposition. The pH (i.e. acidity) of the humus layer of forest soils is primarily regulated by cation exchange. This is a simple process involving the exchange of cations between the solid and liquid phases in the soil, the direction of exchange being determined by the concentrations of the different cations in the soil solution and those on the cation exchange sites, and their ability to compete with each other for the cation exchange sites.

The distribution of different cations in bulk deposition at the seven plots in Lapland during the one-year period is given in Fig. 14a, and the relative proportions of the individual cations in Fig. 14b. The different cations are calculated as equivalent values (meq/m^2/a) in order to make them directly comparable. The total amount of cations (Fig. 14a) in bulk precipitation in Lapland is very low - below 30 meq/m^2/a. The corresponding value for southern Finland is around 100 meq/m2/a. The proportion of H^+ out of total cations in Lapland was only about 30%, and in Sevettijärvi as low as 22%. The fact that NH_4^+ was the major cation in bulk deposition at almost all the plots is somewhat unexpected. However, this does not mean that there is any immediate danger of nitrogen saturation in the soil because the absolute values for total N deposition in Lapland are very low - 1.5 to 3.5 kg N/ha/a. The contribution played by the Arctic Ocean in cation deposition in northern Lapland is well illustrated by the relatively high proportion of Na and Mg at Sevettijärvi and Raja-Jooseppi. The reason for the relatively high proportion of K at Ainijärvi is not known. These figures well illustrate the dangers of restricting measurements to the H^+ load only when attempting to estimate the effects of acidic deposition on forest soil.

Conclusions

The results presented in this paper represent deposition data collected during the first full year of operations on only 7 of the 14 ion-balance monitoring plots. Although no definite conclusions can yet be drawn about the magnitude and distribution of anthropogenic deposition in Lapland as a result of emissions from the Kola Peninsula, some tentative results can be presented concerning the monitoring period July 1989 - June 1990:

There were no signs of elevated H^+ or S deposition levels in bulk precipitation in eastern Lapland.

As expected, N deposition throughout the whole of Lapland was very low, and can be considered to represent the background level.

The proximity of the Arctic Ocean had a marked effect on the deposition of Mg and Na, and probably S, in northern and central Lapland.

The proportion of H^+ out of the major cations in bulk precipitation was very low (about 30%). NH_4^+ was the predominant cation in bulk precipitation at almost all the collection sites.

References

Järvinen, O. & Vänni, T. 1990. Bulk deposition chemistry in Finland. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer-Verlag, Berlin. p. 151-166.

Leinonen, L. & Juntto, S. 1990. Ilmanlaadun tuloksia tausta-asemilta, heinäkuu-joulukuu 1989. (Results of air quality at background stations, July - December, 1989). 75 p.

Reissell, A. 1989. Kansallinen ilman rikidioksidin ja sadeveden analyysivertailu 1989. Finnish Meteorological Institute, Air Quality Department. 35 p.

A comparison of element analyses of pine needle samples

Hannu Raitio
Finnish Forest Research Institute,
Parkano Research Station
SF-39700 Parkano, Finland

Abstract

The results of an intercalibration of element analysis by three laboratories are evaluated. Although the methods used differed somewhat from one another, the results were comparable with regard to the elements analysed so far.

Introduction

While scientific methods may have different shades of meaning to different people, most would agree that the aim of scientific research, and those involved in it, should be to make accurate observations and measurements. Nowadays, there is an increasing number of ecological studies being conducted which are concerned with nutrient pools and fluxes. In research projects dealing with the state of the environment, foliar analysis has been one of the most frequently used methods. With time, the collection of the samples and methods of analysis have been refined to be quite uniform in the various countries where foliar analysis is used. But some differences do still remain. Standardised collection and analysis methods are available in several countries. Despite the existence of standards, it is important at set intervals to compare the analysis results obtained for the same batch of samples in different laboratories. Indeed, IUFRO (International Union of Forest Research Organizations) Working Party S1.02-08 Foliar Analysis has already carried out a few international comparisons (Van Goor et al. 1971, La Bastide & van Goor 1978, Will 1986). Not only should we regularly carry out international comparisons, but national ones as well; in addition, every laboratory should conduct constant quality control.

Material and methods

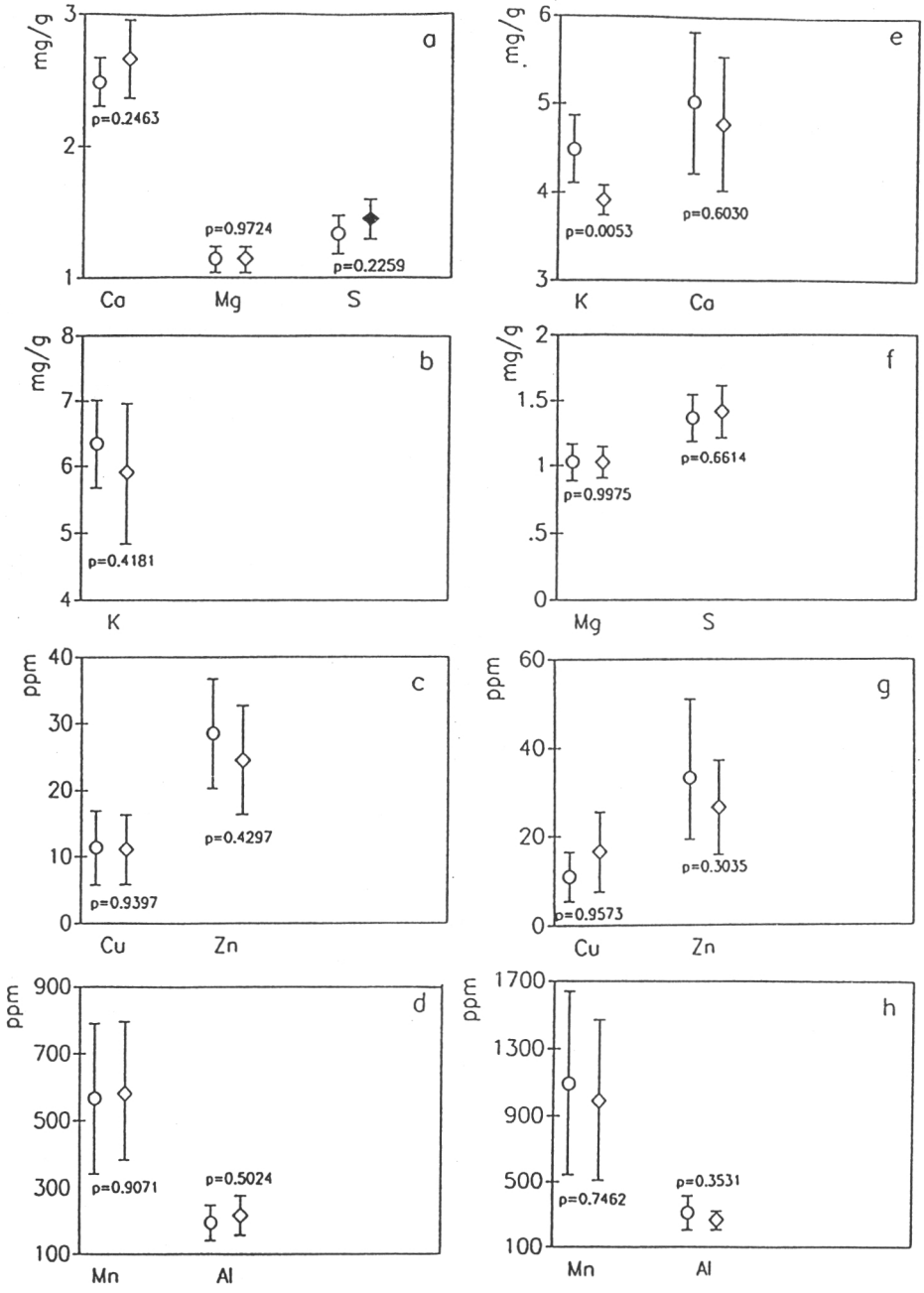
Numerous needle samples will also be collected in conjunction with the Lapland Forest Damage Project. The Department of Botany in the Oulu University, the Finnish Forest Research Institute and Soviet researchers employed in Apatity in the Kola Science Centre of the U.S.S.R.'s Academy of Sciences will be responsible for collecting and analysing these samples. For this reason we have right at the start carried out a preliminary comparison between the laboratories involved.

The Soviet colleagues collected needle samples for the purpose from eight Scots pine trees in the Kola Peninsula. Needle samples were collected separately from each tree so that the youngest needles formed one sample and 1-year old needles formed another. Each laboratory was provided with unhomogenised samples from the common material. In the laboratories of the Finnish Forest Research Institute, the HNO_3-H_2O_2-wet digestion samples were analysed for N, P, K, Ca, Mg, S, Fe, Cu, Zn, Mn and Al using vacuum ICP emission spectroscopy. So far, at the Department of Botany in the Oulu University, the samples have been analysed for their sulphur concentration using the X-ray fluorescence method. Our Soviet colleagues have so far carried out atom absorption spectrophotometric analyses of Ca, Mg, K, Cu, Mn, Zn and Al concentrations of dry-ashed samples.

Results and discussion

Although the methods used differed somewhat from one another, the results were almost without exception comparable with regard to the elements analysed so far (Figs. 1a-1h). The one exception was the potassium concentration of 1-year old needles. The results obtained in the Soviet laboratory were a little lower than those obtained at the Finnish Forest Research Institute (Fig. 1e).

In 1970 six foliage samples were analysed by 30 institutes (Van Goor et al. 1971). There were substantial between-laboratory differences in results, as well as some within-laboratory differences (La Bastide & van Goor 1978). Some other studies (e.g. Madgwick 1967, Watson 1981) have also shown that unacceptably large variations in results occur within and between laboratories. According to Will (1986) the results of the interlaboratory comparisons of chemical analysis of standard foliage samples indicated that for many analyses a majority of laboratories are in good agreement but there were some extreme values. Best agreements are usually found in N and P foliage analyses.



Figures 1a-1h. The foliar element concentrations and the confidence interval at the 95 % level as analysed by The Finnish Forest Research Institute (○), the Department of Botany in the University of Oulu (◆) and the Kola Science Centre (◇). p = tail probability between two laboratories, n=8. Figs. 1a-1d. current pine needles, Figs. 1e-1h. 1-year old pine needles.

According to the findings of the comparison carried out by Jarva & Tervahauta (1989), the sulphur concentration of needles can be analysed relatively quickly and reliably by three different methods: (1) Leco sulphur analysis, (2) X-ray fluorescence and (3) vacuum ICP emission spectroscopy. The sulphur analysis made using the X-ray fluorescence method at the University of Oulu of the material collected from the Kola Peninsula gave the same results as the vacuum ICP emission spectroscopy method used at the Finnish Forest Research Institute when analysing wet digestion samples.

Although the results now obtained of the unhomogenised needle samples have provided us with quite a reliable picture of our analysis methodology, we shall, nonetheless, be shortly conducting a more comprehensive mutual comparison involving homogenised samples in order to ensure the comparability of the results obtained.

References

La Bastide, J.G.A. & van Goor, C.P. 1978. Interlaboratory variability in the chemical analysis of leaf samples. Plant and Soil 49: 1-7.

Van Goor, C.P., de Wit, M. & van den Burg, J. 1971. International comparison of methods for soil and plant analysis. Report on activities in 1970. Forest Research Station "De Dorsachkamp" Wageningen. Report 14. 5p.

Jarva, M. & Tervahauta, A. 1989. Neulasten rikkianalyysivertailu. Summary: A comparison of sulphur analyses of conifer needle samples. Silva Fennica 23(2): 117-124.

Madgwick, H.A.I. 1967. Height growth and foliar analysis in a plantation of Norway spruce (Picea abies Karst.). Advancing Frontiers of Plant Sciences 18: 53-62.

Watson, M. R. 1981. Interlaboratory comparison in the determination of nutrient concentrations of plant tissue. Communicationes in Soil Science and Plant Analysis. 12: 601-617.

Will, G.M. 1986. Results from interlaboratory comparisons of chemical analysis of standard foliage samples. Proceedings of 18th IUFRO World Congress, Ljubljana, Yugoslavia, September 7-21, 1986. Division 1, Vol 1. Forest Environment and Silviculture. p. 368-377.

Mineral contents of fruit bodies of three mushroom species in Salla, eastern Lapland

Risto Jalkanen
Finnish Forest Research Institute,
Rovaniemi Research Station
P.O.Box 16, SF-96301 Rovaniemi, Finland

Introduction

Due to their wide mycelial network, edible and other mycorrhizal or non-mycorrhizal fungi living in the forest soil are able to take in nutritional or other elements from the soil. Especially the amount of certain heavy metals has been studied in urban environments, on roadsides, in parks etc. (e.g. Laaksovirta & Alakuijala 1978, Ohtonen 1982). Less attention has been given to elemental concentrations of mushrooms in the forest (Hårdh 1977), particularly with respect to the use of mushrooms as biological indicators of pollution in rural forests (see Vogt & Edmonds 1980). Very little is known about the variation of sulphur content of different mushroom species in large forested areas.

The vicinity of the Soviet Kola industry to Salla, in eastern Finnish Lapland, has given rise to the question of whether mushrooms contain increased amounts of minerals there. The interest is in whether mushrooms could be used as biological indicators of the level of pollution; i.e. the amount of elemental deposition.

Material and methods

Samples of three mycorrhizal fungi, *Lactarius rufus* (Fr.) Fr., *Suillus variegatus* (Fr.) O. Kunze and *Rozites caperata* (Fr.) Karst. were collected in seven localities in northern Salla, in eastern Finnish Lapland, where deposition is thought to be somewhat higher than in the other parts of Lapland. Control samples were collected in or near Rovaniemi, from a nitrogen fertilization experiment 20 km north of Rovaniemi and in Korkalovaara, Rovaniemi. They both are about 200 km southwest of the Naruska-Sätsi area (Fig. 1).

Three of the Salla sampling sites (Papulampi, Papuoiva, Sankarjoki) formed the compositesample Tuntsa and the rest (Sorsajoki, Ahvenseljät, Kenttälampi, Sätsi) the compositesample Naruska. There were 6 samples of *L. rufus*, 7 samples of *S. variegatus* and 2 samples of *R. caperata*. The samples from the fertilization experiments were a mixture of different species, but they mainly consisted of *L. rufus* and *S.*

variegatus in addition to *Paxillus involutus* (Fr.) Fr. The sample from Korkalovaara consisted of *S. variegatus*. The sample size was 5-15 fruit bodies in Salla, more from the fertilization experiment and only one specimen from Korkalovaara. The total number of mushroom samples was 15 from Salla and 9 from Rovaniemi.

The samples were brought to the laboratory within two days, where they were then dried at 35°C, ground and wet-digested in NHO_3-H_2O_2 at FFRI's Rovaniemi Research Station. The samples were then sent to FFRI's central laboratory in Tikkurila, where their mineral compositions were determined using vacuum ICP emission spectroscopy.

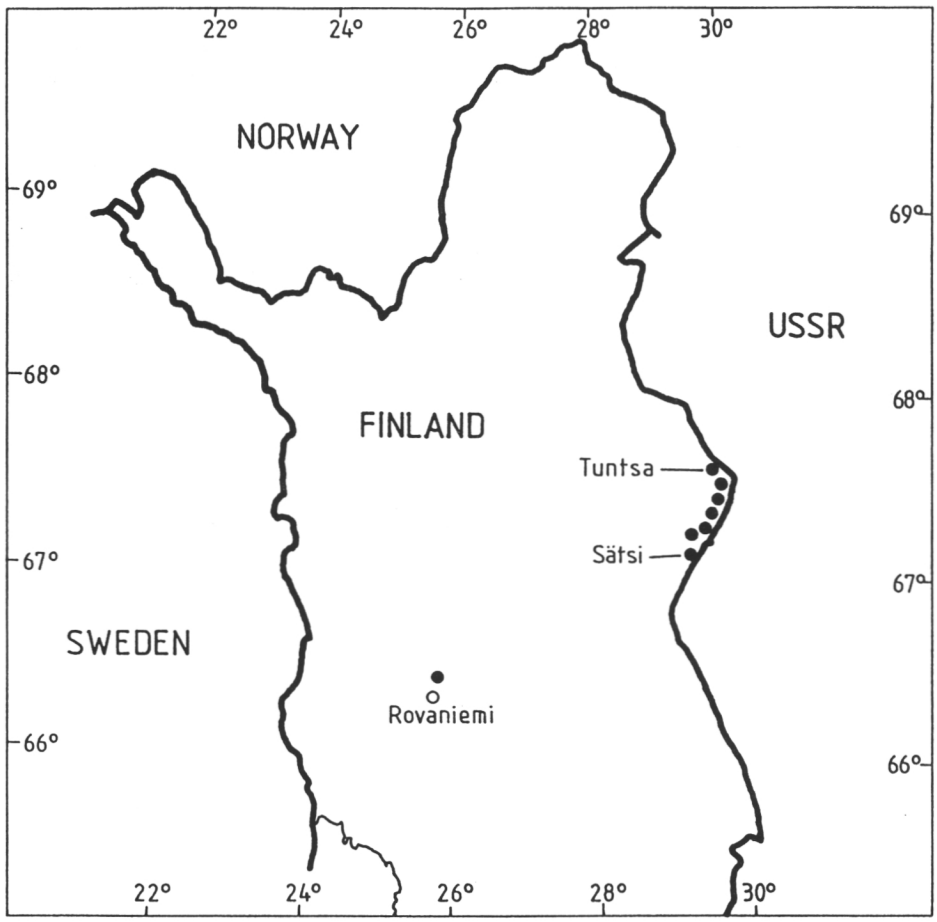


Figure 1. Locations of the forests where fruit body samples were collected.

Results and discussion

It is well known that the ability of various mycorrhizal fungi to take minerals varies from one species to another. The species which take a lot of one or several minerals, represent bioconcentration; those fungi which take clearly less than the average, are representatives of bioexclusion (Tyler 1980). The fruit bodies of the three species grown in Salla showed clear differences in this respect (Table 1). Within the material examined, *R. caperata* had high concentrations of S, K, Ca, Mg, Mn and Cd. *S. variegatus* resulted in highest values in the case of Al and especially in Fe concentration, which is, in fact, well known (Ohtonen 1982). *L. rufus* showed no indication of bioconcentration or bioexclusion in the case of any of the minerals examined. Although it was the only species which showed a Ni concentration other than zero, its Ni level was low. *R. caperata* seemed to be bioexcluser with respect to B concentrations.

Table 1. The average mineral contents of the fruit bodies of *Lactarius rufus* (LR), *Suillus variegatus* (SV) and *Rozites caperata* (RC) collected from seven localities in Salla, and the samples of mixed species consisting mainly of LR and SV from Rovaniemi, northern Finland. No analysis = (-)

	Salla			Rovaniemi
	LR	SV	RC	mixed
	n = 6	n = 7	n = 2	n = 9
Element		Concentration		
		% d.w.		
N_{tot}	3.68	3.55	3.34	3.69
		ppm d.w.		
S	4014	4144	13318	2113
K	71050	59580	107730	28681
P	(-)	(-)	(-)	6146
Ca	73.1	98.4	271.3	199.9
Mg	1587	1835	2258	869
Na	64.4	77.1	49.3	123
Al	31.0	181	24.2	61.3
Fe	109	6231	157	125
Mn	32.3	23.4	59.6	33.6
B	4.27	2.42	0.18	3.41
Cr	0	0	0	3.77
Cu	36.2	34.2	30.2	120
Cd	0	1.85	4.12	1.28
Pb	0	0	0	1.32
Zn	160	193	180	73.7
Mo	0	0	0	0.13
Ni	0.21	0	0	(-)
Ti	0.08	0.26	0.61	(-)
V	0	0	0	(-)

There were clear differences between the two areas in terms of mineral concentrations. Mushrooms from Salla had much higher levels of S, K, Mg and Zn than those from Rovaniemi, and clearly lower levels of Na, Cr, Cu and Pb, respectively (Table 1). The really high levels of S in Salla indicate sulphur deposition originating from the Soviet Union. The S level in Rovaniemi was, however, about twice as high as the S concentrations of the needles in general in the background areas (e.g. Raitio et al. 1990). On the other hand, high S concentrations may be typical for northern mycorrhizal fungi. Sulphur concentrations of non-mycorrhizal, cultivated mushrooms such as common champignon (*Agaricus bisporus* L.) seem to have similar levels as *L. rufus* and *S. variegatus* in Salla (Verma et al. 1987). It is interesting to note the high level of K in Salla, the reason for which is as yet unknown, but which may be anthropogenic (see Geochemical Atlas... 1986). This is supported by the increased level of K in the snow of the same area, too (Jalkanen & Kurkela 1991). The same observations apply to Zn, too. The increased levels of heavy metals like Cr, Cu and Pb in Rovaniemi indicate that Monchegorsk, for instance, does not emit much copper to Salla forests. The same can be said about Ni. Increased chromium levels indicate the effect of the steel industry in Tornio. The distance between Tornio and Rovaniemi is about 120 km.

Unfortunately, relevant information about mineral contents of ordinary mushroom species does not exist, and comparisons must be done using results obtained from other areas. According to such reports, at least the overall level zinc was higher than normal (Ohtonen 1985). The lack of data is an indication of the need for more research in the field of mineral contents of edible mushrooms in particular.

References

Geochemical Atlas. 1986. 19 p. + 155 maps.

Hårdh, J.E. 1977. Raskasmetallit ravintokasveissa ja maassa. Abstract: The heavy metals in alimentary crops and in soils. Journal of the Scientific Agricultural Society of Finland 49: 209-220.

Jalkanen, R. & Kurkela, T. 1991. Coloured snow in Salla, eastern Lapland. Manuscript. Finnish Forest Research Institute, Rovaniemi Research Station. 6 p.

Laaksovirta, J. & Alakuijala P. 1978. Lead, cadmium and zinc contents of fungi in the parks of Helsinki. Annales Botanici Fennici 15: 253-257.

Ohtonen, R. 1982. Mineral contentrations in some edible fungi and their relation to fruit-body size and mineral status of substrate. Annales Botanici Fennici 19: 203-209.

– 1985. Sienten kivennäisaineista. Sienilehti 37(2): 20-22.

Raitio, H., Tikkanen, E. & Nöjd, P. 1990. Mäntyjen ravinnetalous Sallan puustovaurioalueella. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 23-31.

Tyler, G. 1980. Metals in sporophores of basidiomycetes. Transactions of the British mycological Society 74(1): 41-49.

Verma, A., Keshervani, G.P., Sharma, Y.K., Sawarkar, N.J. & Singh, P. 1987. Mineral content of edible (dehydrated) mushrooms. The Indian Journal of Nutrition and Dietetics 24: 241-245.

Vogt, K.A. & Edmonds, R.L. 1980. Patterns of nutrient concentration in basidiocarps in western Washington. Canadian Journal of Botany 58:694-698.

A survey of element concentrations in the epiphytic lichen *Hypogymnia physodes* in Northern Finland in 1986[1]

Eero Kubin
Finnish Forest Research Institute,
Muhos Research Station
SF-91500 Muhos, Finland

Abstract

A total of 2385 samples of *Hypogymnia physodes* were collected systematically in 1985 - 86 from sites distributed over the whole country and analysed for Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, N, Na, Ni, Pb, S, Ti and Zn, chiefly for the purpose of tracing areal variations in the deposition of air-borne metal elements.

The material represents 908 clusters of sites distributed evenly over the whole country, about which 92 were in the two northernmost Forestry Board Districts, those of Lapland and Koillis-Suomi. The 154 samples from this part of the country were collected in 1986 and the results given in this report deal only with this district.

The determinations showed this lichen species to be well suited for monitoring relative differences in deposition. The results point to certain larger areas of high and low concentrations of these elements carried in the air in the form of metal dusts or gaseous compounds. In some cases high concentrations can be linked with particular sources of emissions. The occurrence of high concentrations of certain elements in eastern Lapland is interpreted as implying long-distance transport from the Kola Peninsula.

Since air-borne pollution includes components which have a major effect on soil and water acidity, and components which are not among the nutrients normally taken up by plants, increased emphasis should be placed on the necessity for plans and actions aimed at reducing anthropogenic emissions into the atmosphere to the lowest possible levels.

---

[1] Published also in the Proceedings of the Symposium on Environmental Geochemistry in northern Europe, in Rovaniemi, Finland, 17-19 October 1989. Geological Survey of Finland. Special paper 9.

Introduction, materials and methods

As one part of the Finnish Research Project on Acidification (HAPRO), the Finnish Forest Research Institute set up a project to study the effects of air pollution on forest ecosystems (known as the ILME project). The aim was to gather as wide a body of data as possible to cover changes detectable in the forests throughout the country, and for this purpose a set of 3009 secret monitoring sites were established for observations on various parts of the forest ecosystem (Valtakunnan ...1986). The same sites were also used for collecting moss, bark and lichen samples to measure the relative deposition of heavy metals and some other elements. The lichen selected for sampling was *Hypogymnia physodes*, which is commonly found on the trunks and branches of trees. Since the epiphytic lichens receive the majority of their nutrients from rainwater, they are particularly suitable for the analysis of airborne substances.

Hypogymnia physodes is a widely distributed epiphytic lichen which is relatively resistant to impurities in the air, as seen from the fact that in experiments on the effects of sulphur dioxide on lichens (O'Hare & Williams 1975) changes appeared in the chlorophyll of *Usnea subfloridana* after only two days, whereas the time lag was 24 days in *Hypogymnia* and 21 days in *Pseudevernia furfuracea*. All the species studied had a higher sulphur dioxide content after the experiment than did the control samples. In transplant experiments (O'Hare 1974) both *Usnea subfloridana* and *Hypogymnia physodes* accumulated sulphur in proportion to the mean ambient level of sulphur dioxide. Griffith (1966, cit. Hawksworth 1973) similarly observed that the sulphur content of specimens of *Hypogymnia physodes* was related to that of the ambient air. Guderian (1977) goes so far as to note that it is of particular value for this purpose in places where the concentrations of pollutants in the air are low.

Samples of *Hypogymnia physodes* for chemical analysis were collected here in a systematic manner, to cover the whole of Finland. The sites were defined on the basis of the nationwide grid employed in the 5th National Forest Inventory (Kuusela & Salminen 1969). The index points on the grid were located 16 km apart in a N-S and E-W direction, except in the northernmost Forestry Board Districts of Lappi and Koillis-Suomi, where they were 32 km apart in an E-W direction and 24 km apart from N to S. Thus where the number of samples obtained from all over the country was 2385, those applying to the two northernmost districts amounted to only 154. The monitoring sites themselves are arranged in clusters of four associated with each index point in the denser grid area and three on the sparser grid (Fig. 1), which also contributed to the lower number of samples from the latter area.

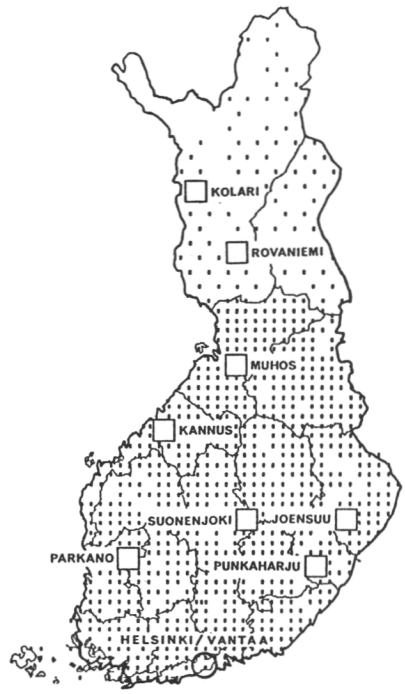


Figure 1. Location of the clusters of monitoring sites, the Forestry Board Districts and the research stations maintained by the Finnish Forest Research Institute. Sampling took place in summer 1985 in the area with the denser network and in summer 1986 in the less dense area comprising the two northernmost Forestry Board Districts. The samples were gathered together and stored at the Muhos Forest Research Station.

The present paper discusses areal variations in the concentrations of certain elements in this northern region of Finland (Fig. 1). The methods used are the same as in earlier reports constructed on a national scale (Kubin 1989, 1990b), so that no attempt is made to repeat them. A corresponding discussion restricted to this specific geographical area has been published in Finnish (Kubin 1990a), but based on only some of the chemical elements concerned here.

Results

Presentation of the results

Since the samples originated from monitoring sites arranged in clusters, mean values for the clusters were calculated for presentation on stan-

dardized maps of Finland. The number of clusters concerned was 908 for the whole country and 92 of the two northern Forestry Board Districts. The method serves to smooth out the influence of individual high values, and at the same time improves the reliability of the data from each cluster for representing the particular characteristics of the site concerned.

When constructing the areal maps, the original irregularly distributed data points were redesigned to form a regular grid, which was then used for plotting purposes. The element concentration classes depicted on the maps were obtained by dividing the observations for each element into five groups of equal size, hence the somewhat irregular distribution of boundary values.

The order of presentation of the elements follows the division into macro- and micronutrients and inessential substances with respect to the higher plants (Allen 1974, Larcher 1975, Mengel & Kirkby 1979). The latter category comprises substances found in plants but upon which they are not dependent. Many of these are toxic metals, which are dealt with here under the heading of heavy metals, aluminium and titanium.

Sulphur and nitrogen

Sulphur and nitrogen are both crucial nutrients which plants consume in large amounts, and both make an essential contribution to the structure of enzymes and protoplasm, for example. Correspondingly, both play a similar role in the development of acid rain, since their oxides form chemical compounds which, via a number of intermediate steps, serve to increase the acidity of water, i.e. the numbers of hydrogen ions present. The significance of sulphur and nitrogen for the natural environment has come to the fore especially clearly in relation to pollution generated by human activity, chiefly industry and traffic.

Where the mean sulphur concentration in the *Hypogymnia physodes* samples for the whole country was 1092 µg/g and the range of values 599-2610 µg/g, the samples gathered from the Forestry Board Districts of Lappi and Koillis-Suomi gave a mean concentration of 832 µg/g and a range of 599-1250 µg/g. The highest concentrations were grouped in a number of specific areas (Fig. 2), one of which extended from the border with the Soviet Union at the latitude of Salla and Kemijärvi as far as central Lapland and southwards from there. Another area of high concentrations lay north of the towns of Kemi and Tornio, and another around Kolari on the western border. A further area of a similar kind existed in the extreme north of Inari Lapland, although no samples were obtained from very close to the eastern border.

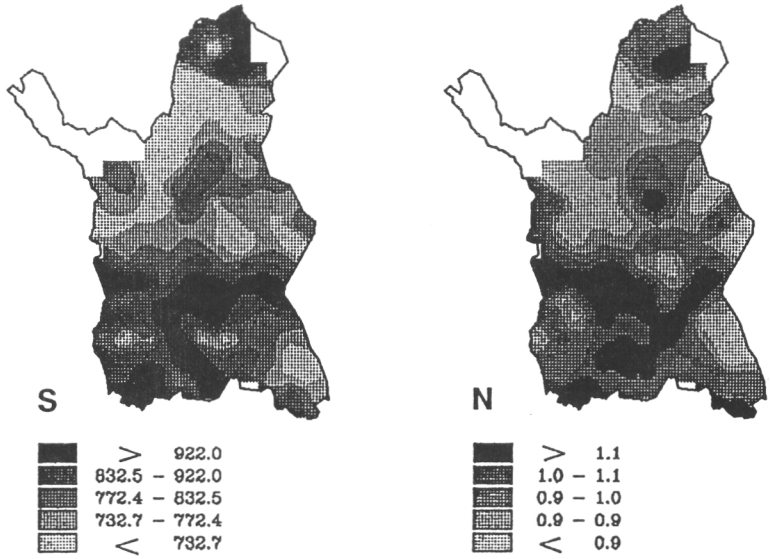


Figure 2. Areal variations in sulphur and nitrogen concentrations in the lichen *Hypogymnia physodes* in the Forestry Board Districts of Lappi and Koillis-Suomi in 1986. Areas left blank are those from which no samples were collected. Concentrations are determined in µg/g of dry lichen.

The mean nitrogen content of the lichens from this northernmost region of Finland was 1.0 % dry weight, with a range of 0.7-1.4 %, as compared with figures of 1.3 % and 0.75-2.56 % for the country as a whole. The areal distribution of the concentration classes is to a great extent similar to that observed for sulphur (Fig. 2).

Other macronutrients

Calcium, magnesium and potassium are nutrients which plants require in relatively large amounts, the first two being mostly of structural significance to the plant, while potassium is best known as a functional nutrient, which in the higher plants, for example, is engaged in a rapid cyclic circulation between the living plant tissues and the soil. Sodium is mentioned as an essential nutrient for plants, but less emphasis is placed on its functional significance. These substances are probably not of any direct significance as air pollutants, unless one considers direct fall-out in the form of dust. A particularly high incidence of calcium will have the effect of neutralizing acidity, of course.

The following calcium, magnesium, sodium and potassium concentrations (µg/g of lichen) were measured for the present material from the Forestry Board Districts of Lappi and Koillis-Suomi:

	Whole country			Lappi and Koillis-Suomi		
	x	Min	Max	x	Min	Max
Potassium	2751	1448	6045	2517	1587	3582
Calcium	3344	388	33375	5518	388	29512
Magnesium	399	210	989	455	232	819
Sodium	41	21	521	48	24	169

The areas affected by high concentrations are substantial in extent (Fig. 3), with those for calcium and magnesium coinciding both on the eastern border and in the north-western part of the area studied. Major deposition of potassium is recorded close to both the eastern and western borders and of sodium in the north. It should be emphasized that ecological conditions can influence the recorded concentrations of these substances more than does their transport in the atmosphere. On the other hand, some of the sodium can be assumed to originate from the sea, and both calcium and magnesium can be transported along with ash and dust.

Micronutrients

Copper, iron, manganese and zinc are the chief micronutrients of significance for the basic metabolism of plants and other reactions. With the exception of iron, they are frequently mentioned as environmental pollutants if they occur in nature in high concentrations, and since they tend to form complex compounds in soil solutions, deficiency symptoms with respect to one or more of these can appear in plants under certain conditions.

The mean copper content of the lichen samples from the northern region was 6.9 µg/g and the range of values 4.0-22.4 µg/g, as compared with national figures of 7.3 µg/g and 3.5-199.6 µg/g. There is a clear accumulation of high values in the north-east of Lapland (Fig. 4). Corresponding values for iron content were 344 µg/g of lichen (range 180-782 µg/g) in the northern region and 544 µg/g (range 180-3759 µg/g) in the country as a whole, with the highest values recorded along the southern edge of the region and in Inari Lapland.

Where the mean manganese concentration for Finland in general was 131 µg/g of lichen and the range 20-693 µg/g, the mean value obtained in this northern region was 172 µg/g, with the same range. It is significant that in this case the mean is higher than for the country as a whole. The mean zinc concentration on a national scale was 86 µg/g and that for the northern region 91 µg/g, with a range of 38-216 µg/g in both cases, the areal distribution of high values being somewhat similar for these two metals (Fig. 4).

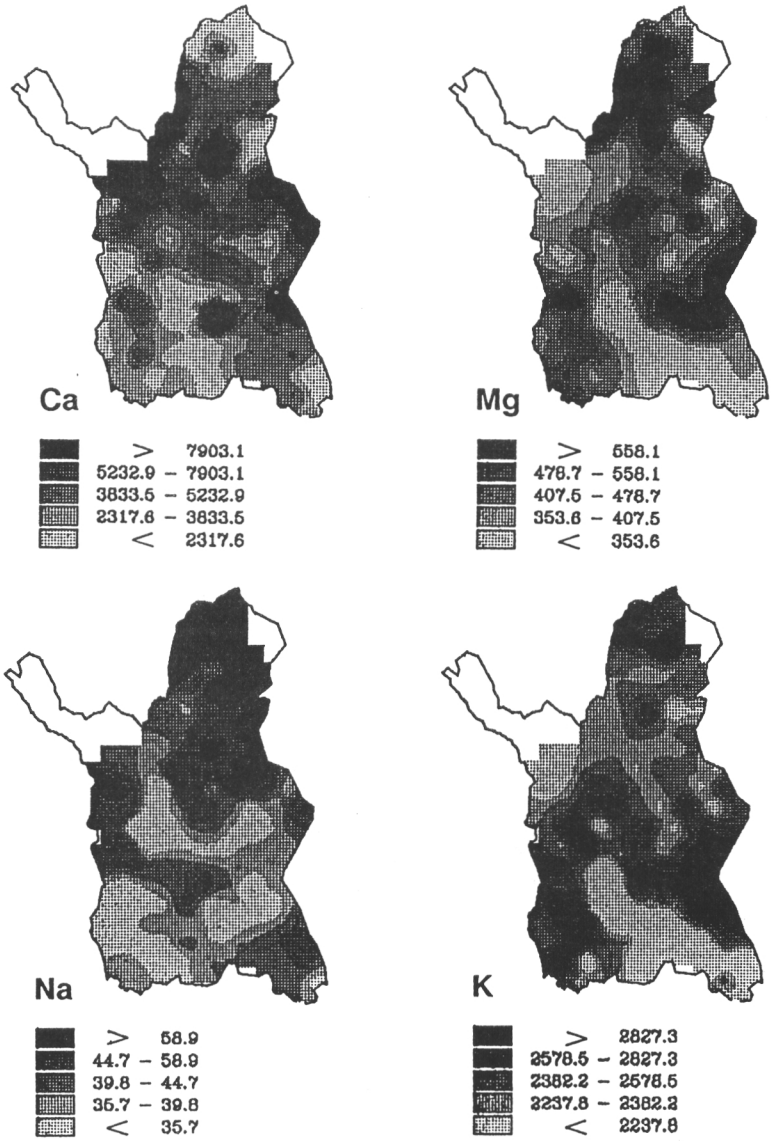


Figure 3. Areal variations in calcium, magnesium, sodium and potassium concentrations in the lichen *Hypogymnia physodes* in the Forestry Board Districts of Lappi and Koillis-Suomi in 1986. Areas left blank are those from which no samples were collected. Concentrations are determined in µg/g of dry lichen.

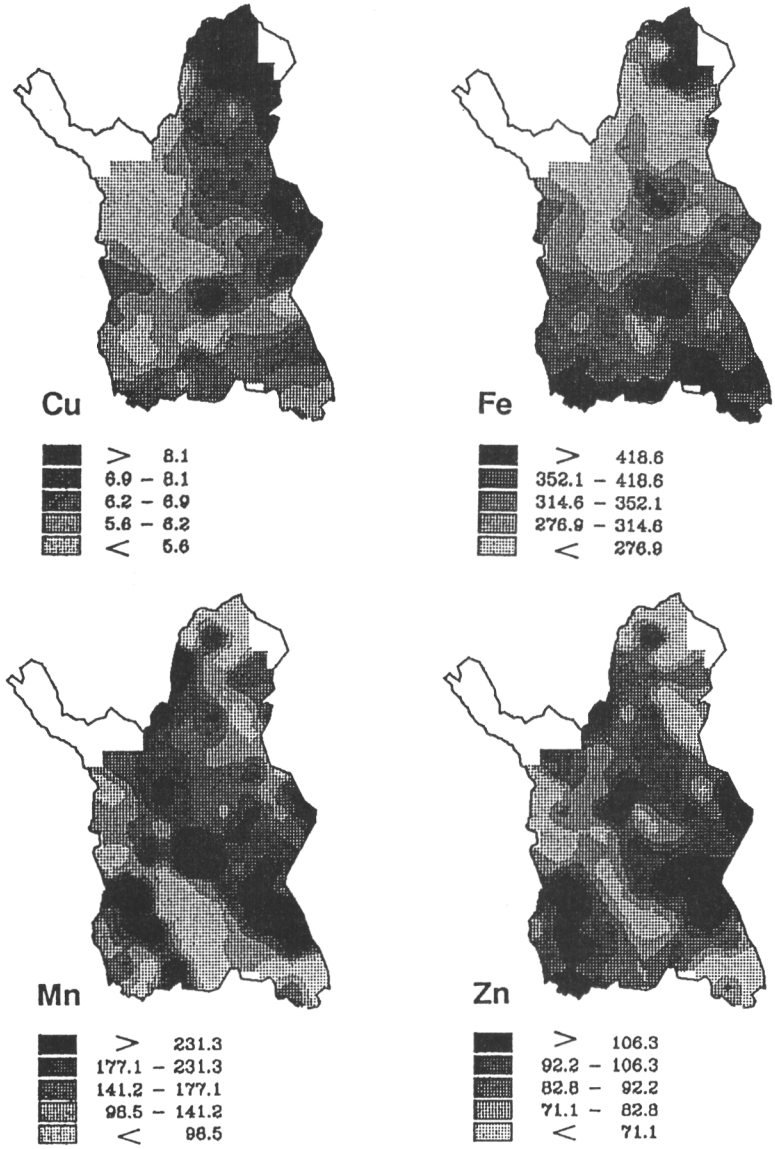


Figure 4. Areal variations in copper, iron, manganese and zinc concentrations in the lichen *Hypogymnia physodes* in the Forestry Board Districts of Lappi and Koillis-Suomi in 1986. Areas left blank are those from which no samples were collected. Concentrations are determined in µg/g of dry lichen.

Heavy metals, aluminium and titanium

The elements determined here which fall into the class of heavy metals in terms of their chemical character and biological effects are cadmium, chromium, lead and nickel. Although these are to be found in plants, they are not mentioned as being in any way essential elements for plant life. In the same way plants take up aluminium and titanium, but it is not entirely known what significance these have for the plant. Aluminium can easily be toxic for plants, while titanium determinations are often used as indicators of industrial emissions.

Cadmium is a detrimental substance for both human and plant life. Its effect on plants is derived from its ability to block the involvement of zinc in enzymatic reactions, while in humans it has been shown to have a cumulative toxic effect. Plant cells normally contain 0.1-1.0 µg/g cadmium (Mengel & Kirkby 1979), but this figure can easily be exceeded where cadmium is readily available. The mean cadmium content of the present lichen samples was 0.57 µg/g with a range of 0.12-1.93 µg/g, compared with a national mean of 0.70 µg/g and a range of 0.12-4.25 µg/g. Marked concentrations were recorded in the Kemi-Tornio area and in the western, central and eastern parts of Lapland. Bearing in mind that lichens usually require little in the way of nutrients by comparison with higher plants, the maximum values recorded here may be regarded as high.

The significance of chromium for the metabolism of plants is as yet unresolved, and it does not occur in any very large quantities in plant tissues, being present in the soil in a highly insoluble form. It is generally regarded as a toxin. The mean chromium content in the total material, 2.13 µg/g of lichen, with a range of 0.30-56.00 µg/g, is high in relation to the values of 0.02-1.00 µg/g customarily reported in plants (Mengel & Kirkby 1979), and the figures for the present northern region are also high, with a mean of 3.84 µg/g and a range of 0.53-56.00 µg/g. The highest values are grouped in a single broad area (Fig. 5) which may be linked locally with a major precision steel works.

Lead is above all a roadside pollutant (Rühling & Tyler 1968, Takala & Olkkonen 1981) and is highly toxic to humans. The toxicity of its effects on plants is not fully understood, however. The mean lead concentration in the present lichen samples was 17.2 µg/g and the range 1.2-39.6 µg/g, compared with 18 µg/g and 1.0-62.0 µg/g for Finland as a whole. The major area with high concentrations occurred to the north of the more industrialized Kemi-Tornio district (Fig. 5).

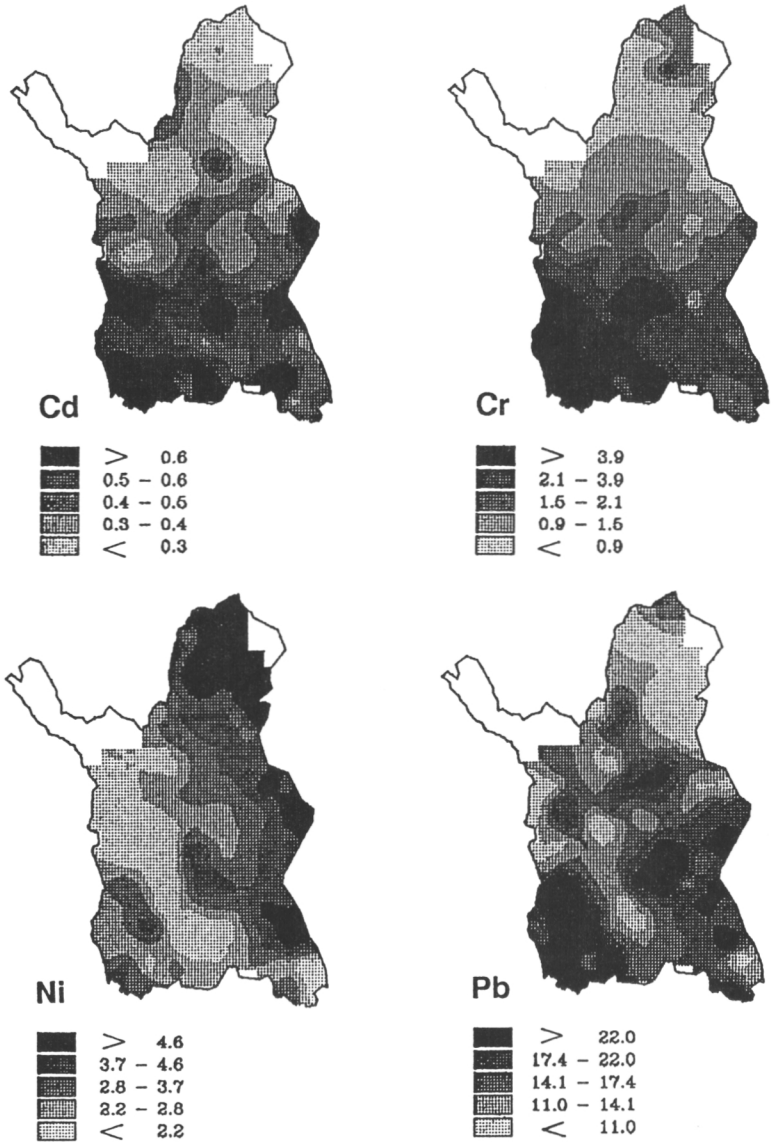


Figure 5. Areal variations in cadmium, chromium, nickel and lead concentrations in the lichen *Hypogymnia physodes* in the Forestry Board Districts of Lappi and Koillis-Suomi in 1986. Areas left blank are those from which no samples were collected. Concentrations are determined in µg/g of dry lichen.

Nickel is known to be toxic to plants, even though it is normally to be found in their tissues to the extent of 0.1-5.0 µg/g dry weight. Where large amounts of nickel are present in the soil, however, its concentrations in plants can be very much higher. The mean nickel content of the total set of lichen samples was 2.6 µg/g, with a range of 0.00-51 µg/g, with corresponding values of 3.8 µg/g, range 1.2-16.5 µg/g, for those from Lappi and Koillis-Suomi. The large area of high values in Lapland is confined to the eastern part of the region and in all probability is attributable to the major industrial areas on the Kola Peninsula of the U.S.S.R. in the Soviet Union.

Our knowledge of the function of aluminium in plants and of its necessity for plant life is still incomplete. It exists in the soil in large quantities and increases in solubility with increasing soil acidity, so that its toxic effects have been associated primarily with acid soils. The amounts encountered in plants vary within the range 100-1000 µg/g (Allen 1974).

The mean aluminium concentration of the present lichens was 276 µg/g, with a range of 119-516 µg/g, whereas the mean for the whole country was 480 µg/g, range 119-1358 µg/g. The major areas of high concentrations were in the southern part of the region and in Inari Lapland (Fig. 6).

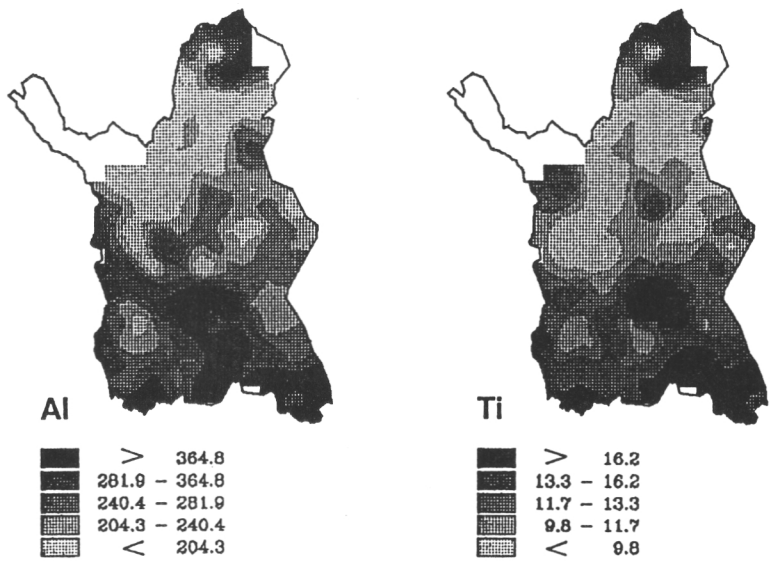


Figure 6. Areal variations in aluminium and titanium concentrations in the lichen *Hypogymnia physodes* in the Forestry Board Districts of Lappi and Koillis-Suomi in 1986. Areas left blank are those from which no samples were collected. Concentrations are determined in µg/g of dry lichen.

Titanium is an element about which little is known in relation to its effects on plants, and few analyses are available of its content in plant tissues. According to Allen (1974), its concentrations in plants vary in the range 0.4-8.0 µg/g, representing considerably lower figures than those recorded here, where the mean was 13.1 µg/g and the range 5.8-49.4 µg/g. The mean figure for Finland as a whole was still higher, 25.9 µg/g, with a range of 5.8-49.4 µg/g, the maximum value for the whole country having been measured in Lapland. The main areas with high concentrations were in the south-west, the central part of the region and Inari Lapland (Fig. 6).

Discussion

Many extensive series of tests have shown that lichens are particularly sensitive indicators of air pollution and can be used for this purpose in a variety of ways (see Ferry et al. 1973, Kauppi 1980, Nash III & Wirth 1988). Other plants used in the Nordic countries for mapping the distribution of heavy metals in particular are mosses, by means of which Rühling & Tyler demonstrated as early as 1971 that concentrations of certain heavy metals were as much as ten times greater in the southern parts of Scandinavia than in the north (Rühling & Tyler 1971). New moss samples were then collected in all the Nordic countries in 1985 and a set of maps published jointly to show the distribution of depositions of heavy metals over the whole region (Rühling et al. 1987). The present lichen-based survey is linked with this work insofar as the lichen samples were collected in southern part of Finland at the same time and from the same sites as the mosses and in the area presented in this paper in 1986, when the monitoring sites were established.

Comparison of the lichen results with those obtained from the mosses (Rühling et al. 1987) shows a high measure of correspondence in the areal patterns for chromium, iron and nickel concentrations, and also for copper. At the same time the maps for copper, cadmium, iron and lead are much more detailed when based on lichen samples, perhaps because there were more than four times more lichen samples available and twice as many means for clusters were available as there had been moss collection sites, although it also seems that lichens are more sensitive in this respect.

Apart from the metals, the concentrations of sulphur and nitrogen in the lichens offer some points of interest. The range of variation in sulphur content in a set of samples taken in different parts of Finland in 1979-81 (Takala et al. 1985) was 430-1010 µg/g from the same northern area with this study, whereas that reported here for the means of the clusters was 599-1249 µg/g. Since both surveys included some obvious "background samples", sulphur concentrations in the northern

part of Finland may be said to have increased in general in the early 1980's. It should be admitted, however, that the material obtained by Takala et al. (1985) was not particularly extensive.

The highest sulphur concentrations recorded in the lichens in southern Finland coincide well with the highest deposition of sulphur as determined in the model for this constructed for southern Finland (Kulmala 1985). As far as northern Finland is concerned, unofficial maps have been published in the press suggesting that deposition over extensive areas of eastern Lapland is of the same order as in the south of the country. The present results of this lichen material do not support this suggestion, however, but indicate that the highest figures in the region are to be found in the extreme north, beyond Lake Inari, as is also shown in the most recent unpublished models. Westman (1986) has specifically shown sulphur concentrations in *Hypogymnia physodes* to be high in places where deposition is high and low in places where this is low. It should be emphasized, however, that the lichen samples were collected in 1986 and that the situation discussed in this paper represents the year of collection and the time immediately preceding it.

It would seem, therefore, that since the predominant wind directions in northern Finland are towards the north-east, with a much lower frequency of winds blowing from the Kola Peninsula into Lapland or along the Finnish-Soviet border, sulphur does not accumulate in the lichens of eastern Lapland to the same extent as it does in the south-western corner of Lapland or in southern Finland. There is indeed some deposition from the Kola area on the Finnish side of the border, as observed here in the case of some of the metals, but the distribution of air-borne metal dusts would seem to be quite different from that of the predominantly gaseous sulphur and nitrogen emissions. Although the areal patterns for sulphur and nitrogen concentrations are similar, even to the occurrence of a peak in the extreme north of Lapland, it would be useful to conduct further experiments on the accumulation of sulphur in lichens under varying ambient conditions, and work to this effect is now in progress.

The distinct peaks in magnesium and calcium content in the north of Lapland are interesting. The results may have been dependent more on throughfall from the crowns of the trees than on any other factor, even though no connections with the occurrence of rich grass-herb forests can be detected. Although the areal variations in the occurrence of these elements which are of importance as plant nutrients are not of such immediate interest as those in detrimental substances, the major areas of high calcium and magnesium concentrations in Lapland must be of some significance and call for further investigation.

The elements determined here which are not essential for plant life are Cd, Cr, Ni, Pb, Al and Ti, of which the highest concentrations of Cd, Cr and Ni occur in the same area, close to the towns of Kemi and

Tornio. The other extensive area of high nickel concentrations is in eastern Lapland, where they coincide with accumulations of copper.

The present results serve to indicate what elements form the main factors in deposition from the air in different parts of the country, but they do not, of course, allow any conclusions to be reached on the absolute volumes of deposition, nor is any attempt made here to explain the effects of this deposition on the natural environment. They should, however, provide an excellent starting point for the targeting of research of this kind to the appropriate geographical areas and the identification of sites on which investigations of the effects of such air pollution should be focused.

Acknowledgements

The material for this survey was collected as part of the 8th National Forest Inventory, and a very large number of people were involved in the planning of the work, the fieldwork stage and the processing and analysis of the samples. While thanking all of these people, the author wishes to mention in particular the work of Anna-Liisa Mertaniemi and Sirpa Ronkainen, laboratory technicians at the Muhos Forest Research Station, and Jari Vanhatalo, Cand.Phil., who was responsible for the computer processing of the results, together with Albert Colpaert, Cand.Phil., of the Department of Geography, University of Oulu, who produced the interpolated contour maps. This paper was translated from Finnish into English by Mr. Malcolm Hicks.

References

Allen, S. E. (ed.). 1974. Chemical analysis of ecological materials. Blackwell Scientific Publications. Oxford. 565 p.

Ferry, B. W., Baddeley, M. S. & Hawksworth, D. L. (eds.). 1973. Air pollution and lichens. The Athlone Press of the University of London. 389 p.

Griffith, J. L. 1966. Some aspects of the effect of atmospheric pollution on the lichen flora to the west of Consett, Co. Durham. M.Sc. thesis, University of Durham.

Guderian, R. 1977. Air Pollution. Phytotoxicity of acidic gases and its significance in air pollution control. Ecological studies 22. 127 p.

Hawksworth, D. L. 1973. Mapping studies. In: Ferry, B.W., Baddeley, M.S. & Hawksworth, D.L. (eds.). Air pollution and lichens. The Athlone Press of the University of London. p. 38-76.

Kauppi, M. 1980. Methodological contributions on the use of lichens as a tool for studying air pollution. Acta Universitatis Ouluensis A 104. 22 p.

Kubin, E. 1989. Sulphur content of the epiphytic lichen Hypogymnia physodes as an indicator of atmospheric deposition in Finland. Meddelelser fra Norsk Institutt for Skogforskning 42(1): 109-120.

– 1990a. Sormipaisukarvejäkälän, Hypogymnia physodes, alkuainepitoisuudet Lapin ja Koillis-Suomen metsälautakuntien alueella 1986. In: Varmola, M. & Palviainen, P. (eds.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. Metsäntutkimuslaitoksen tiedonantoja 347: 131-140.

– 1990b. A survey of element concentrations in the epiphytic lichen Hypogymnia physodes in Finland in 1985-86. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer-Verlag, Berlin. p. 421-446
Kulmala, A. 1985. Air quality in Finland. In: Symposium on the effects of air pollution on forest and water ecosystems. The Foundation for Research of Natural Resources in Finland. Esan kirjapaino Oy, Lahti. p. 3-15.
Kuusela, K. & Salminen, S. 1969. The 5th national forest inventory in Finland. General design, instructions for field work and data processing. Communicationes Instituti Forestalis Fenniae 69(4). 72 p.
Larcher, W. 1975. Physiological plant ecology. Springer-Verlag, Berlin, Heidelberg. 252 p.
Mengel, K. & Kirkby, E. A. 1979. Principles of plant nutrition. AG, Bern, Switzerland. 2nd Edition. 593 p.
Nash III, T. H. & Wirth, W. (eds.). 1988. Lichens, bryophytes and air quality. Bibliotheca Lichenologica 30.
O'Hare, G. P. 1974. Lichens and bark acidification as indicators of air pollution in west central Scotland. Journal of Biogeography 1: 135-146.
– & Williams, P. 1975. Some effects of sulphur dioxide flow on lichens. Lichenologist 7:116-120.
Ruhling, Å. & Tyler, G. 1968. An ecological approach to the lead problem. Botaniska Notiser 121: 321-342.
– & Tyler, G. 1971. Regional differences in the deposition of heavy metals over Scandinavia. Journal of Applied Ecology 8: 497-507.
–, Rasmussen, L., Pilegaard, K., Mäkinen, A. & Steinnes, E. 1987. Survey of atmospheric heavy metal deposition in the Nordic countries in 1985. Nord. 21. 44 p.
Takala, K. & Olkkonen, H. 1981. Lead content of an epiphytic lichen in the urban area of Kuopio, east central Finland. Annales Botanici Fennici 18:85-89.
–, Olkkonen, H., Ikonen, J., Jääskeläinen, J. & Puumailainen, P. 1985. Total sulphur contents of epiphytic and terricolous lichens in Finland. Annales Botanici Fennici 22:91-100.
Valtakunnan...1986. Valtakunnan metsien 8. inventointi. Pysyvien koealojen kenttätyön ohjeet 1985-86. 2. painos. Metsäntutkimuslaitos, Metsänarvioinnin tutkimusosasto. Metsäninventoinnin tutkimussuunta. 83 p.
Westman, L. 1986. Lavars indikatorvärde vid studier av luftföroreningar och skogsskador. Statens Naturvårdsverk Rapport 3187. 52 p.

Tissue and cellular effects of air pollutants on coniferous trees

Sirkka Sutinen
Finnish Forest Research Institute,
Suonenjoki Research Station
SF-77600 Suonenjoki, Finland

Abstract

The needles of spruce (*Picea abies* L. Karst.) and those of pine (*Pinus sylvestris* L.) trees exposed to ozone (40-300 µg/m3), ozone plus sulphur dioxide (30 and 150 µg/m3) and acid rain (pH 3.0 and 5.6) were studied at light and electron microscopical level. The results showed e.g., that cell injuries occurred when conifers were exposed to ambient and moderately elevated concentrations of ozone and sulphur dioxide and acid rain with pH 3.0. Furthermore, the results also showed that different pollutants affected the structure of the needles on their own specific ways. This observation increases the value of structural studies as a tool for diagnosing the cause-effect relationships in trees becoming damaged in the field.

Introduction

Many parts of Europe are experiencing forest decline. The reason for this decline is not clear but air pollutants are considered important as pollution adds stress to trees (McLaughlin 1985). The aim of the present investigation was to study whether ambient concentrations of ozone, sulphur dioxide and acid rain affects conifers and to characterize structural changes occurring in the needles of spruce and pine exposed to these pollutants.

Material and methods

The plant material consisted of clones of spruce (*Picea abies* L. Karst.) and seedborne pine (*Pinus sylvestris* L.). One part of the experiment was carried out in eight climate chambers in Neuherberg, FRG, as follows:

1. 40 µg/m3 ozone for 9 hours per day
2. 100 µg/m3 ozone for 9 hours per day
3. 150 µg/m3 ozone for 3 hours per day

4. 300 µg/m3 ozone for 3 hours per day
5. 40 µg/m3 ozone for 9 hours per day + 150 µg/m3 sulphur dioxide for 3 hours per day
6. 150 µg/m3 ozone for 3 hours per day + 30 µg/m3 sulphur dioxide continuously
7. and 8. filtered air. (For more detailed information see Sutinen 1987a).

The other experiment was carried out in open-top chambers at the Rörvik Experimental Station in Sweden during the summers 1985, 1986 and 1987. Three concentrations of ozone were used (7 h seasonal mean):

1. non-filtered air (about 55 µg/m3 ozone)
2. non-filtered air added with extra ozone (about 90 µg/m3 ozone)
3. charcoal filtered air (about 10 µg/m3 ozone). (For more detailed information see Sutinen et al. 1990)

The acid rain experiment was carried out at the Suonenjoki Research Station, Finland, in summer 1988. The plant material was pine (*Pinus sylvestris* L.) and the pH of the artificial rain water was 5.6 and 3.0.

At the time of sampling, which took place in Germany shortly after the end of the fumigation period, in Sweden from February 1985 to October 1987 and in Finland in September 1988, all trees were visibly healthy-looking. The results reported here concern green current and one-year-old needles observed both at the light and electron microscopical level.

Results

Intact cell structure of needles of young as well as mature spruce and pine needles are characterized by granular tannin, light cytoplasm and lens-shaped chloroplasts. The chloroplasts have light stroma, a well-developed thylakoid system, a small amount of plastoglobuli and starch grain during the growing season (Soikkeli 1980, Sutinen et al. 1990). This kind of intact cell structure (Figs. 1a and 1b) was characteristic for all the control needles of treatments presented here.

All concentrations of ozone induced the same type of cell injury and same advance of tissue damage in needles of both spruce and pine (Sutinen 1987b). Changes appeared first in the outer cell layer of the sky side of the needles. The damage then gradually advanced down to the ground side of the needles (Fig. 2a).

A gradual advance of damage was also observed within individual cells. Ultrastructural changes were first observed in the choloroplasts. The size of chloroplasts decreased and the smaller the chloroplasts be-

came the denser the stroma became. At the same time accumulation of ribosome-like granules could be seen together with a decrease in the size of starch grains. An increase of plastoglobuli could also be observed especially on the sky side of the needles (Fig. 2b). The second organelle to be affected was the microbody, and the last one the mitochondria. At a later stage the cytoplasm was also disintegrated.

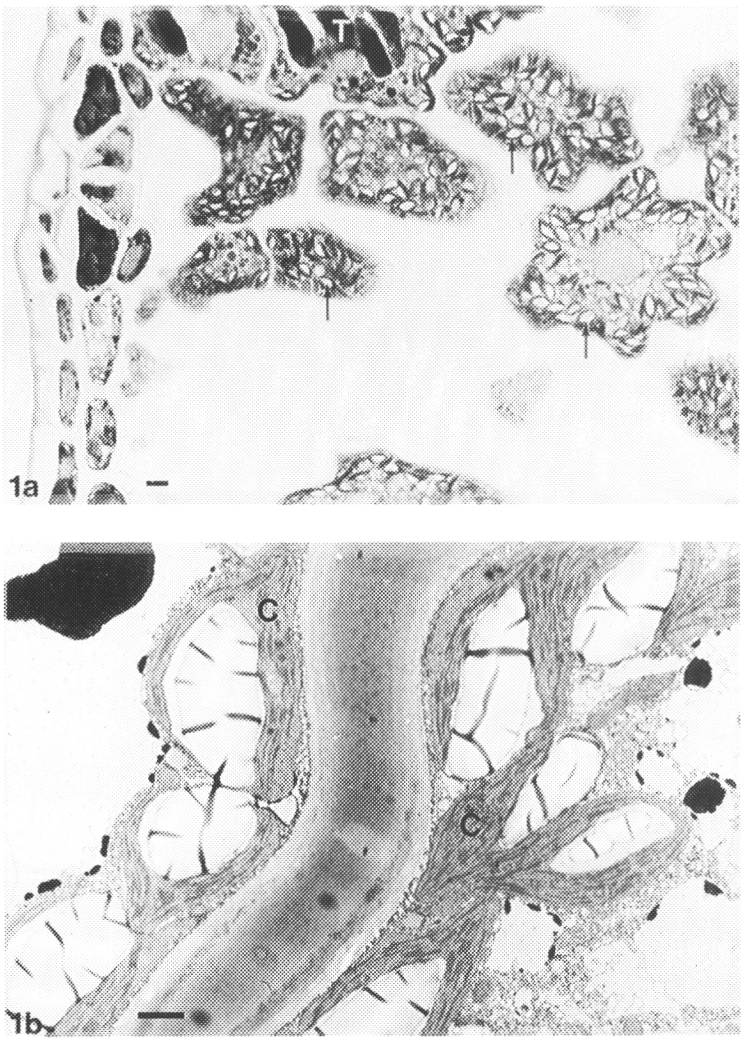
Fumigations with ozone and sulphur dioxide caused the same injuries as with ozone, but the injury was much more severe than with ozone alone (Fig. 3a). Other changes could also be seen. E.g. needles exposed to 150 µg/m^3 ozone for 3 hours per day and 30 µg/m^3 sulphur dioxide continuously had extremely small chloroplasts, whose shapes were like tadpoles or worms. Grana stacks were often very thin or totally reduced (Fig. 3b). The changes caused by ozone alone and ozone plus sulphur dioxide were more advanced in older than in younger needles.

The change induced with acidified water (ph = 3.0) was characterized by the ribboning of the tannin in the central vacuole (Fig. 4a) at the light microscopical level. The change was seen evenly scattered in the mesophyll tissue without any graduality as seen in ozone-exposed needles. The first change seen in the fine structure was the vesiculation of the plasmalemma as well as the vacuolisation of the cytoplasm (Fig. 4b).

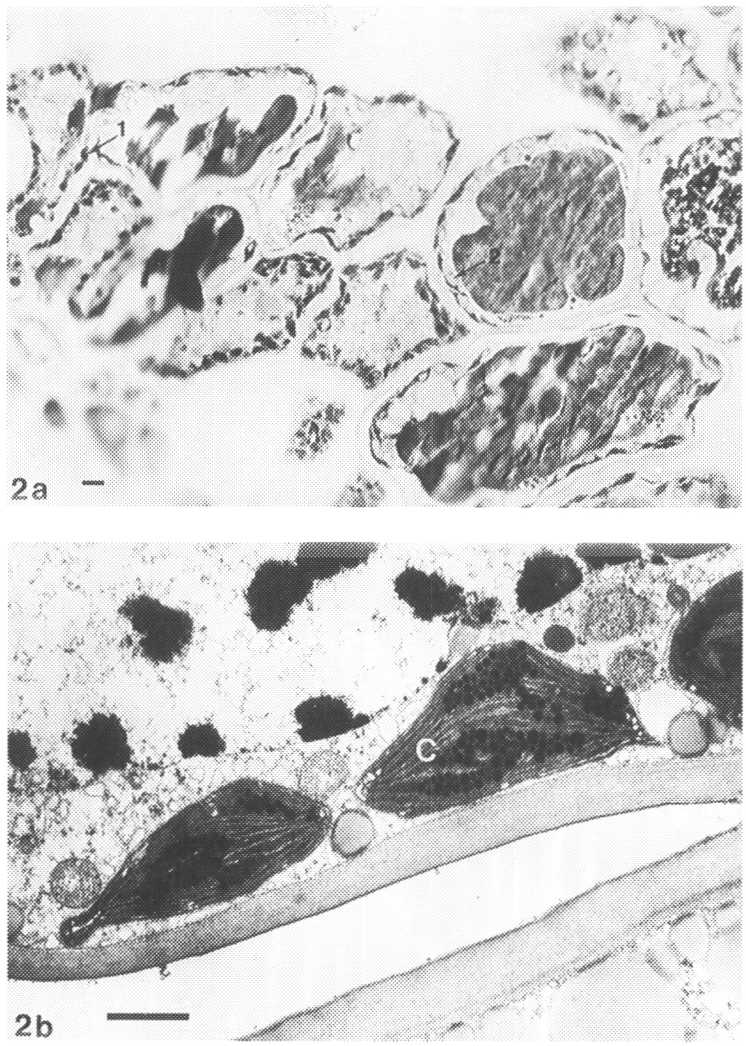
Conclusions

The results from these investigations have shown that remarkable cell injuries occurred when conifers were exposed to ambient and moderately elevated concentrations of ozone and sulphur dioxide and acid rain with pH 3.0. The results also showed that these changes occurred well before any visible changes were observed. As the ozone and sulphur dioxide concentrations used in the studies are within the concentrations found in Europe (see e.g. Koziol & Whatley 1984, Grennfelt et al. 1987) negative effects of these pollutants of forest trees can be expected over wide regions in Europe.

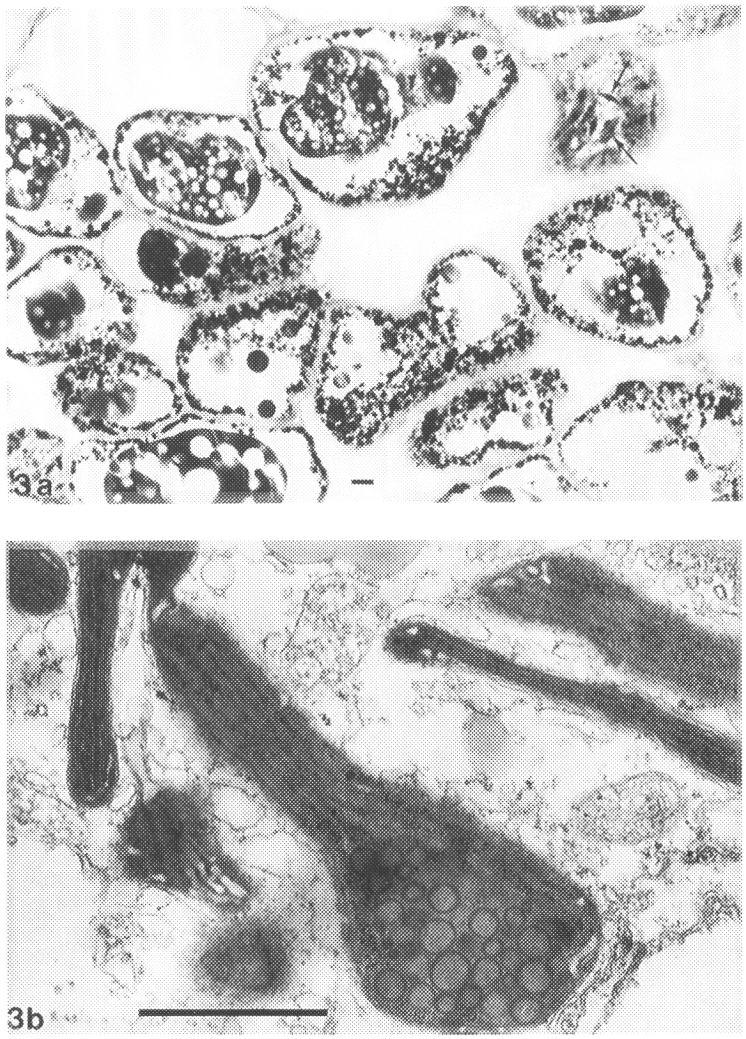
The results also indicated that different pollutants here affected the structure of the needles on their own specific ways. The changes described here are also different from those caused by SO_2 (e.g. Kärenlampi & Houpis 1986), by fluorides (Soikkeli & Tuovinen 1979) or by chlorine (Reinikainen & Kärenlampi 1987). Furthermore, the changes reported here differ also from those induced by nutrient deficiency (Holopainen & Nygren 1989), by frost (Soikkeli & Kärenlampi 1984), by drought stress (S. Sutinen, data not published) and by the ageing of the needles (Sutinen 1987c). The characteristic symptoms of each stress factor studied so far increase the value of structural studies, when a tool is sought for diagnosing the cause-effect relationships in trees becoming damaged in the field.



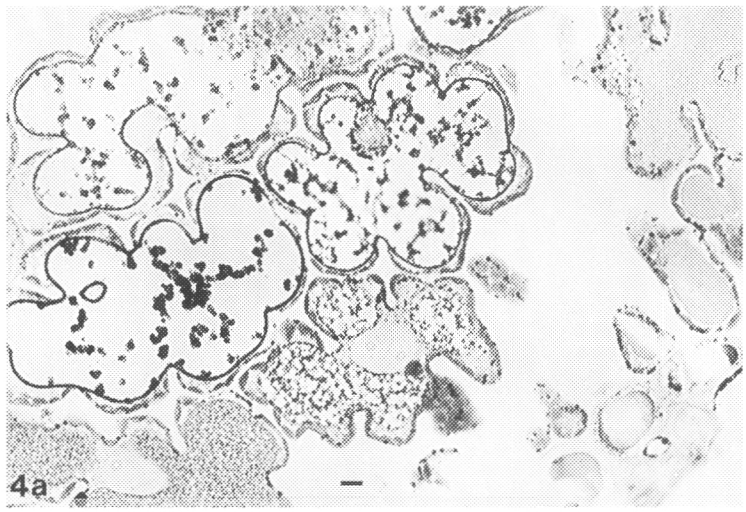
Figures 1a. and 1b. Light and electron microscope pictures of a needle of Norway spruce exposed to filtered air in an open-top chamber at the Rörvik Experimental Station in Sweden. The needle was sampled on April 7, 1986. Fig. 1a. The cells have light cytoplasm, normal granular tannin (T) as well as intact chloroplasts with starch grains (arrows). Bar = 6 µm. Fig. 1b. The intact chloroplasts (C) have light stroma, a well-developed thylakoid system and starch grains. Bar = 1 µm.

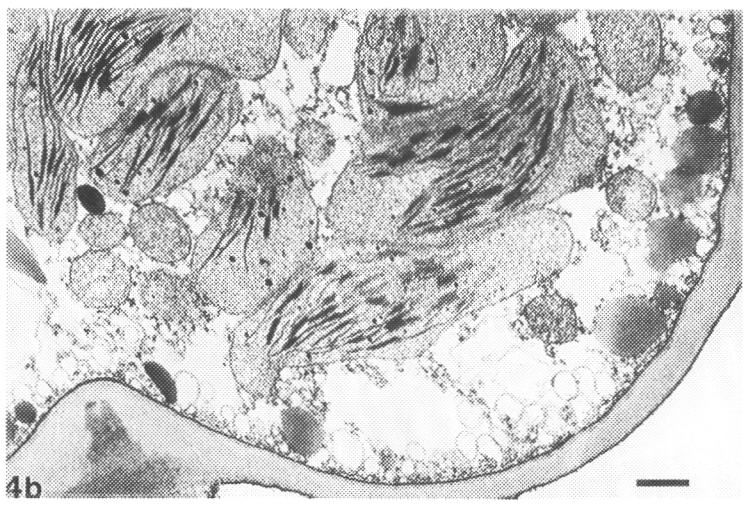


Figures 2a. and 2b. Light and electron microscope pictures of a needle of Norway spruce exposed to ozone in an open-top chamber at the Rörvik Experimental Station in Sweden. The needle was sampled on April 7, 1986. Fig. 2a. Comparison of the size of chloroplasts near the epidermis (arrow 1) to that in the innermost cells (arrow 2) shows the gradual advance of the ozone-induced change. Bar = 6 µm. Fig. 2b. The chloroplasts (C) with reduced size have electron-dense, granulated stroma, an increased amount of plastoglobuli and no starch grains. Bar = 1µm.



Figures 3a. and 3b. Light and electron microscope pictures of a needle of Norway spruce exposed simultaneously to ozone (150 µg/m³ 3h/day) and sulphur dioxide (30 µg/m³ 24 h/day) in a laboratory fumigation chamber in Neuherberg, FRG. The needle was sampled on January 19, 1986. Fig. 3a. The chloroplasts are so small that they can be resolved only in the innermost cells (arrows). Bar = 6 µm. Fig. 3b. The minute chloroplasts have electron-dense, granulated stroma as well as an abnormal shape. Bar = 1 µm.





Figures 4a. and 4b. Light and electron microscope pictures of a needle of Scots pine exposed to acidified water (pH = 3.0) in an open field experiment at the Suonenjoki Research Station in Finland. Fig. 4a. The effect of acid rain can be seen in the ribboning of the tannin (arrows). The cells with normal granular tannin can be seen as well. Bar = 1 μm. Fig. 4b. Observe the vesiculation of the plasmalemma (arrows) as well as heavily vacuolated cytoplasm. Bar = 1 μm.

References

Grennfelt, P., Saltbones, J. & Schojoldager, J. 1987. Oxidant data collection in OECD-Europe 1985-87 (oxidate) NILU, OR 22.

Holopainen, T. & Nygren, P. 1989. Effects of potassium deficiency and simulated acid rain, alone and in combination, on the ultrastructure of Scots pine needles. Canadian Journal of Forest Research 19: 1402-1411.

Kärenlampi, L. & Houpis, J.L.J. 1986. Structural conditions of mesophyll cells of Pinus ponderosa var. scopulorum after SO_2 fumigation. Canadian Journal of Forest Research 16: 1381-1385.

Koziol, M.J. & Whatley, F.R. 1984. Gaseous air pollution and plant metabolism. Butterworths. 466 p.

McLaughlin, S.B. 1985. Effects of air pollution on forests. Journal of Air Pollution Contral Association 35: 512-534.

Reinikainen, J. & Kärenlampi, L. 1987. Tissue and cell injuries caused by chlorine water to Scots pine needles. European Journal of Forest Pathology 17: 12-18.

Soikkeli, S. 1980. Ultrastructure of the mesophyll in Scots pine and Norway spruce: Seasonal variation and molarity of the fixative buffer. Protoplasma 103: 241-252.

– & Kärenlampi, L. 1984. The effects of nitrogen fertilization on the ultrastructure of mesophyll cells of confer needles in northern Finland. European Journal of Forest Pathology 14: 129-136.

– & Tuovinen, T. 1979. Damage in mesophyll ultrastructure of needles of Norway spruce in two industrial environments in central Finland. Annales Botanici Fennici 16: 50-64.

Sutinen, S. 1987a. Ultrastructure of mesophyll cells of spruce needles exposed to O_3 alone and together with SO_2. European Journal of Forest Pathology 17: 362-368.

– 1987b. Effects of ozone on the ultrastructure of needles of pine, Pinus silvestris, and spruce, Picea abies. In: Air pollution research report 4. Direct effects of dry and wet deposition of forest ecosystem - in particular canopy interactions. Proceedings of a workshop jointly organised by the Comission of the European Communities, the Swedish University of Agricultural Sciences and the Institute of Environmental Research, Lökeberg 19-23 October 1986. p. 167-170.

– 1987c. Cytology of Norway spruce needles. I. Changes during ageing. European Journal of Forest Pathology 17: 65-73.

–. Skärby, L., Wallin, G. & Sellden, G. 1990. Long term exposure of Norway spruce, Picea abies (L.) Karst., to ozone in open-top chambers. II. Effects on the ultrastructure of needles. New Phytology 115: 345-355.

Field experiments on the effects of pollution at Kevo Subarctic Research Station

Seppo Neuvonen
University of Turku, Department of Biology
SF-20500 Turku, Finland

Abstract

An experiment aimed to study the effects of simulated acid rain in a subarctic area with low ambient pollution level is described. The experimental set-up followed randomized blocks design with 20 replicate plots of four different treatments. The treatments included dry controls, irrigated controls and two acid rain treatments (pH 4 and pH 3). The mass loss of pine and birch litter was significantly lower on acid treated than on irrigated control plots. The quality of foliage for some insect species was enhanced by the acid rain treatments but most of the species tested did not show a significant response. Acid rain treatment affected the interaction between *Neodiprion sertifer* and its viral disease: the larvae fed on control foliage suffered significantly more from virus application than larvae which were fed with needles from acid (pH 3) treated trees.

Introduction

In spite of large research efforts the effects of "acid rain" (or air pollutants in general) on different components of the ecosystem are poorly known. Changes in plants or in ecological processes have often been reported for sites close to sulphuric emission sources or in combination with rather drastic experimental acidification. The interpretation of the first type of studies is complicated by the possibility that the changes may be explained by the effects of pollutants other than sulphuric emissions or even by factors not related to pollution (cf. Leith & Fowler 1987). Controlled and well replicated field experiments with realistic pollutant concentrations are thus necessary for revealing causal links between pollutants and ecological processes. Furthermore, it is important that the experiments last several years, because changes associated with acid rain are often slow and their direction may even change in different phases of acidification.

I will describe studies with the aim to investigate the effects of artificial acid rain and heavy metals in a subarctic area with low ambient pollutant loads but with harsh environmental conditions. I concentrate on the effects of simulated acid rain on interactions between trees

(Scots pine and mountain birch) and their insect herbivores and on litter decomposition (for a more detailed review, see Neuvonen et al. 1990b).

Experimental set-up

The study was conducted in a mixed pine - mountain birch woodland near the Kevo Subarctic Research Station (69° 45' N, 27° 00' E), in northern Finland. Kevo is situated about 60 km north of the continuous Scots pine forests, but in the river valleys around Kevo there is one of the northernmost pine stands in the world. The mean annual temperature is -2.0°C and the mean annual precipitation is about 390 mm (30-40 % falling as snow). Minimum winter temperatures fall often below -40 °C.

In 1985 80 study plots of about 5 m * 5 m (each having at least one pine and one mountain birch) were selected from an area of about 3 hectares. The height of pines varied from 2.5 to 5.5 m and that of mountain birches from 1.5 to 6 m.

To guarantee a good interspersion of treatment replicates the study area was divided into 20 blocks of four plots, and within each block each plot was given randomly one of four treatments: dry controls (DC) with no additional irrigation; irrigated controls (IC), which were treated with spring water of pH 6; pH 4-treatment (A4); and pH 3-treatment (A3). The water for the A4 and A3 treatments was prepared by adding both sulfuric and nitric acids to the control water. Treatments IC, A4 and A3 received similar of artificial rain (60 mm/month during summer), applied with sprinklers over the canopy, three times (about 5 mm per occasion) per week. The amounts of sulphur and nitrogen applied during the first four years are shown in Table 1.

Table 1. Cumulative amounts of sulphur (S) and nitrogen (N) added by spring water irrigation (IC) and simulated acid rain treatments (A4 & A3) after each field season in 1985-1988.

	Amounts of S & N added by treatments					
	S mg m^{-2}			N mg m^{-2}		
	IC	A4	A3	IC	A4	A3
After -85	25	155	505	5	50	175
After -86	145	645	2905	25	200	995
After -87	245	1095	5205	40	335	1780
After -88	360	1590	7840	60	490	2680

The ambient levels of sulphur and nitrogen deposition at Kevo Station in 1985 to 1987 were as follows: 152 mg (m^2 year)$^{-1}$ SO_4-S, 32 mg (m^2 year)$^{-1}$ NH_4-N, and 40 mg (m^2 year)$^{-1}$ NO_3-N. The A3-treatment was about 15-fold to the ambient sulphur load and about 11-fold to the ambient nitrogen load, but was still within the range of deposition over wide areas in Europe.

Measurement of responses

Our aim has been to study the effects of simulated acid rain on the quality of foliage for herbivorous insects and on the rate of mass loss of leaf or needle litter. Foliage quality was assessed with bioassays. In our terminology good foliage quality means that an insect species has high growth and/or reproduction rates on that foliage.

It is probable that different insect species do not respond similarly to the chemical and/or physical changes in foliage quality caused by simulated acid rain. Thus we have used several insect species in bioassays to get a picture of the variation in responses among different insect groups. The specific names of experimental animals are shown in table 2.

The effects of treatments were generally assessed by analysis of variance. With some insect species we used bioassays to measure the quality of host foliage in 1985 (before the treatments were begun), and this value was used as a covariate when analysing data subsequent bioassays.

Table 2. Insect species used in bioassaying the effects of simulated acid rain on foliage quality.

	On *Pinus sylvesteris*	On *Betula pubescens* ssp.*tortuosa*
Chewing insects		
Lepidoptera:	*Panolis flammea*	*Epirrita autumnata, Erannis defoliaria*
Hym., Symphyta:	*Neodiprion sertifer* *Diprion pini*	*Dineura virididorsata, Arge* sp.
Sucking insects		
Aphids:	*Schizolachnus pineti,* *Cinara pinea*	*Euceraphis punctipennis,* *Berulaphis quadrituberculata*

The effects of simulated acid rain on herbivorous insects

In general, our results with birch feeding aphids show that their performance on pH 3 treated trees was consistently higher than on IC-trees. Our previous experiments in southern Finland showed that simulated acid rain of pH 3.5 (only H_2SO_4) enhanced the performance of *Euceraphis betulae* especially during periods which were drier than average (Neuvonen & Lindgren 1987). In five of the six bioassays with pine feeding aphids the reproduction of aphids was higher on acid treated (pH 3 and/or pH 4) than on irrigated control pines. Although the quality of foliage for aphids was enhanced by the acid rain treatments, most of the leaf or needle chewers tested did not show a significant response.

Two series of experiments were designed to reveal the effects of simulated acid rain on the interactions between different trophic levels. The first deals with the damage-induced decrease in the quality of birch foliage, and the second with the interaction between the European pine sawfly and its virus disease. Damage-induced changes in foliage quality may be important for the population dynamics of fores insects, since they may act as density-dependent feedbacks (with or without time lags) and may thus regulate insect population densities (Haukioja & Neuvonen 1987). Especially the delayed damage-induced increase in the resistance of host tree foliage (i.e. the lower quality of leaves in the year(s) following partial defoliation) seems to play an important role in the population dynamics of the autumnal moth, *Epirrita autumnata* (Haukioja et al. 1988). This delayed induced resistance introduces a time-lag to the negative feedbacks regulating the population dynamics of insects and is one of the factors generating cyclic density fluctuations in *E. autumnata*. We have started an experiment studying the interactive effects to the acid rain treatments and partial defoliation of mountain birch foliage on the expression of the delayed induced resistance against *E. autumnata*. Defoliation had a significant negative main effect on the pupal weights of *E. autumnata*. Moreover, the results suggested an interaction between defoliation and acid rain treatments: the negative effects of defoliation on the quality of birch foliage in the subsequent year were stronger with acid treated than with control birches. Further experiments are necessary to reveal whether this kind of interaction affects the frequency or amplitude of cyclic fluctuations in the density of *E. autumnata* (cf. Neuvonen 1990).

The effects of simulated acid rain on the susceptibility of European pine sawfly (*Neodiprion sertifer*) to its nuclear polyhedrosis virus were studied with bioassays in 1987 and 1989. Acid rain treatment affected the interaction between *Neodiprion sertifer* and its viral disease: the proportion of larvae surviving after virus application was significantly higher than on control foliage when the larvae were fed with needles from acid treated trees (Neuvonen et al. 1990a). Our results showed that the interaction between *N. sertifer* larvae and the nucleopolyhedro-

sis virus depended on the quality of host foliage and, furthermore, that simulated acid rain may delay the mortality of *Neodiprion* larvae to the viral disease.

The effects of simulated acid rain on the decomposition of pine and birch litter

After 2 or 3 years of incubation the mass loss of pine and birch litter was significantly lower on acid treated than on irrigated control plots especially on drier vegetation types (Neuvonen & Suomela 1990). This indicates that even small additions in acid deposition may retard the decomposition rate of both coniferous (pine) needle and deciduous (birch) leaf litter. Our experiments suggested that the reduction in decomposition due to acid treatments was caused by changes in the incubation sites and not by changes in litter quality. Studies on soil microbiology in the experimental plots suggest that a reduction in the amounts of bacteria in different physiological groups (e.g. those utilizing cellulose, starch, pectin, xylan and protein; Kytöviita et al. 1990) may at least partially explain the reduced decomposition rate.

We have also started experiments studying the effects of emission from Nickel on litter decomposition. Pine needle litter is incubated at different sites on a gradient from Svanvik, Norway (close to Nickel), to Kaamanen, Finland. Humus samples and needle litter from these sites has also been transported to the plots of the simulated acid rain experiment at Kevo. The factorial design of this experiment facilitates the separation of effects of humus and litter quality (pollution gradient) and simulated acid rain.

Concluding remarks

It is obvious that the effects of mild "acid rain" in the nature are often subtle and have a long lag-phase. Consequently, it is not surprising that the results discussed here (concerning only the first four years of the experiment) show only few statistically significant effects of acid treatment. However, in spite of the high level of natural variation among the plots we found some interesting and statistically significant acid treatment effects. Furthermore, other research groups have used this experiment in their studies and found significant negative effects of acid irrigation of e.g. epiphytic microflora on birch leaves and on pine needles (Helander & Rantio-Lehtimäki 1990, Ranta 1990) and on mycorrhizas.

The results obtained until now make continuation of the experiment worthwile. Some modification in the experimental system has been done, starting from summer 1989. The most important modification

concerns the composition of the simulated "acid rain". From 1985 to 1988 we have used a mixture of both sulphuric and nitric acids, but from 1989 onwards also sulphuric or nitric acids alone has been applied on some plots.

New factorial experiments will be started in 1990 with the aim of studying the effects of simulated acid rain (sulphuric acid) and heavy metals on the interactions between Scots pine, insects, endo- and epiphytic fungi and diseases.

References

Haukioja, E. & Neuvonen, S. 1987. Insect population dynamics and induction of plant resistance: The testing of hypotheses. In: Barbosa, P. & Schults, J. (eds). Insect Outbreaks. Academic Press. p. 411-432.

–, Neuvonen, S., Hanhimäki, S. & Niemelä, P. 1988. The autumnal moth in Fennoscandia. In: Berrymann, A.A. (ed.). Dynamics of Forest Insect Populations; Patterns, Causes, and Management Strategies. Plenum Press. p. 163-178.

Helander, M.L. & Rantio-Lehtimäki, A. 1990. Effects of watering and simulated acid rain on quantity of phyllosphere fungi of birch leaves. Microbial Ecology 19: 119-125.

Kytöviita, M., Fritze, H. & Neuvonen, S. 1990. The effects of acidic irrigation on soil micro-organisms at Kevo, northern Finland. Environmental Pollution 66: 21-31.

Leith, I.D. & Fowler, D. 1987. Urban distribution of Rhytisma acerinum (Pers.) Fries (tar spot) on sycamore. New Phytologist 108: 175-181.

Neuvonen, S. 1990. Interactions between acid rain and the population dynamics of forest pests. Proceedings on the "Soviet-Finnish Symposium of Factors of Herbivores Population Dynamics" at Novosibirsk, 26 - 28 August 1986. In press.

– & Lindgren, M. 1987. The effects of simulated acid rain on performance of the aphid Euceraphis betulae (Koch) on silver birch. Oecologia (Berlin) 74: 77-80.

– & Suomela, J. 1990. The effect of simulated acid rain on pine needle and birch leaf litter decomposition. Journal of Applied Ecology. 27: 857-872.

–, Saikkonen, K. & Haukioja, E. 1990a. Simulated acid rain reduces the susceptibility of the European pine sawfly (Neodiprion sertifer) to its nuclear polyhedrosis virus. Oecologia 83: 209-212.

–, Suomela, J., Haukioja, E., Lindgren, M. & Ruohomäki, K. 1990b. Ecological effects of simulated acid rain in a subarctic area with low ambient sulphur deposition. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin. p. 477-493.

Ranta, H. 1990. Effects of simulated acid rain on epiphytic and endophytic microfungi of Scots pine (Pinus sylvestris L.). Environmental Pollution. 67: 349-359.

Effects of acid irrigation on conifer seedlings

Jaana Reinikainen, Minna Turunen and Satu Huttunen
University of Oulu, Department of Botany
SF-90570 Oulu, Finland

Abstract

A long-term acid rain irrigation experiment showed this treatment to affect the survival and viability of Norway spruce and Scots pine seedlings and the ability of their needles to withstand desiccation and low temperatures. Deterioration of the epicuticular waxes and cellular membranes had an effect on the photosynthetically active needle mass. Norway spruce was observed to be more susceptible to indirect acid rain effects than Scots pine, whereas the latter exhibited significant cellular damage and disturbances in the surface wax layers. These effects were seen more clearly in the northern provenances of the conifers.

Introduction

Plants growing in the extreme north have evolved special mechanisms for resisting the potentially fatal strains caused by the environmental factors which detract from growth, e.g. low temperature sum or periods of severe coldness. These mechanisms include adaptation to a short growth period, protective cuticular structures and special mechanisms for adaptation to the cold, during the hardening period (e.g. Tranquillini 1976, Sakai & Larcher 1987).

The responses of plant organs to air pollutants such as acid rain can be reflected via an indirect effect on these protection mechanisms or on growth, or via direct injuries to the assimilating and protecting organs (Evans & Curry 1979, Percy 1986, 1987), while susceptibility to damage caused by cold or pathogens increases due to the diminished viability of the trees (Elstner et al. 1985, Davison & Barnes 1986).

Material and methods

An acid rain experiment was established in 1986 in the central Finland (Oulu 65 °N), with two to four-year old Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L. Karst.) seedlings of 29 provenances. The canopy of the seedlings was sprayed with water of pH 3 or pH 4 (simulating acid rain) or clean water three times a week during the

summer months, corresponding to a rainfall of 5 mm each time. The acid rainwater was prepared with H_2SO_4:HNO_3 in the ratio 2:1 (vol:vol). All the plants also received the natural rainfall of 50 - 60 mm/month, and a dry control group was included which received no additional water.

The seedlings were sampled monthly for scanning and transmission electron microscopy in order to gain information on their hardening rhythm and the damage caused by the acid rain treatment. Visual damage symptoms occurring in needles were kept under observation, as was the growth and viability of the seedlings. The exposure and sampling procedures are discussed in detail in Huttunen et al. (1990).

Results and discussion

No visible acid rain damage was seen on the needles of any of the treated seedlings within the three years, but evaluation of seedling viability revealed that especially the northern spruce seedlings receiving pH 3 treatment were suffering from excess acidity and were in very poor condition after two summer's irrigation (Fig. 1) (Huttunen et al. 1990). The viability of seedlings decreased during the exposure time in all exposure groups, although the dry control seedlings were in the best condition throughout.

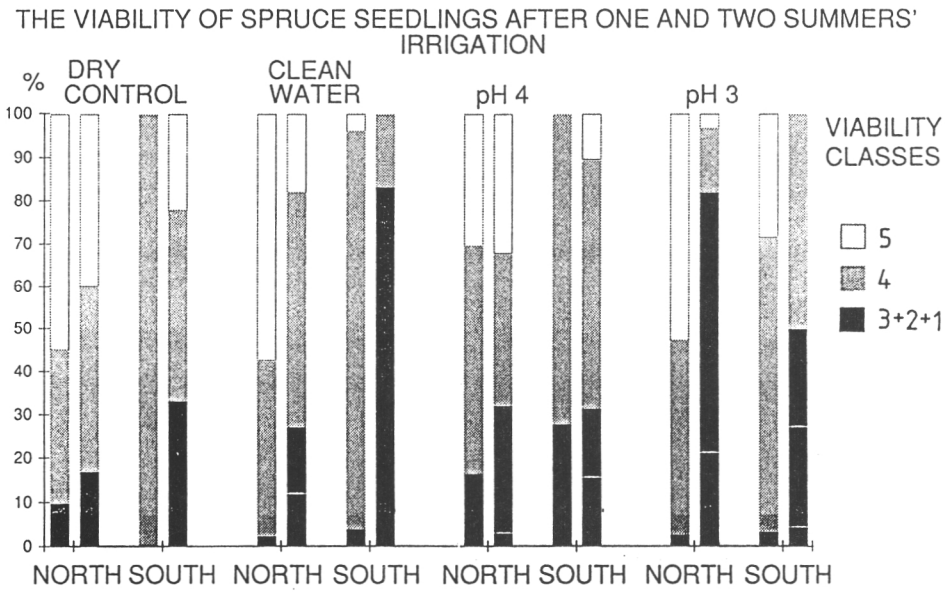
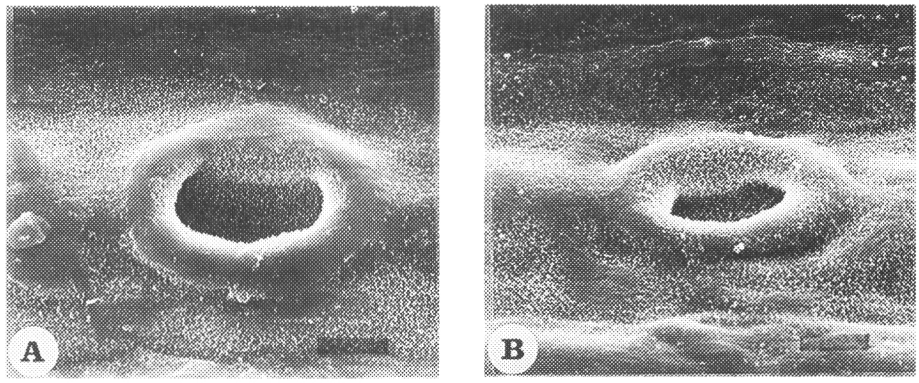


Figure 1. Viability of northern and southern provenances of spruce seedlings after one (left bar) and two (right bar) summers' irrigation with acid rain. Seedling viability classes 3+2+1: poor or fairly poor condition, class 4: good condition, class 5: excellent condition.

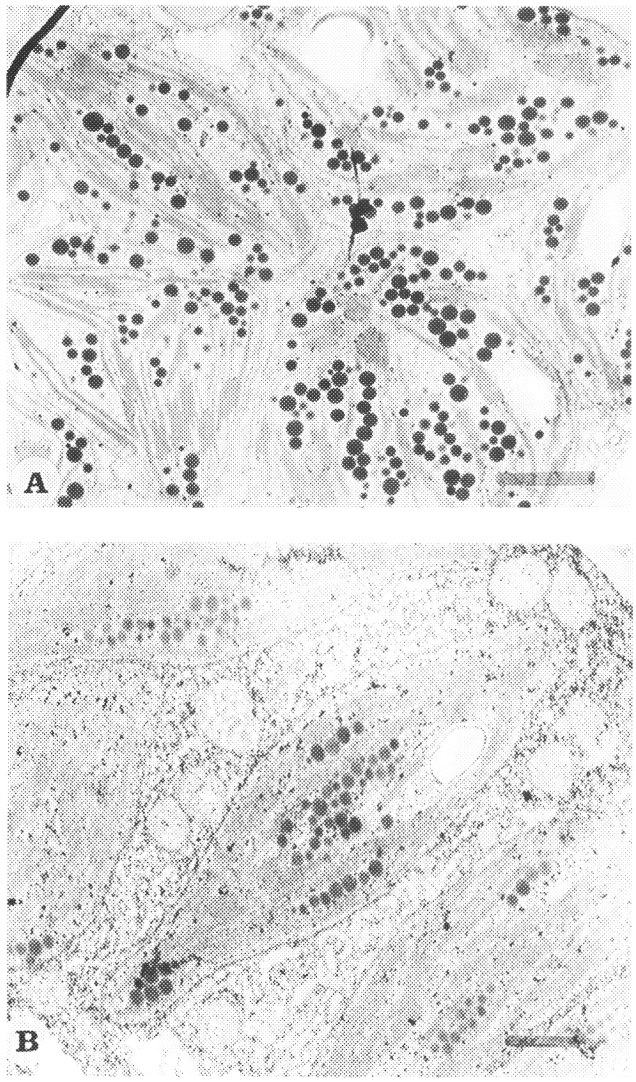


Figures 2a. and 2b. Pine needles after one summer's irrigation. Bar = 10 µm. Fig. 2a. pH 3 -irrigation in September. Provenance Muhos (Oulu region), current year needle. Development of the epicuticular wax structure is markedly delayed, the marginal epicuticular wax has not been crystallized and the stoma has remained half open. Fig. 2b. pH 3 -irrigation in January, provenance Muhos (Oulu region), current year needle. This needle at the wintering stage has no protective crystalloid waxes on the stoma.

The fact that the clean water treatment caused poor viability in the southern spruce seedlings may be related to the excess of water and increased infections with pathogenic fungi such as *Ascocalyx* sp. and *Lophodermium* sp. The detrimental effect of clean water of pH about 7 points to the significance of water balance for maintaining maximum growth efficiency and seedling viability.

Scanning electron microscope observations revealed delayed undeveloped cuticular structures in the pine needles after acid rain irrigation (Turunen & Huttunen 1990) (Figs. 2a and 2b), and the accumulation of piles of $CaSO_4$ crystalloids on the needle surfaces was also a characteristic effect of acid rain treatment (Turunen & Huttunen 1989, Huttunen et al. 1990, Turunen 1990).

Light microscopy of the visually uninjuried needles showed the most intercellular space to exist in the pH 4 -treated northern spruce provenance during the hardening period (Reinikainen 1990). The cellular injuries took the form of collapsed cells and broken and plasmolyzed cell structures. The epidermal and hypodermal cells were not injured at the light microscopy level.



Figures 3a. and 3b. Spruce needles in October 1988 (after three years), two-year old needles, provenance Salla (northern). S = starch, P = plastoglobuli. bar = 1 µm. Fig. 3a. Dry control. The chloroplasts contain little or no starch, an intact thylakoid system and abundant accumulations of plastoglobuli. Fig. 3b. pH 3 -irrigation. The chloroplast stroma is dark and the plastoglobuli are electron-opaque.

The needles of the pH 3 -treated conifer seedlings, especially those of the southern provenances had the thickest grana stacking in the mesophyll cells, whereas the amount of starch in these needles was lowest after three years. The chloroplasts had also decreased in size in the mesophyll cells. Lipid accumulations in the cytoplasm varied according to the treatment, the greatest accumulation being in the oldest needles of the pH 3 -treated seedlings, and the same needles also had the greatest amount of starch in October, implying an insufficient degree of hardening (Figs. 3a and 3b).

References

Davison, A.W. & Barnes, J.D. 1986. Effects of winter stress on pollutant responses. In: COST-Workshop 23.-25.3.1986. EEC National Agency of Environmental Pollution, Air Pollution Laboratory.

Elstner, E.F., Osswald, W. & Youngman, R. J. 1985. Basic mechanisms of pigment bleaching and loss of structural resistance in spruce (Picea abies) needles: Advances in phytomedical diagnostics. Experientia 41: 591-596.

Evans, L.S. & Curry, T.M. 1979. Differential responses of plant foliage to simulated acid rain. American Journal of Botany 66: 953-962.

Huttunen, S., Reinikainen, J. & Turunen, M. 1990. Wintering response of conifers to acid rain under northern conditions. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer-Verlag, Berlin. p. 607-633.

Percy, K.E. 1986. The effects of simulated acid rain on germinative capacity, growth and morphology of forest tree seedlings. New Phytologist 104: 473-484.

- 1987. Effects of simulated acid rain on leaf cuticular characteristics and surface properties. PhD Thesis. University of Bristol, England. 181 p.

Reinikainen, J. 1990. Ympäristötekijöiden vaikutuksista havupuiden neulasten hienorakenteeseen. PhLic Thesis. University of Oulu, Department of Botany, Finland. 123 p.

Sakai, A. & Larcher, W. 1987. Frost Survival of Plants. Responses and Adaptation to Freezing Stress. Ecological Studies 62. Springer-Verlag, Berlin. 321 p.

Tranquillini, W. 1976. Water relations and alpine timberline. In: Lange, O.L. et al. (eds.). Water and Plant Life, Problems and Modern Approaches. Ecological Studies 19. Springer-Verlag, Berlin. p. 473-491.

Turunen, M. 1990. Response of epicuticular characteristics of conifer needles to air pollution. PhLic Thesis. University of Oulu, Department of Botany, Finland. 103 p.

- & Huttunen, S. 1989. The pH and structure of the needle surfaces of Scots pine and Norway spruce seedlings after acid precipitation. In: Bucher, J.B. & Bucher-Wallin, I. (eds.). Air Pollution and Forest Decline. Proceedings of 14th International Meeting for Specialists in Air Pollution Effects on Forest Ecosystems. IUFRO P2.05, Interlaken, Switzerland, Oct. 2.-8., 1988. Birmensdorf. p. 535-537.

- & Huttunen, S. 1990. Effect of long-term acid rain treatment on epicuticular wax of Scots pine needles in northerly conditions. Manuscript, submitted to Canadian Journal of Botany.

Pollution-induced changes in the primary production of spruce ecosystems in the Kola Peninsula

Natalia Lukina & Vjatcheslav Nikonov
Kola Science Centre of the
U.S.S.R.'s Academy of Sciences
184200 Apatity, Region Murmansk, U.S.S.R.

Abstract

Changes in the primary production of spruce stands subjected to sulphur and heavy metal pollution in the northern timber line region (Kola Peninsula) are considered in this paper. High functional correlations were found between dendrometric parameters (d^2h) and bioproduction characteristics. The use of a defoliation coefficient for characterizing the initial stages of spruce defoliation in areas exposed to atmospheric pollution is proposed.

Introduction

Picea obovata Ldb. is one of the major components of forests in the northern timber line region. The amount of living phytomass in basic spruce ecosystems in the northern part of the Kola Peninsula is not large, and is characterized by a wide range of variation: 7 - 171 t ha^{-1} (Tšepurko 1971, Manakov & Nikonov 1981, Nikonov 1985). Production is about 2 - 6 t ha^{-1} $year^{-1}$. Only under optimum conditions for spruce (grass spruce ecosystems) does the tree layer reach 95 % of the total phytomass. In ecosystems of the *Piceetum fructiculoso-hylocomiosum* type this parameter is not more than 80-85 %. Industrial pollution has been shown to cause significant changes in the amount and structure of the phytomass in the tree layer of spruce ecosystems (Karpenko 1983, Tšernenkova 1985). However, their investigations were only preliminary ones because primary productivity was determined without the use of statistical methods.

Table 1. Stand parameters of the spruce ecosystems.

Type of spruce ecosystem	Composition of tree stand (%)	Number of trees per hectar		Basal area m^2/ha	Crown projection	Spruce			
		living	dead			Number of trees per hectar		mean height, m	mean diameter, cm
						living	dead		
Fruticuloso-hylocomiosum	S80B20*	1293	73	16.3	0.6	933	33	8.1	13.7
Hylocomioso-fruticulosum	S80B20	1110	60	13.6	0.6	490	20	9.2	16.4
Graminoso-fruticulosum	S90B10	480	200	11.9	0.4	450	140	11.7	19.1
sparse *Piceetum empetrosum*	S50B50	150	590	0.9	0.02	70	460	6.2	10.2

* S - spruce, B - birch

Material and methods

Spruce ecosystems of the *Piceetum fruticuloso-hylocomiosum* type, which appear to be the most widely distributed type of forest ecosystem in the Kola Peninsula, were studied. The sample plots present a series of spruce ecosystems in various stages of transformation as a result of varying levels of pollution originating from the "Severonickel" smelter complex (Tables 1 and 2). Classification of the study sites as *Fructiculoso-hylocomiosum* type spruce ecosystems was confirmed by the geobotanical descriptions made by Monchetundra prior to the onset of industrial pollution in the area (Bobrova & Katšurin 1936). The amount and annual production of spruce phytomass were determined using model-tree methods. The model trees were selected according to diameter classes. The data were converted using an equation of the type: $\log y = a + b \log d^2h$, where y = mass of production, d = breast height diameter and h = height. Factor analysis methods were used to identify the different states of the tree layer (Harman 1972).

Table 2. Deposition parameters.

Pollution component	Deposition, kg ha^{-1} y^{-1}*) summer	winter	total	Natural removal mg kg^{-1}	Annual needle fall mg g^{-1}
		Piceetum fruticuloso-hylocomiosum (I)			
S	12.100	3.130	15.230	710.0	0.676±0.0370
Ni	0.018	0.006	0.024	37.2**)	0.007±0.0001
Cu	0.025	0.009	0.034	44.8**)	0.004±0.0002
		Piceetum hylocomioso-fruticulosum (II)			
S	19.000	6.230	25.230	702.0	0.793±0.0730
Ni	0.133	0.156	0.289	349.0**)	0.020±0.0006
Cu	0.178	0.338	0.516	181.8**)	0.008±0.0009
		Piceetum graminoso-fruticulosum (III)			
S	30.600	10.530	41.130	713.0	1.324±0.054
Ni	0.575	0.336	0.919	860.5**)	0.052±0.003
Cu	1.260	0.723	1.983	741.5**)	0.033±0.008
		sparse *Piceetum empetrosum* (IV)			
S	40.010	12.310	52.310	1100.0	1.643±0.011
Ni	1.785	1.201	2.986	2342.0**)	0.115±0.007
Cu	3.344	1.252	4.596	1322.8**)	0.040±0.003

*) Data of Z.A.Jevtjugina (1988), S -SO_4

**) Data of G.M.Kašulina (1988)

Results and discussion

The ecosystems under study have developed under similar natural conditions, but are subjected to different pollution loads. This has resulted in essential differences in the structure and amount of living spruce phytomass. However, regression analysis proved to be highly effective in all cases. The data were most accurately described using an equation of the type log y = a + b log d^2h (Tables 3 and 4). This demonstrates the high degree of functional connection between the parameters depicting the amount and annual production of phytomass and the dendrometric characteristics (d^2h).

Table 3. Parameters of the regression equations of the type log y = a + b log x used for determining spruce biomass.

Coefficient	Biomass compartments					
	Needles	Thin branches	Thick branches	Stem wood	Stem bark	Dead branches
			Piceetum fruticuloso-hylocomiosum (n=9)*)			
a	-0.628	-1.424	-2.520	-1.206	-1.622	-1.992
b	0.430	0.626	1.004	0.872	0.579	0.636
t_a	2.480	8.840	16.150	24.120	46.340	5.330
t_b	4.180	11.360	18.870	50.170	47.790	4.900
			Piceetum hylocomioso-fruticulosum (n=9)			
a	-0.864	-0.860	-0.812	-0.978	-1.816	-0.667
b	0.528	0.474	0.497	0.797	0.644	0.302
t_a	6.040	8.780	6.020	19.960	36.320	2.190
t_b	11.360	14.930	5.200	49.520	39.270	3.040
			Piceetum graminoso-fruticulosum (n=9)			
a	-1.057	-0.559	-1.283	-1.164	-1.917	-1.012
b	0.515	0.347	0.621	0.827	0.649	0.397
t_a	5.480	2.610	3.340	12.790	13.600	1.930
t_b	9.110	5.520	5.490	31.040	15.620	2.580
			sparse *Piceetum empetrosum* (n=15)			
a	-1.256	-1.246	-1.959	-1.455	-2.120	-1.726
b	0.485	0.527	0.824	0.901	0.705	0.716
t_a	4.240	3.690	10.650	11.930	13.590	4.340
t_b	4.990	4.730	13.630	22.030	13.770	5.470

*) n here and in Table 4 = number of model trees
t_a, t_b Student's coefficients

Table 4. Parameters of the regression equations of the type log y = a + b log x used for determining spruce annual production.

Coefficient	Annual production			
	Needles	Branches	Wood	Bark
	Piceetum fruticuloso-hylocomiosum (n=9)			
a	-1.827	-1.923	2.664	-3.097
b	0.523	0.487	0.684	0.396
t_a	4.360	7.100	14.250	16.830
t_b	3.660	5.930	10.730	6.340
	Piceetum hylocomioso-fruticulosum (n=9)			
a	-1.659	-2.174	-2.324	-3.172
b	0.505	0.584	0.551	0.402
t_a	12.470	21.960	13.360	18.880
t_b	11.660	18.000	10.220	7.340
	Piceetum graminoso-fruticulosum (n=9)			
a	-1.580	-1.974	-2.424	-3.072
b	0.473	0.501	0.516	0.310
t_a	7.900	8.160	11.330	11.900
t_b	8.340	7.710	8.190	4.080
	sparse *Piceetum empetrosum* (n=15)			
a	-1.885	-2.430	-2.394	-2.927
b	0.555	0.623	0.489	0.259
t_a	4.960	11.740	16.980	15.320
t_b	4.320	9.210	10.610	4.110

An increase in the pollution level caused a decrease in the amount of living spruce phytomass from 64.8 on the *Piceetum fruticuloso-hylocomiosum* site to 1.4 t ha^{-1} on the sparse *Piceetum empetrosum* site (Table 5). The number of living spruce trees decreased from 933 to 70 ha^{-1}, or more than 13-fold. The ratios between the masses of different tree compartments changed. The needle compartment decreased by 40 % (out of the aboveground part of the spruce phytomass) compared to the control. This phenomenon is caused by the decrease in the number of needle age classes from an average of 13-14 in the unaffected ecosystems to 2-3 on the sparse *Piceetum empetrosum* site. The decrease in the value of coefficient "a" in the equations, describing the correlation between needle mass and d^2h, reflects the decrease in the size of the needle compartment (Fig. 1).

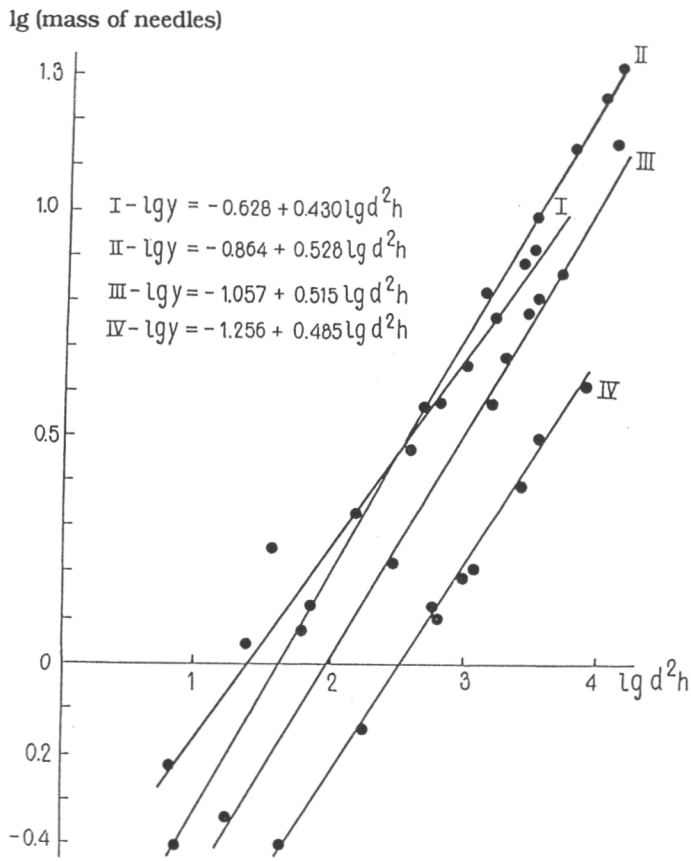


Figure 1. Regression between spruce needle mass and dendrometric parameters (d^2h). I = *fruticuloso-hylocomiosum*; II = *hylocomioso-fruticulosum*; III = *graminoso-fruticulosum*; IV = sparse *Piceetum empetrosum*.

Atmospheric pollution first causes the death of individual parts of the tree, and then the death of the whole tree. This trend was reflected in the increase in the amount of dead biomass from 2.5 on the control to 21 t ha^{-1} on the sparse *Piceetum empetrosum* site (Table 5).

Table 5. Amount and distribution of spruce biomass in different compartments in *Piceetum fruticuloso-hylocomiosum* ecosystems of varying condition, t ha^{-1}.

Compartment	Type of spruce ecosystem state			
	Fruticuloso-hylocomiosum	*Hylocomioso-fruticulosum*	*Graminoso-fruticulosum*	sparse *Piceetum empetrosum*
		Living biomass		
Stem				
wood	37.85	27.65	30.27	0.83
bark	1.41	1.05	1.07	0.06
Total	39.26	28.70	31.34	0.89
Crown				
needles	4.47	3.65	2.38	0.07
thin branches	3.15	2.30	1.78	0.14
thick branches	5.42	3.10	3.60	0.02
Total	13.04	9.05	7.76	0.23
Above-ground part	52.30	37.75	39.10	1.12
Under-ground part	12.48	9.01	9.34	0.26
Total	64.78	46.76	48.44	1.38
		Dead mass		
Stems	1.25	0.52	17.19	15.57
Branches	1.25	0.96	1.76	5.34
Total	2.50	1.48	18.95	20.91

The state of spruce trees subjected to industrial pollution can be characterized on the basis of their annual production. The annual production on the *Piceetum fruticuloso-hylocomiosum* and *Piceetum graminoso-fruticulosum* sites was comparable (1.4 and 1.1 t ha^{-1} $year^{-1}$), but it decreased sharply on the sparse *Piceetum empetrosum* site (0.03 t ha^{-1} $year^{-1}$) (Table 6). The pollution factor brought about a marked change in the allocation of production: an increase in the proportion of assimilative organs from 30-35 % on the *Piceetum hylocomiosum* site to 50 % on the *Piceetum graminoso-fruticulosum* one. On the sparse *Piceetum empetrosum* spruce site, production mainly consisted of the formation of needle biomass. Needle biomass increased from 11 % of the total biomass on the *Piceetum hylocomiosum* site to 30 % on the sparse *Piceetum empetrosum* site.

The pollution factor caused an increase in the amount of annual removal (Table 6). The major parameter depicting species stability in an ecosystem is the ratio of organic material produced to that lost in litterfall.

Table 6. Annual production and annual removal of spruce in *Piceetum fruticuloso-hylocomiosum* ecosystems of varying condition, t ha^{-1} $year^{-1}$.

Compartment	Type of spruce ecosystem state			
	Fruticuloso-hylocomiosum	*Hylocomioso-fruticulosum*	*Graminoso-fruticulosum*	sparse *Piceetum empetrosum*
	Annual production			
Stem				
wood	0.26	0.13	0.09	0.00
bark	0.01	0.01	0.01	0.00
Total	0.27	0.14	0.10	0.00
Crown				
needles	0.51	0.45	0.50	0.03
branches	0.33	0.28	0.26	0.00
Total	0.84	0.73	0.76	0.03
Above-ground part	1.11	0.87	0.86	0.03
Under-ground part	0.32	0.21	0.21	0.01
Total	1.43	1.08	1.07	0.04
	Annual removal			
Stems				
wood	0.21	0.13	0.99	0.90
bark	0.00	0.01	0.01	0.04
Total	0.21	0.14	1.00	0.94
Crown				
needles	0.47	0.73	0.26	0.04
branches	0.26	0.16	0.11	0.11
Total	0.73	0.89	0.37	0.15
Above-ground part	0.94	1.03	1.37	1.09
Under-ground part	0.28	0.23	0.30	0.25
Total	1.22	1.26	1.67	1.34

In the case of the *Piceetum fruticuloso-hylocomiosum* sites, 1 t of production resulted in 0.8 t of natural removal annually. These parameters were similar on the *Piceetum hylocomioso-fruticulosum* plot (1.0 and 1.2 t respectively), but on the *Piceetum graminoso-fructiculosum* plot removal markedly exceeded production (1.6 and 1.0 t respectively). This indicates destruction of the spruce component of the ecosystem. On the sparse *Piceetum* plot spruce was not a major component, because 1 t of production was associated with 4.3 t of removal.

There were profound changes in the composition of the removal. Overall, there was a decrease in the proportion of needles in removal. However this trend was not universal. During the initial stage of pollution-induced transformation (*Piceetum hylocomioso-fruticulosum*) there was an increase in the proportion of needles in removal, and the

amount of needles in removal exceeded the amount of needle production. This phenomenon was caused by the intensive cast of older needles that are more sensitive to pollution, whereas the proportion of needle production out of total production in spruce remained practically unchanged compared to the control. This was confirmed by the ratios between the masses of individual needle year classes, starting with the second one, although under these conditions needles may normally remain on the trees for 13 to 14 years.

The defoliation of spruce was clearly evident on the *Piceetum graminoso-fruticulosum* plot: the needles remained on the trees for an average of not more than 5-6 years. However, needle production exceeded needle fall in these conditions, and the amount of production was comparable with the control. Production is mainly used for renewal of the assimilative organs. The death of individual spruce trees occurred at the same time, and there was a clear transition from the spruce forest stage to the sparse forest stage. On the sparse *Piceetum* plot, spruce removal mainly consisted of stemwood.

Thus there were different trends in the formation of biomass and the removal of spruce with increasing industrial pollution: the proportion of assimilative organs out of production increased, whereas removal consisted primarily of the perennial organs (stemwood).

Table 7. Principle component analysis of dendrometric and bioproductivity parameters of spruce subjected to industrial pollution.

Parameter	Principal components	
	P_1	P_2
Dendrometric:		
1. diameter	0.967	0.122
2. height	0.918	0.145
Bioproductivity:		
3. wood mass	0.969	-0.003
4. bark mass	0.961	0.041
5. needle mass	0.932	-0.254
6. thin branch mass	0.906	-0.038
7. thick branch mass	0.927	0.078
8. dead branch mass	0.635	0.567
9. annual needle production	0.974	0.061
10. annual wood production	0.832	-0.278
11. annual bark production	0.789	-0.288
12. annual branch production	0.975	0.023
13. defoliation coefficient	-0.008	0.807
14. coefficient of assimilative organ productivity	-0.071	0.920
Variation *)	9.810	2.094

*) Variation for each component is the sum of the squares of the elements in the matrix columns.

Different parameters characterizing the organic matter dynamics were obtained for the spruce component of the spruce ecosystem subjected to industrial pollution. Factor analysis methods were used to develop more informative criteria about the state of the ecosystem. The results are presented in Table 7. The loadings are correlation coefficients between the principal components and the parameters.

Two components (P1, P2) account for about 90 % of the variation. All the coefficients for the first principal component are comparable except for those of two parameters: the defoliation coefficient and the productivity coefficient of the assimilative organs (ratio of annual mass production to total needle mass). These parameters explain the maximum (72 %) of the variation in the second principal component. Spruce ecosystems in three different stages can be distinguished: 1 spruce, 2 spruce defoliated, 3 sparse spruce (Fig. 2). One of the more informative parameters for defining the state of a forest is the following defoliation coefficient. This coefficient is the ratio of annual needle mass to total needle mass. This parameter is based on the varying retention of different-aged spruce needles when subjected to atmospheric pollution. The youngest needles are more stable. The increase in the proportion of youngest needles indicates crown defoliation in spruce.

This coefficient could be modified and used for investigating the dynamics of spruce in different stages. In this case the coefficient is determined as the ratio of each year needle mass, starting with the second year, to the annual needle mass. It would appear that the correlations between this parameter and needle age (starting with the second year) are more accurately described by an equation of the type $y = a * 10bx$ (Fig. 3). Intensification of defoliation is indicated by an increase in the value of coefficient "a" and a decrease in the value of coefficient "b".

Conclusions

(1) A high degree of functional correlation was observed between dendrometric parameters (independent variable d^2h) and the spruce phytomass and production characteristics in background spruce ecosystems and those subjected to industrial pollution.

(2) The defoliation coefficient, as determined by the ratio of the needle mass (starting with the second year) to annual needle mass, allows us to identify the initial stages of spruce crown defoliation, and is an informative criterion of the state of the forest.

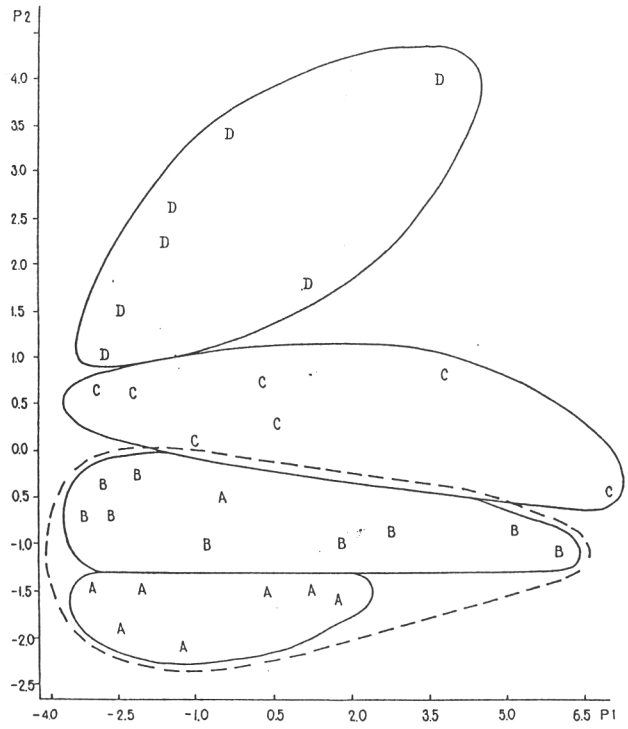


Figure 2. Distribution of the *Piceetum fruticuloso-hylocomiosum* ecosystems subjected to different degrees of atmospheric pollution in the two coordinate plot. A,B = spruce (state 1); C = spruce defoliated (state 2); D = sparse spruce (state 3).

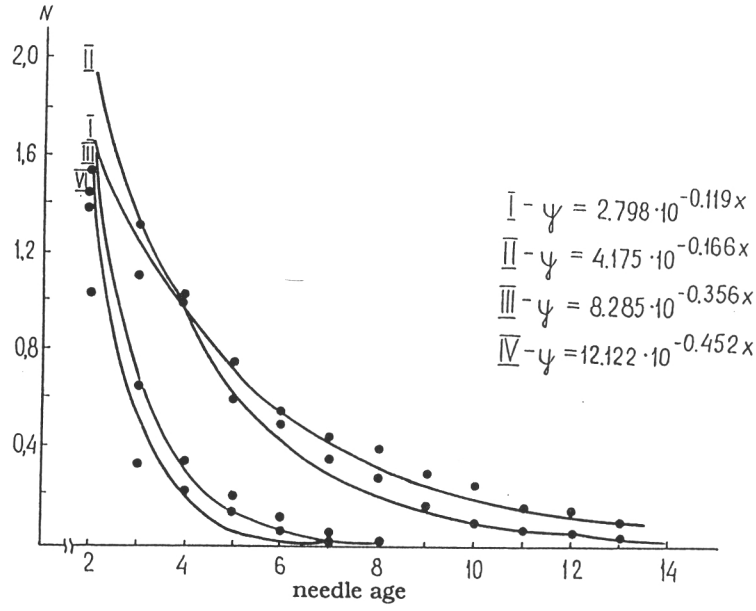


Figure 3. Regression between the defoliation coefficients and needle age.

References

Bobrova, L. I. & Katšurin, M. H. 1936. Otšerk rastitelnosti montšetundry. Materialy po rastitelnosti tsentralnoj i zapadnoj tšastej Kolskogo poluostrova. Moskva-Leningrad. Izd-vo AN SSSR. s. 95-121.

Evtjugina, Z. A. 1988. Nekotorye osobennocti formirovanija himitšeskogo sostava snega v jelovyh lesah zony aerotehnogennogo zagrjaznenija. Antropogennoe bozdejctvie na ekosistemy Kolskogo Severa. Apatity. Izd-vo Kolskovo filiala AN SSSR. s. 55-59.

Harman, G. 1972. Sovremennyh faktornyj analiz. Moskva. 485 s.

Karpenko, A. D. 1983. Blijanie promyšlennyh vybrosov na jelovye fitotsenozy severnoj tajgi Kolckogo polyoctrova. Tartu. 17 s.

Kašulina, G. M. 1988. Soderžanie i zapasy tjaželyn metallov v podctilke jelnikov, podveržennyh tehnogennomu bozdejctviju. Antropogennoe vozdejstvie na ekosistemy Kolckogo Severa. Apatity. Izd-vo Kolckogo filiala AN SSSR. s. 51-54

Manakov, K. N. & Nikonov, V. V. 1981. Biologitšeski krugovorot mineralnyh elementov i potšvoobrazovanie v jelvnikah Krajnego Severa. Leningrad, Nauka. 196 s.

Nikonov, V. V. 1985. Pervitšnaja produktivnoct i biologitšeskaja migratsija v proizvodnyh sosnovyh lesah na severnom predele rasproctranenija. Stabilnoct i produktivnoct lesnyh ekosistem. Tartu. s. 88-89.

Tšepurko, N. L. 1971. Biologitšeskaja produktivnoct i krugovorot himitšeskih elementov v lesnyh i tundrovyh soobstšeštvah Hibinskih gor. Biologitšeckaja produktivnoct i krugovorot himitšeskih elementov v ractitelnyh soobštšestvah. Leningrad, Nauka. s. 213-219.

Tšernenkova, T. V. 1965. Vlijanie promyšlennyh vybrocov metallyrgitšeskih kombinatov na lecnye fitotsenozy. Moskva. 17 s.

The atmospheric pollution load on forest ecosystems in the central part of the Kola Peninsula

Zinaida Jevtjugina
Kola Science Centre of the
U.S.S.R.'s Academy of Sciences
184200 Apatity, Region Murmansk, U.S.S.R.

Abstract

The atmospheric pollution load of sulphur, copper and nickel on forest ecosystems in the central part of the Kola Peninsula was evaluated on the basis of empirical data. The deposition levels in a background spruce forest (without any visible signs of deterioration) during the winter period were 1.5 mg m^{-2} day^{-1} for SO_4^{2-}, 0.004 for Cu and 0.003 for Ni, and during the summer period 5.2, 0.019 and 0.012, respectively. The annual deposition of S was 4.0 kg ha^{-1} (12 kg ha^{-1} as SO_4^{2-}), of Cu 0.04 and of Ni 0.03. The maximum deposition values occurred in a sparse *Piceetum-empetrosum* stand (7 km), and not in the completely destroyed ecosystem (4 km) lying closer to the emission source. The maximum values were 17 kg ha^{-1} for S, 4.6 for Cu and 3.0 for Ni. Trees play an important role in increasing the acid load on the ecosystem in spruce stands subjected to high levels of atmospheric deposition.

Introduction

One of the problems which arises when studying the structural and functional organization of forest ecosystems subjected to industrial emissions is the quantitative characterization of the atmospheric deposition of pollutants. Obtaining an estimate of these parameters during the growing period and the winter dormancy period, and determining the role of the tree stand in the distribution of the deposition of atmospheric pollutants within forest ecosystems, are extremely urgent tasks.

Emissions from the Severonickel smelter complex at Monchegorsk in the central part of the Kola Peninsula have brought about a significant deterioration in the state of health of forest ecosystems, and even their complete destruction. The aim of this study is to estimate the annual atmospheric pollution load on these ecosystems.

Material and methods

Atmospheric deposition was sampled on five plots at different distances from the Severonickel smelter complex, Monchegorsk, one of the largest emission sources of sulphur, copper and nickel in the Kola Peninsula. The background plot (Plot V, *Piceetum fruticuloso-hylocomiosum* type ecosystem) is situated in the SE part of the Umbozero watershed. The other four plots (I-IV) are located to the west of the Imandra watershed, and represent ecosystems suffering to a varying degree from the effects of atmospheric pollution: Plot I, completely destroyed ecosystem without any tree cover, 4 km from the emission source; Plot II, *Piceetum empetrosum* ecosystem with a sparse growth of trees, 7 km; Plot III, *Piceetum graminoso-fruticulosum* type ecosystem, 20 km; Plot IV, *Piceetum hylocomioso-fruticulosum* type ecosystem, 36 km (Fig. 1, Table 1). These four plots are located along a line running approximately in a S-SW direction from the emission source. The prevailing wind direction in the Monchegorsk district is submeridianal (Fig. 2a).

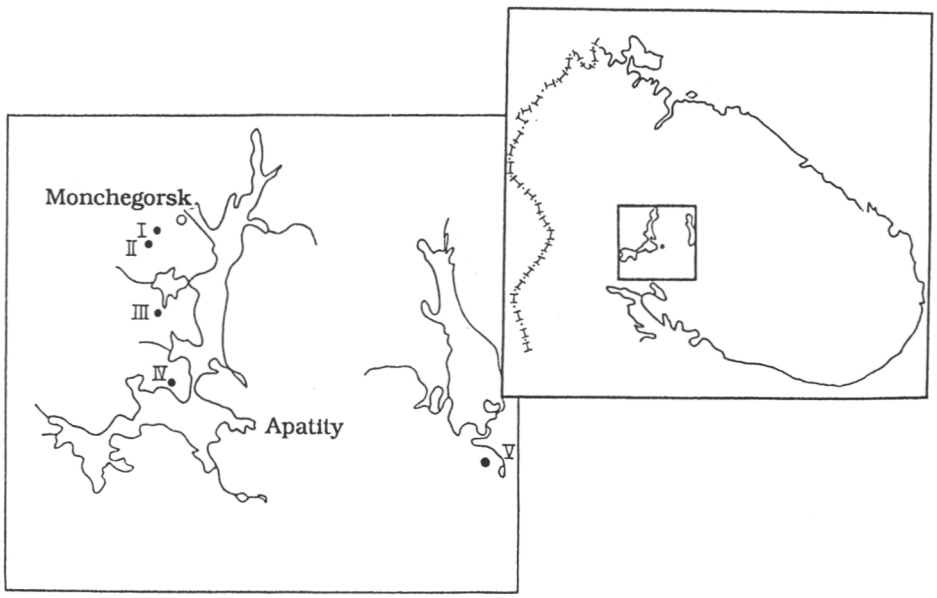


Figure 1. Location of the monitoring plots.

Table 1. Some characteristics of the monitoring plots.

Plot	*)Tree species composition %	*)Number of spruce trees ha^{-1}		Needle biomass t ha^{-1}	Spruce canopy coverage %	Site type
		living	dead standing trees			
I	-	-	-	-	-	Completely destroyed ecosystem
II	S50B50	70	330	0.07	17	Sparse *piceetum-empetrosum*
III	S90B10	590	40	2.38	30	*Piceetum-graminoso-fruticulosum*
IV	S80B20	624	-	3.65	32	*Piceetum-hylocomioso-fruticulosum*
V	S80B20	933	-	4.47	36	*Piceetum-fruticuloso-hylocomiosum*

*) N. Lukina (1988), S - spruce, B - birch

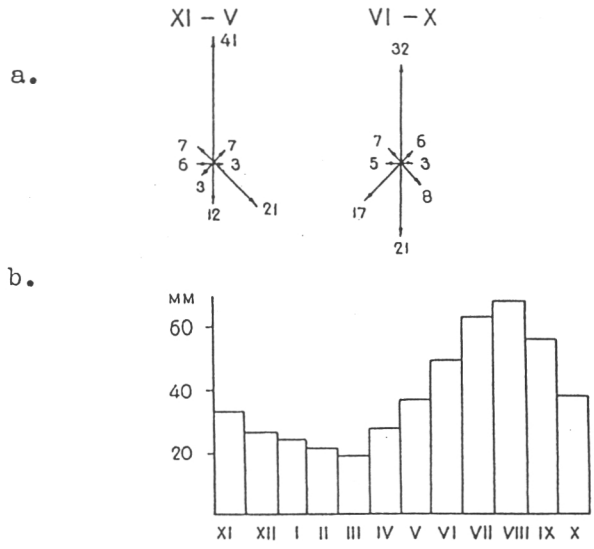


Figure 2. Long-term average data for the Monchegorsk meteorological station: frequency of wind direction (a), monthly precipitation (b).

According to long-term data, a permanent snow cover is usually established in this region by November 1, and melts by May 20. During this period the average precipitation is 191 mm, and during the rest of the year 274 mm (Fig. 2b).

Winter deposition (snow) was taken using polythene tubes pushed down through the whole snow cover at points between the crown canopy and half way along the crown projections of sample trees. Four to five samples were taken under and between the canopies on each plot. A single sample consisted of snow from 2-4 tubes. As a rule, sampling was carried out over a period of two days.

Rainwater samples were collected using funnels located under and between the spruce crowns. In addition, canopy drip was collected using special gutters (V-shaped) extending from a short distance from the stem out to the limit of the crown projection. The rainwater was collected in a bottle connected by a tube to the end of the gutter. The bottles were located underground in cool, dark conditions. Sampling was carried out after one or two heavy rainfall episodes (more than 100 mm/day). Plots I, II and III were sampled on the same day, and Plots IV and V a few days later.

The pH of the samples was measured (EV-74 pH meter). After filtration through hard filter paper, sulphate was determined by a turbidometric method, and Cu and Ni by atomic absorption spectrophotometry.

The annual deposition of S, Cu, Ni and H^+ were calculated from their deposition levels (mg m^{-2} day^{-1}) in winter (November - May) and

summer (June - December). Daily deposition was estimated from the concentrations of S, Cu, Ni and H^+, the amount of precipitation during the sampling period, the number of days when the sampling equipment was in use during the summer, and the number of days elapsed from the establishment of a permanent snow cover up until the snow sampling date during the winter period.

Samples were taken from Plots II-IV in 1986, 1987, and 1988, and from Plots I and V during 1987 and 1988.

Results and discussion

The pH of the precipitation samples collected in these ecosystems is determined by the combined effect of a number of factors. Spruce clearly increased precipitation acidity in the ecosystem when the distance to the emission source decreased and the condition of the tree stands subsequently deteriorated (Fig. 3).

The average H^+ concentrations (calculated from the pH values) of throughfall in the background spruce stand (Plot V) were 59 µmol l^{-1} under the canopy, and 16 µmol l^{-1} between the canopy. The spruce stand had no significant effect on the H^+ concentration in snow collected from below and between the canopy: 19 and 16 µmol l^{-1}, respectively.

In the spruce stands suffering from atmospheric pollution the situation was different: the pH of throughfall was lower than that in the background forest, and there was a statistically significant difference ($p<0.01$) between precipitation acidity under and between the canopy during both winter and summer. The average H^+ concentrations during the summer below the canopy on Plots II, III and IV were 178, 324 and 219 µmol l^{-1}, respectively, and between the canopy 42, 42 and 20 µmol l^{-1}. All the precipitation collected from below the canopy on these plots fulfilled the criterion of acid water (pH < 4.5).

Overall, the acidity of the snow collected on the plots affected by atmospheric deposition was less than the acidity of rainfall during the summer (Table 2).

The annual H^+ deposition on the ecosystems located to the west of the Imandra watershed was estimated to be ca. 10 mg m^{-2} y^{-1} for Plot I, 22 for Plot II, 36 for Plot III, and 19 for Plot IV.

The snow SO_4^{2-} concentrations in the background spruce forest were 2.3 mg l^{-1} under the canopy and 3.8 between the canopy. The corresponding values for Cu were 6 and 11 mg l^{-1}, and for Ni 5 and 7 mg l^{-1} (Table 1).

In the region directly affected by atmospheric pollution the average concentration of sulphate in snow was 9.2 under the canopy and 9.1 mg l^{-1} between the canopy. The corresponding values for Cu were 1871 and 1055 µg l^{-1}, and for Ni 1175 and 1759 µg l^{-1} (Table 3).

During the summer period the S concentrations in precipitation in the pollution zone exceeded the background values by more than five-fold between the canopy, and were double under the canopy. The Cu and Ni concentrations considerably exceeded the background values. The Cu concentrations increased to 887 μg^{-1} between the canopy and to 3139 $\mu g\ l^{-1}$ under the canopy, and for Ni to 400 and 1815 $\mu g\ l^{-1}$, respectively.

Table 2. Statistical parameters of the pH of precipitation collected on the plots. BC = between the canopy, UC = under the canopy.

Plot,	Winter				Summer			
situation	n	min	max	med.interval	n	min	max	med.interval
I								
	9	4.70	5.21	4.9-5.1	9	4.40	4.99	4.5-4.7
II								
BC	14	4.69	5.09	4.7-4.9	19	4.12	4.80	4.3-4.5
UC	17	3.91	5.13	4.5-4.7	29	3.30	4.25	3.7-3.9
III								
BC	15	4.50	4.89	4.5-4.7	11	3.95	4.96	4.3-4.5
UC	16	3.90	4.89	4.1-4.3	30	3.03	3.86	3.3-3.5
IV								
BC	12	4.50	4.87	4.5-4.7	12	4.30	5.03	4.5-4.7
UC	13	4.20	4.72	4.3-4.5	19	3.16	4.43	3.5-3.7

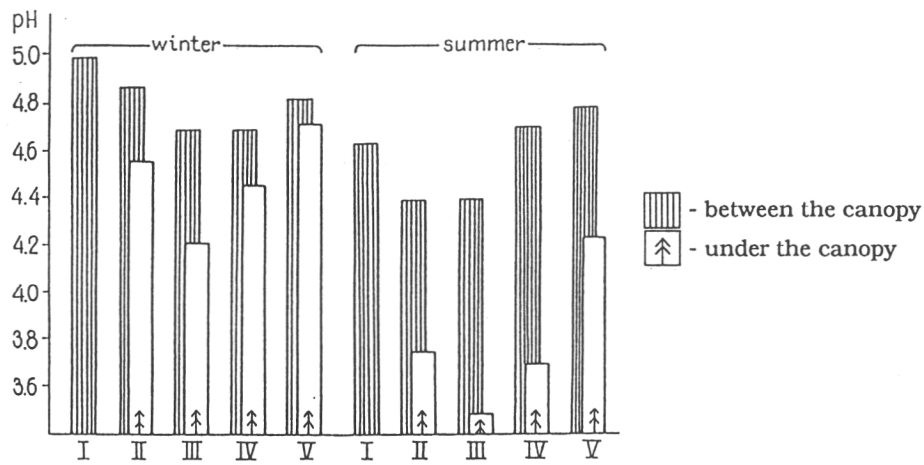


Figure 3. pH of throughfall on the monitoring plots.

Table 3. The volume-weighted average concentrations of SO_4^{2-} (mg l^{-1}), Cu, Ni (µg l^{-1}) in atmospheric deposition. BC = Below the canopy, UC = under the canopy.

Component		Completely destroyed ecosystem		Sparse *piceetum empetrosum*		*Piceetum-graminoso-fruticulosum*		*Piceetum-hyloco-mioso-fruticulosum*		*Piceetum-fruti-culoso-hylocomiosum*	
		plot I		plot II		plot III		plot IV		plot V	
		winter	summer	winter	summer	winter	summer	winter	summer	winter	summer
SO_4^{2-}	BC	9.1	7.0	6.4	11.3	5.4	8.6	2.8	3.5	2.3	2.1
	UC	-	-	9.0	28.8	9.2	28.9	5.9	33.3	3.8	14.7
Cu	BC	1055	887	477	761	231	213	86	22	6	6
	UC	-	-	1871	3139	601	1095	260	237	11	15
Ni	BC	1579	400	532	388	110	120	44	20	5	5
	UC	-	-	1175	1815	233	489	105	155	7	8

The deposition of S, Cu and Ni was greater under the canopy than between the canopy during both summer and winter in the spruce stands subjected to industrial pollution. The statistical significance of the differences between the deposition level under and between the canopy was evaluated on the basis of the Fisher and Student coefficients. In the severely damaged spruce stand (Plot II) Cu and Ni deposition under the canopy was 3-4 times that between the canopy during the summer and winter, and for S almost 3 times (Fig. 4). The total load on the ecosystem was calculated using the area of the spruce crown projections and that of the open spaces between the canopies on each plot. The highest pollution load occurred on Plot II, where the annual deposition of SO_4^{2-} was 54 kg ha^{-1}, of Cu 4.6 and of Ni 3.0 (Figs. 5 and 6).

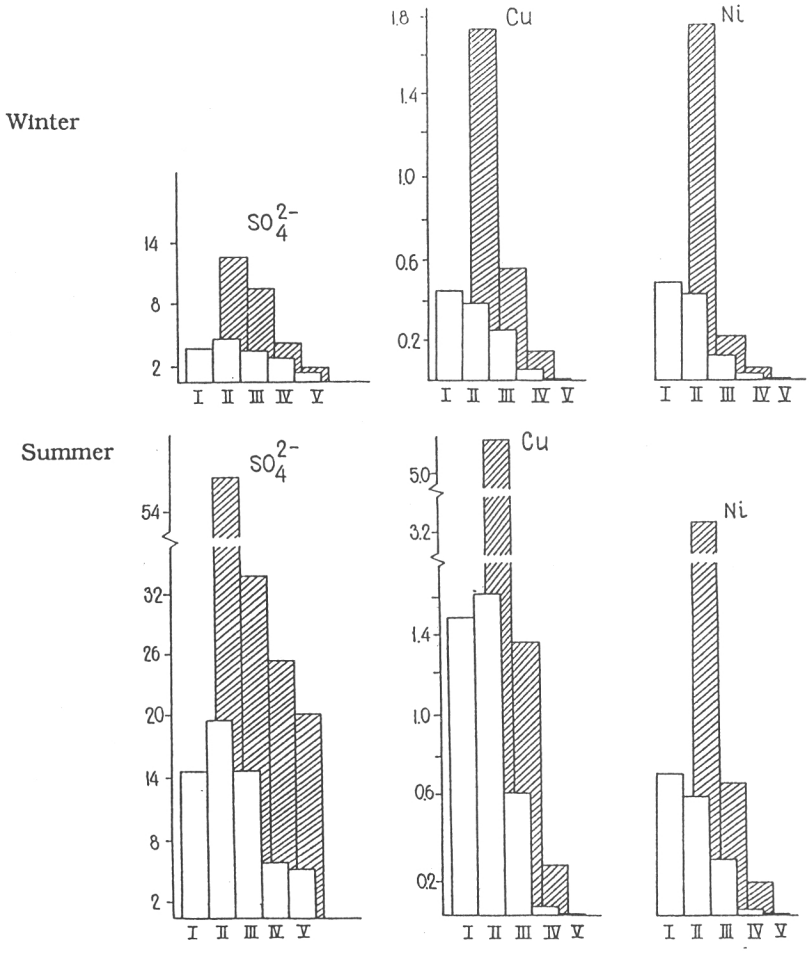


Figure 4. Deposition of SO_4^{2-}, copper, nickel (mg m^{-2} day) between (□) and below (▨) the spruce canopies on the monitoring plots.

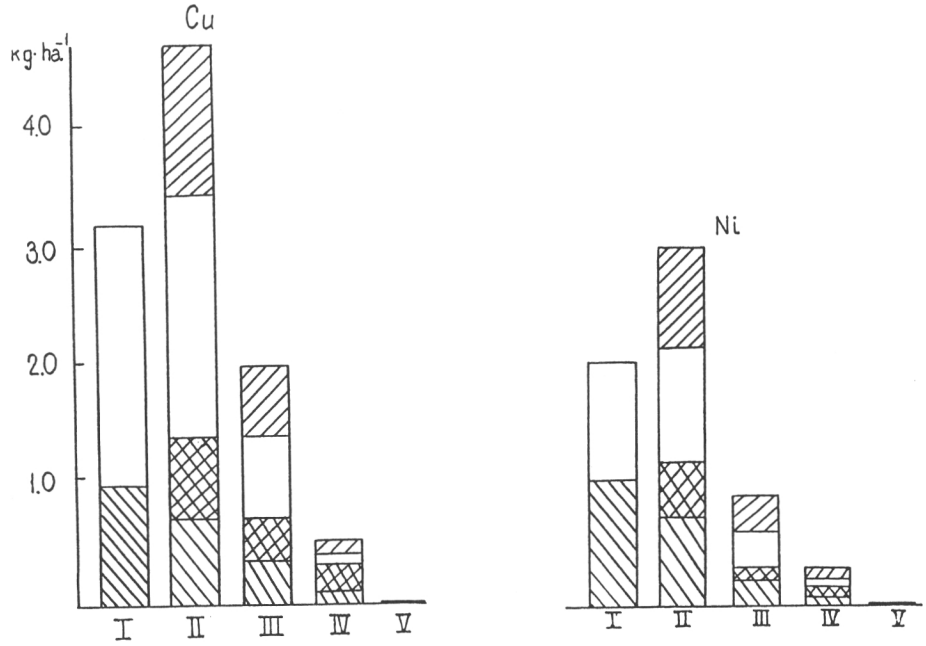


Figure 5. Deposition of copper and nickel (kg ha^{-1} y^{-1}) on the monitoring plots (I-V). Distribution of annual deposition: on the area of canopy projections (▨) in summer, (▩) in winter; on the area without crown coverage (□) in summer, (▧) in winter.

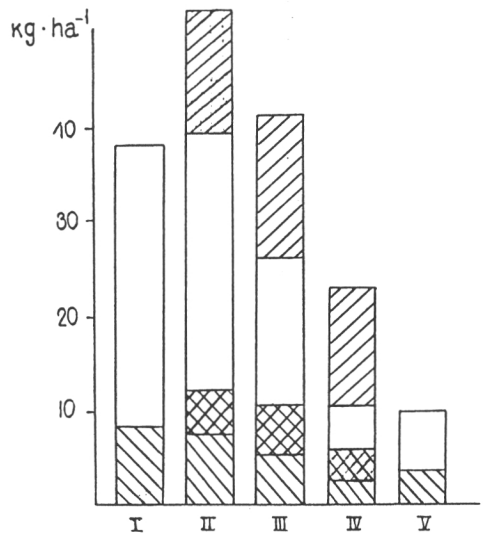


Figure 6. Sulphate deposition (kg ha^{-1} y^{-1}) on the monitoring plots. (Screens the same as in Fig. 5).

It is interesting to note that the pollution load was greater on Plot II, where the tree stand is severely damaged, than on Plot I, where the tree stand has been completely destroyed.

The forest ecosystems were subjected to the maximum pollution load during the summer period: 71-77% of the annual Cu and Ni deposition, and 65-77% of the sulphate occurred during the five summer months.

There were no significant differences between metal deposition (attributable to industrial pollution) under and between the tree canopies in the background spruce forest (Plot V). Deposition of Cu and Ni on this plot during winter was 0.004 and 0.003 mg m^{-2} day^{-1}, and during summer 0.019 and 0.012 mg m^{-2} day^{-1}, respectively. Annual Cu deposition was 0.04 kg ha^{-1}, and for Ni 0.03 kg ha^{-1}.

The canopy was not found to have any effect on the redistribution of the atmospheric S load during the winter period. In contrast, deposition of S during the summer period was three times greater under the canopy than between the canopy. If we assume that this increase is due to leaching from the tree canopy, then the annual deposition of S in the background region can be estimated on the basis of the daily SO_4^{2-} deposition between the canopy during the summer (5.2 mg m^{-2}) and winter (1.5 mg m^{-2}). Annual background SO_4^{2-} deposition is thus about 12 kg ha^{-1}.

It should be noted, however, that when estimating the S load on the plots subjected to industrial pollution the portion of S leached from the canopy during the summer period was not subtracted, and neither was the contribution of S in stemflow measured. However, the needle biomass on Plot II, which had the highest S load, was only about 2% of that on the background plot (see the data of N. Lukina). We can therefore suppose that the leaching of S from the canopy on Plot II is insignificant. More detailed investigations on these questions are needed.

References

Lukina, N. 1988. Technogenic transformation of the structure and reserve of organic substances of Kola North forests. In: Soil formation on the Kola North, Apatity, p. 72-80.

Spatial variation in podzol development in a spruce ecosystem in the Kola Peninsula

Galina Kašulina
Kola Science Centre of the
U.S.S.R.'s Academy of Sciences
184200 Apatity, Region Murmansk, U.S.S.R.

Abstract

A preliminary study on soil formation in a spruce-green moss-dwarf shrub ecosystem indicated that there is spatial variation in soil properties. Although soil formation within the ecosystem was of the same type, Al-Fe-humus podzol, there were considerable differences in the soil properties under the main vegetation associations. One of the major factors affecting the variation in soil properties was the tree cover. The most sensitive part of the ecosystem was the soil under the moss-lichen association.

Introduction

The soils of forest ecosystems are traditionally characterized on the basis of their vegetation cover. However, it is known that forest ecosystems have a complicated structural and functional organization. The high spatial variation in the intensity of biological turnover, caused by the uneven distribution of the living biomass, results in the formation of microstructural units. Deelis (1974) called the microstructural units of the ecosystem compartments, and defined them as the structural compartments of the horizontal division of the ecosystem down its complete vertical axis. The compartments are distinguished from each other in composition, structure, the properties of the components, and the exchange of matter and energy (Deelis 1974). Bearing in mind the natural spatial heterogeneity of soil properties, it can be assumed that these compartments will possess varying resistance to anthropogenic impacts. Investigation of soil properties is thus an important aspect when considering the state of ecosystems subjected to pollution loads.

The aim of this study was to carry out a preliminary investigation of a spruce-green moss-dwarf shrub ecosystem located in the central part of the Kola Peninsula. The soil studies are part of a comprehensive investigation being carried out on the transformation of spruce ecosystems subjected to atmospheric pollution from the Severonickel smelter complex.

Table 1. Some characteristics of the compartments.

Compartment	Arboreous layer	Ground vegetation	Proportion of total area, %
moss-dwarf shrub	absent	*Empetrum hermaphroditum* *Pleurozium schreberi* *Hylocomium splendens* *Vaccinium myrtillus* *V. vitis-idaea* *Deschampsia flexuosa*	79
moss-lichen	absent	*s.s.Cladina* *P.schreberi* *E.hermaphroditum* *s.s.Vaccinium* *D.flexuosa*	2
spruce-empetrum	*Picea obovata*	*E.hermaphroditum* *V. vitis-idaea*	8
spruce	*Picea obovata*	absent	11

Material and methods

The site was a spruce-green moss-dwarf shrub ecosystem formed on sandy, stony till. The site and ground vegetation are described in detail by Lukina & Nikonov (1991) in these proceedings. Four soil pits were dug in the main compartments, designated on the basis of the vegetation cover (Table 1). Samples were collected from all the main soil horizons: A_0, A_2, B_{hfa1}, B_{hfa2}, BC, and C. The samples were dried and passed through a 1 mm sieve. The following analyses were performed on this fraction.

pH. The $pH_{(H_2O)}$ and $pH_{(KCl)}$ of the organic layer (1:25, w/v) and mineral soil horizons were measured from slurries of soil (1:2.5, w/v) and deionized water and 1N KCl. Titratable acidity was determined by titration with 0.1N NaOH after extraction with 1N CH_3COONa (see Nikonov 1987, Nikonov & Pereverzev 1989). Exchangeable Ca and Mg were determined by titration with trilon B after complete extraction with 1N NaCl (see Nikonov 1987, Nikonov & Pereverzev 1989). Cation exchange capacity was calculated as the sum of titratable acidity and exchangeable Ca and Mg.

Organic matter. Total C_{org} content was determined by the Tiuri method. Group and fractional composition of the humus substances was determined accccording to the Tiuri analytical scheme, modified by Ponomareva and Plotnicova (see Nikonov 1987, Nikonov & Pereverzev 1989). This fractionation scheme divides the soil humus into three humic acid fractions, four fulvic acid fractions and one humin fraction (insoluble residue).

The insoluble organic matter fraction is characteristic of the degree of humification of the organic matter. The ratio C_{ha}:C_{fa} is a qualitative characteristic of the organic matter.

Total composition. The total Si, Al, Fe, Ca, Mg and Mn contents were determined by atomic absorption spectrometry after fusion of the samples with Na_2CO_3 and $Na_2B_4O_7$. Total K and Na were determined by emission spectrometry, P colorimetrically using ascorbic acid, and S by the turbodimetric method after digestion of the samples in the presence of fluoric acid.

Iron compounds. Groups and forms of Fe were determined according to the Zonn analytical scheme (Zonn 1982) as the following fractions. Total Fe content (Fe_t); Fe_j, extraction by Na dithionite-citrate-bicarbonate; Fe extracted sequentially by 0.1M $Na_2P_2O_7$ (Fe_{ext}) and Na dithionite with CH_3COONa (Fe_{res}); Fe_o, extraction with a mixture of $C_2H_2O_4$ and $(NH4)_2C_2O_4$. The groups and forms of Fe compounds were calculated as follows:

1. Silicate = Fe_t-Fe_j
2. Non-silicate = Fe_j
3. Crystalline = Fe_j-Fe_o
   3.1. strongly = Fe_j-(Fe_{ext}+Fe_{res})
   3.2. slightly = (Fe_{ext}+Fe_{res})-Fe_o
4. Amorphous = Fe_o
   4.1. organic = Fe_{ext}
   4.2. inorganic = Fe_o-Fe_{ext}

Results and discussion

Morphological features

All the pits had profiles typical of podzolic Al-Fe-humus soils, i.e. A_0-$A2_h$-B_{hfa}-BC-C. The higher litterfall and its specific botanical composition have resulted in the formation of a distinct litter horizon under the spruce canopy. The pits in the Spruce empetrum and spruce compartments had the following set of horizons: 0-A_0-$A2_h$-B_{hfa}-BC-C. More detailed investigation of the organic layer (Table 2) indicated marked variation in thickness and dry weight within the whole ecosystem. Fac-

tor analysis showed statistically significant differences ($P < 0.05$) in the thickness and dry weight (F values 17 and 13 respectively) between the compartments. According to Nikonov (1987), the structural composition of the vegetation cover plays a dominant role in determining the spatial variation in the dry weight of the organic layer.

Table 2. Dry weight and thickness of the organic layer in spruce green moss - shrubby ecosystems.

Compartment	Thickness (cm)		Dry weight (kg/m^2)	
	x(n)	variation	x(n)	variation
Moss-dwarf shrub	6.0 (31)	1.1	2.8 (5)	0.4
Moss-lichen	2.0 (29)	1.1	1.3 (5)	0.1
Spruce-empetrum	6.7 (16)	2.0	3.4 (4)	0.6
Spruce	11.4 (16)	3.1	7.9 (4)	3.1

Owing to the high litterfall (needles and twigs), the greatest amount of organic matter occurred under the canopy - 7.9 kg m^2 for the spruce compartment. The values for the open compartments were much lower. In the moss-lichen compartment, which had the lowest biomass value, dry matter in the organic layer did not exceed 2 kg m^2.

As regards morphological properties of the mineral soil horizons, the eluvial horizon in the moss-lichen compartment was thinner and had a brighter colour. The darker colour of the eluvial horizon in the moss-dwarf shrub compartment probably reflected the penetration of humus substances deeper into the mineral soil. The latter was confirmed by chemical analysis (Table 3).

The ochre colour of the illuvial horizon in the moss-lichen compartment, and its weak differentiation into subhorizons, indicated a low C_{org} content (Table 3) and the accumulation of predominatly amorphous forms of inorganic Fe (Table 4). The spruce compartment had a well differentiated illuvial horizon. The upper part of this horizon (B1) was very thin and had a more intense brownish colour. The analytical data showed a higher content of C_{org} and amorphous organic Fe compounds (Tables 3 and 4).

Table 3. Content and composition of organic matter, $C_{org.}$ % of soil dry weight.

Compartment		Humic acids			Fulvic acids				Cha:Cfa	Unhydrolized residue (humin)
		1	2	3	1[a]	1	2	3		
					Organic layer					
Moss-dwarf shrub	52.8	2.48	0.4	3.48	0.33	4.23	0	3.07	0.84	38.7
Moss-lichen	46.1	2.31	0.1	2.43	0.46	3.70	0.18	1.15	0.85	35.7
Spruce empetrum	51.4	4.89	0	4.94	0.41	4.71	0.21	4.08	1.04	32.2
Spruce	52.7	5.33	0	5.86	0.33	4.66	0	4.19	1.22	32.3
					A_2					
Moss-dwarf shrub	1.6	0.14	0	0.11	0.04	0.17	0.03	0.12	0.69	1.0
Moss-lichen	0.8		-		-		-		-	
Spruce empetrum	1.1	0.03	0	0.05	0.03	0.08	0.01	0.06	0.44	0.9
Spruce	1.2	-	-	-	-	-	-	-	-	-
					B					
Moss-dwarf shrub	3.2	0.19	0	0.07	1.16	0.18	0.15	0.13	0.16	1.3
Moss-lichen	1.7	-	-	-	-	-	-	-	-	-
Spruce empetrum	3.2	0.18	0.1	0.06	1.39	0	0.26	0.07	0.14	1.2
Spruce	3.9	-	-	-	-	-	-	-	-	-

Table 4. Contents and forms of iron in podzolic Al-Fe-humus soil, % Fe_2O_3 of ash.

Compartment	Total	Groups		Forms			
				Crystalline		Amorphous	
		silicate	non-silicate	strongly	slightly	organic	inorganic
			A_2 horizon				
Moss-dwarf shrub	5.56	5.44	0.12	0.07	0.02	0.02	0.01
Moss-lichen	3.24	3.19	0.05	0.00	0.04	0.01	0.00
Spruce empetrum	3.67	3.59	0.08	0.05	0.00	0.02	0.01
Spruce	5.30	5.21	0.09	0.01	0.05	0.03	0.00
			Bhfa 1				
Moss-dwarf shrub	6.85	4.37	2.48	0.24	0.29	0.68	1.28
Moss-lichen	6.30	3.51	2.79	0.19	0.43	0.20	1.97
Spruce empetrum	5.66	3.34	2.32	0.22	0.14	0.70	1.26
Spruce	7.12	3.98	3.14	0.08	0.50	1.09	1.38
			Bhfa 2				
Moss-dwarf shrub	4.54	3.60	0.94	0.04	0.18	0.05	0.66
Moss-lichen	4.88	3.88	1.00	0.07	0.04	0.05	0.83
Spruce empetrum	4.80	4.20	0.60	0.00	0.18	0.03	0.39
Spruce	5.02	4.47	0.55	0.03	0.16	0.04	0.32

Chemical properties

There were differences between the compartments as regards certain chemical properties (Table 5). Maximum values of titratable acidity were found in the organic layer under the canopies. The organic layer in the open areas had lower values for some of the parameters, and in one compartment they differed significantly from the other open compartments: the moss-lichen compartment had lower titratable acidity and exchangeable Mg+Ca, and hence lower cation exchange capacity. The exchangeable Mg content of the organic layer samples varied. The moss-dwarf shrub compartment had the highest exchangeable Mg content, the value being twice that for the other compartments. The $pH_{(H_2O)}$ and $pH_{(KCl)}$ values and base saturation of the organic layer samples had the minimum variation.

Some of the chemical properties of the eluvial horizons showed similar trends to those in the corresponding organic layer. All types of acidity and exchangeable bases had minimum values in the moss-lichen compartment. The range in the Ca:Mg ratio was also narrower in the moss-dwarf shrub compartment compared to the compartments with a tree cover (Spruce empetrum and spruce), where Ca was more predom-

inant. The maximum titratable acidity and cation exchange capacity values occurred in the moss-dwarf shrub compartment, which also had the highest content of humus substances. The base saturation values in the A_2 horizons were also highest in compartments under the canopy.

As was the case for the organic layer, the B horizons in compartments with a tree cover had the largest titratable acidity and cation exchange capacity values. The leaching of exchangeable bases down into the illuvial horizons of these compartments did not result in an increase in base saturation. The upper part of the B horizons of the compartments with a canopy cover were also characterized by higher $pH_{(H_2O)}$ and $pH_{(KCl)}$ values.

Table 5. Chemical properties of the podzolic Al-Fe-humus soil.

Compartment	pH		Titratable acidity	Exchangeable cations			Cation exchange capacity	Base saturation
			meq. $100g^{-1}$	meq. $100g^{-1}$			meq. $100g^{-1}$	%
	KCl	Water		Ca	Mg	Σ		
				Organic layer				
Moss-dwarf shrub	2.93	3.80	106.70	15.6	7.8	23.40	130.10	17.90
Moss-lichen	3.05	3.98	87.10	12.5	3.9	16.50	103.60	15.90
Spruce empetrum	2.88	3.84	118.50	16.1	4.2	20.30	138.80	14.70
Spruce	2.97	3.90	112.70	18.5	4.2	4.20	135.40	16.80
				A_2 horizon				
Moss-dwarf shrub	3.21	4.41	8.25	0.23	0.27	0.50	8.75	5.71
Moss-lichen	3.44	5.00	4.29	0.19	0.12	0.31	5.60	5.54
Spruce empetrum	3.08	4.15	5.57	0.30	0.10	0.40	6.00	7.16
Spruce	3.18	4.50	6.01	0.45	0.14	0.59	6.60	8.90
				Bhfa 1				
Moss-dwarf shrub	4.48	5.02	11.70	0.30	0.20	0.50	12.20	4.30
Moss-lichen	5.16	5.44	5.20	0.20	0.10	0.30	5.50	4.30
Spruce empetrum	4.35	4.75	17.10	0.60	0.20	0.80	17.90	4.70
Spruce	4.31	4.73	16.90	0.50	0.30	0.80	17.70	4.50
				Bhfa 2				
Moss-dwarf shrub	5.10	5.29	3.57	0.21	0.12	0.34	3.91	8.70
Moss-lichen	5.37	5.48	3.32	0.13	0.08	0.21	3.53	5.95
Spruce empetrum	4.58	4.73	5.67	0.17	0.11	0.28	5.95	4.70
Spruce	4.97	5.26	3.64	0.19	0.09	0.28	3.92	7.14

Organic matter

The organic layer in the different compartments has very similar total C contents, the minimum value occurring in the moss-lichen compartment (Table 3). There is clear variation in the degree of humification of the organic matter in the organic layer of the different compartments in the ecosystem. The amount of humin (insoluble residue) in the organic layer in the compartments with a tree cover, and hence higher litterfall (Spruce empetrum and spruce compartments), was 32 % of the dry matter, while in the open compartments (moss-dwarf shrub and moss-lichen compartments) it was higher - 36 and 39 % respectively. The difference in the humic acid composition of the organic layer was mainly attributable to the humic acid fractions: their contents in the open compartments were lower. The C_{ha}:C_{fa} ratio in the open compartments was therefore <1, and under the canopy >1.

The variation between the C_{org} content in the eluvial horizon of the different compartments was primarily due to the extreme values of 1.6 and 0.8 % obtained for the open compartments (moss-dwarf shrub and moss-lichen, respectively).

The total C content in the B horizons of the compartments were very similar, apart from the moss-lichen compartment where there was approximately half as much C_{org} as in the other compartments.

Elemental content

The organic layers of the different compartments have rather similar SiO_2 and Al_2O_3 and Fe_2O_3 contents, the maximum values occurring in the moss-lichen compartment (Table 6). The total Ca content of the organic layer samples from under the canopy was higher than those from the open compartments. In contrast, the total Mg content of the open compartments was higher, particular in the moss-dwarf shrub one. The latter compartment was also characterized by high Mn, P, K and Na contents. The differences between the elemental contents of the A_2 and B horizons from the same pits were negligible. The reserves of nutrient elements in the compartments can be estimated on the basis of the data for the total and exchangeable contents of the organic layer (Table 7). The organic layer in the moss-lichen compartment had the smallest values for the accumulation of nutrient elements. Accumulation of Ca under the canopy was more intensive owing to the greater mass of the organic layer and its higher total Ca content. The moss-dwarf shrub compartment showed greater Mg accumulation. The majority of the Ca and Mg in the organic layer was in an exchangeable form (Table 7).

Table 6. Elemental composition, % of ash.

Compartment	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	Na_2O	SO_3
				Organic layer					
Moss-dwarf shrub	61.0	11.2	6.4	5.2	2.6	1.98	3.0	5.6	2.14
Moss-lichen	67.2	13.9	5.6	4.9	1.5	0.76	1.6	2.5	1.13
Spruce empetrum	65.4	12.5	5.5	7.5	1.2	1.28	1.3	-	1.64
Spruce	64.9	11.1	5.0	9.4	1.2	1.38	1.9	1.9	2.32
				A_2 horizon					
Moss-dwarf shrub	73.6	11.2	5.6	3.1	1.1	0.03	1.0	5.1	0.06
Moss-lichen	77.2	10.9	3.2	2.9	0.5	0.04	1.0	3.6	0.08
Spruce empetrum	71.3	11.8	3.7	3.6	1.0	0.05	0.8	5.0	0.10
Spruce	74.3	12.4	5.1	3.1	0.9	0.04	1.2	3.6	0.04
				B horizon					
Moss-dwarf shrub	63.7	17.5	6.9	3.6	2.0	0.07	1.1	5.3	0.09
Moss-lichen	66.1	17.6	6.3	3.6	1.6	0.06	0.9	3.7	0.08
Spruce empetrum	65.3	16.9	5.7	3.2	1.4	0.08	1.0	4.7	0.21
Spruce	63.2	19.2	7.1	3.5	1.9	0.07	1.0	3.4	0.01

Table 7. Amounts of nutrients in the organic layer of the Al-Fe-humus podzols, g/m^2.

Compartment	Dry weight of organic layer kg/m^2	Ca tot.	Ca. exch.	Mg tot.	Mg exch.	K	Na	P	S
Moss-dwarf shrub	2.9	10.7	9.2	4.4	2.8	7.1	11.7	2.4	3.4
Moss-lichen	1.8	3.9	4.0	2.2	0.8	3.1	4.4	0.8	1.5
Spruce empetrum	6.2	30.6	20.0	4.1	3.1	5.9	-	3.1	5.2
Spruce	6.6	38.2	24.6	3.9	3.4	3.6	7.7	3.3	7.3

Groups and forms of iron

The contents of different groups and forms of Fe, as well as their distribution down the soil profile, were typical of podzolic Al-Fe-humus soils (Nikonov & Pereverzev 1989). The non-silicate forms of Fe in the A_2 horizons were present in moderate amounts and, for this reason, it is difficult to identify any intercompartmental differences. The moss-lichen and spruce compartments were characterized by having the highest content of non-silicate forms of Fe. However, this group consists of different forms of Fe. As regards crystalline Fe, slightly crystalline forms are predominant in the spruce compartment. In the moss-lichen compartment, on the other hand, the range in the ratio of slightly and strongly crystalline forms was narrower.

The sharp decrease in the organic forms of Fe in the lower part of the B horizon in all the compartments indicates that these forms are relatively immobile.

Conclusions

According to this preliminary investigation, soil formation in all of the main compartments in this spruce-green moss-dwarf shrub ecosystem had proceeded according to normal development of an Al-Fe-humus podzol. Nevertheless, the intercompartmental differences in soil properties may be significant. The major differences between the compartments were in the thickness and dry weight of the organic layer. Differences in the reserves of some nutrient elements was another characteristic.

The differences between the humic and fulvic acid ratio of the compartments suggests that trees are one factor determining the intercompartmental variation in the quality of the organic matter.

The compartments had differences in the organic matter content of the B horizons: the lowest value was in the moss-lichen compartment, and the highest in the spruce compartments.

The significant differences in some soil properties between the compartments mean that bulked samples do not give an accurate, overall picture of the soil processes taking place in the whole ecosystem. Such parameters have to be characterized on the basis of studies on the internal structure of the ecosystem.

Certain soil parameters, such as the quality and quantity of the organic matter, are known to determine the capacity of soil to resist anthropogenic impacts. The fact that the ground vegetation is composed of sensitive species (green moss and lichen) and there are only small amounts of organic matter with a low cation exchange capacity, make

the moss-lichen compartment the weakest point in these ecosystems when subjected to anthropogenic deposition.

References

Deelis, M. (ed.) 1974. Programma i metody biogeocenotitsheskih issledovanii. Moskva, Nauka. 306 s.

Lukina, N. & Nikonov, V. 1991. Pollution-induced changes in the primary production of spruce ecosystems in the Kola Peninsula. Forest damage and air pollution research in Finnish Lapland and the Kola area of the U.S.S.R.'s. A seminar in Kuusamo, Finland, 25-26 May 1990. The report of papers. Metsäntutkimuslaitoksen tiedonantoja 373. p. 120-131.

Nikonov, V. 1987. Potshvoobrasovanie na severnom predele sosnovych biogeozenosov. Leningrad, Nauka. 142 s.

– & Pereverzev, V. N. 1989. Potshvoobrasovanie v Kolskoji Subarctike. Leningrad, Nauka. 169 s.

Zonn, C.V. 1982. Železo v potšvah. Moskva, Nauka. 207 s.

The chemical composition of wild berries subjected to atmospheric industrial pollution in the Kola Peninsula

Jelena Kruglikova
Kola Science Centre of the
U.S.S.R.'s Academy of Sciences
184200 Apatity, Region Murmansk, U.S.S.R.

Abstract

The chemical composition of wild fruits in the Kola Peninsula is considered on the basis of the fruits of dwarf shrubs such as blueberry (*Vaccinium myrtillus* L.) and lingonberry (*Vaccinium vitis-idaea* L.) which grow widely over the Kola Peninsula. The most essential changes occur with respect to nickel and copper, the concentrations of which exceeded the background values in all samples. There was an increasing trend in the accumulation of these elements in berries on moving towards the pollution source. No connection was found between the biochemical composition of the berries and the level of environmental pollution.

Introduction

The fruits of blueberry (*Vaccinium myrtillus* L.) and lingonberry (*Vaccinium vitis-idaea* L.) are used widely for food in the Kola Peninsula. Wild berries are important in this rather inhospitable region, and may be the only natural source of vitamins for man. They also possess healing properties.

The ferrous and non-ferrous industries, chemical industry and power industry in the region nowadays form a dense industrial centre that has a profound influence on the environment. The chemical composition of the vegetation is altered by atmospheric industrial pollution. As the main pollutants are toxic with respect to man, it is possible that toxic wild berries may be present in some regions.

Material and methods

In 1989 the Laboratory of Ecology of Terrestrial Ecosystems of the Institute of the North Industrial Ecology Problems, Kola Science Centre, Academy of Sciences of the U.S.S.R., began a study on the chemical

and biochemical composition of wild blueberries and lingonberries growing in regions subjected to industrial pollution.

Berry samples were gathered in the areas influenced by the "Pechenganickel" and "Severonickel" copper-nickel smelters, the "Apatity" chemical plant, the aluminium smelter at Kandalaksha, in the Kovdor region, and in the background regions of Pyaozero (north-west Karelia) and the south-eastern part of the watershed of Lake Umbozero (Fig. 1).

The berries were gathered ripe. The area of the berry sample plots was about 1000 m^2. The chemical analyses were carried out by x-ray-fluorescence. Altogether 15 elements were determined: nickel, copper, cobalt, zinc, aluminium, iron, silicon, sulphur, calcium, potassium, titanium, chlorine, manganese, phosphorus and lead.

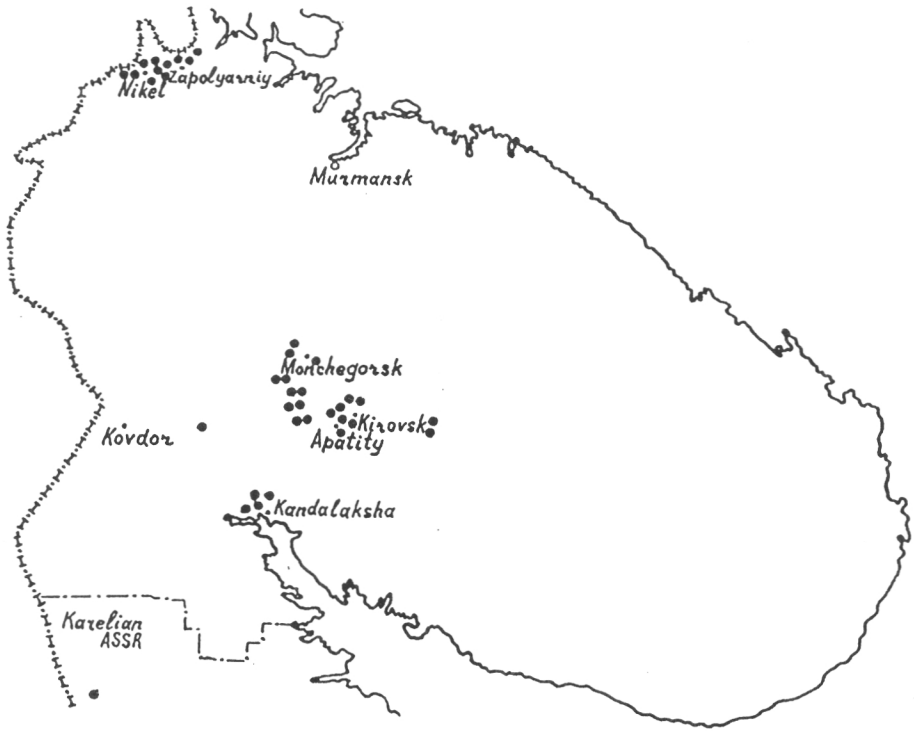


Figure 1. Location of the berry sample plots in the Kola Peninsula.

Results and discussion

The predominant elements in the chemical composition of the blueberry and lingonberry berries were potassium, calcium and phosphorus (several thousand ppm), followed by manganese and sulphur (several hundred ppm), and finally iron and silicon (a few dozen ppm). There were no clear differences between the regions as regards the concentrations of the biophylic elements potassium, calcium and manganese. There was an increasing trend in the sulphur, phosphorus and iron concentrations of the berries from the regions influenced by industrial pollution. This trend was especially distinct in the case of sulphur. In the background regions the sulphur concentration in blueberry was one and a half times higher than that in lingonberry. A similar ratio prevailed in the polluted regions (Table 1).

Nickel and copper are also major pollutants in the Kola Peninsula. The main sources of nickel and copper are the smelters of the nickel-copper industry.

The concentration of nickel in the berries from the polluted regions was almost without exception higher than that in the background regions. There was an increasing trend in the nickel concentration in both berry species on moving towards the emission source. The maximum concentration occurred in the areas affected by atmospheric emissions from the nickel-copper smelters. In the "Severonickel" region the maximum nickel concentration occurred on the plots situated about 7-17 km to the south of the emission source. Background values were exceeded more than 50-fold for blueberry and more than 30-fold for lingonberry (Table 1). In the "Pechenganickel" region the maximum nickel concentration occurred to the north of the city of Zapolyarnyi. The background value was exceeded more than 30-fold for blueberry and lingonberry. In the "Apatity" region the maximum nickel concentration in lingonberries occurred at a distance of about 3 km and in blueberries about 6 km from the industrial zone. The background values were exceeded more than 8-fold for lingonberries and 3-fold for blueberries (Table 1). In the region of the Kandalaksha aluminium smelter the nickel concentration in blueberries and lingonberries was about twice the background level for both kinds of berry. In the Kovdor region the concentration was at the same level as the background values. There was no nickel at all in the berries from Karelia (Table 1).

Atmospheric industrial pollution thus causes nickel accumulation in the wild berries of bluebrry and lingonberry. The most intensive accumulation is in the regions subjected to the effect of copper-nickel smelters.

Table 1. Sulphur, nickel, copper and cobalt concentrations (mg/kg) in blueberries (*Vaccinium myrtillus*) and lingonberries (*Vaccinium vitis-idaea*) subjected to industrial pollution, 1989.

Berries / Sample plot location \ Elements	Blueberry S	Ni	Cu	Co	Lingonberry S	Ni	Cu	Co
Nickel region:								
4 km to the North from Zapolyarnyi	524	7.95	2.79	0.00	344	15.38	6.72	0.63
10 km to the NNE from Nickel	606	3.97	2.73	0.00	260	3.95	2.51	0.00
9 km to the NE from Nickel	1140	9.98	4.61	0.00	265	10.39	4.03	0.00
17.5 km to the ENE from Nickel	767	5.87	3.76	0.00	406	9.06	3.78	0.28
9 km to the E from Nickel	-	-	-	-	312	7.45	3.92	0.18
7 km to the W from Nickel	589	1.75	2.76	0.00	283	2.74	3.52	0.00
Monchegorsk region:								
16 km to the N from Monchegorsk	-	-	-	-	179	5.79	3.86	0.28
2 km to the SE from Monchegorsk	330	3.91	3.70	0.00	283	4.30	3.58	0.00
6 km to the SE from Monchegorsk	-	-	-	-	214	3.16	3.36	0.00
7 km to the S from Monchegorsk	-	-	-	-	325	25.48	10.78	1.06
17 km to the S from Monchegorsk	494	5.81	4.15	0.00	242	9.95	5.81	0.38
20 km to the S from Monchegorsk	474	4.37	3.95	0.00	412	6.56	4.10	0.22
27 km to the S from Monchegorsk	597	2.71	3.85	0.00	368	5.08	4.02	0.21
Apatity region:								
3 km to the E from industrial zone	439	0.48	3.84	0.00	235	4.31	3.23	0.00
6 km to the E from industrial zone	372	1.08	3.23	0.00	192	1.29	2.74	0.00
9 km to the E from industrial zone	356	0.67	3.13	0.00	172	0.72	2.98	0.00
Kovdor region:								
65 km to the E from Kovdor	302	0.18	2.61	0.00	139	0.50	2.23	0.00
Kandalaksha region:								
3 km to the N from Kandalaksha	323	0.37	2.22	0.00	213	0.76	3.22	0.00
5 km to the N from Kandalaksha	249	0.80	2.79	0.00	185	1.01	2.94	0.00
Background regions:								
SE lake Umbozero watershed	283	0.20	2.45	0.00	186	0.49	2.96	0.00
Karelia region	-	-	-	-	199	0.00	2.67	0.00

Accumulation of copper, another major pollutant, does not differ very much from that of nickel. The overall high copper concentration in the berries of blueberry and lingonberry is natural, and is probably connected to the fact that copper is a normal component of their metabolism. However, there was an increasing trend of copper accumulation on moving towards the emission source. This increase was one order of magnitude less than for nickel. The maximum concentration occurred on the same plots as for nickel (see Table 1).

Certain biochemical compounds such as sucrose, total acidity in the form of malic acid and ascorbic acid (vitamin C) were determined on a number of berry samples. According to the literature, the content of biochemical compounds is highly dependent on the microclimatic conditions of the site (moisture and temperature) and the stage of ripeness. It was therefore impossible to determine the correlation between biochemical composition and environment pollution on the basis of such a small sample. The data only show that the content of ascorbic acid in blueberry is twice that in lingonberry.

Conclusion

The chemical composition of berries has changed as a result of atmospheric industrial pollution. The accumulation of pollutants shows an increasing trend on moving towards the emission source. Accumulation of nickel is the most pronounced. The trends are the same for both species of berry.

METSÄNTUTKIMUSLAITOS
ROVANIEMEN TUTKIMUSASEMA

Osoite: PL 16
96301 Rovaniemi
Puhelin: (960) 15 721
Telefax: (960) 314 905

TUTKIJAT

Martti Varmola, MML (tutkimusaseman johtaja)

Kirsti Airaksinen, FM
Timo Helle, FT (erikoistutkija)
Hannu Hökkä, MMK
Risto Jalkanen, MMT
Erkki Kaila, FK
Juha Kaitera, MMK
Eero Mattila, MMT (erikoistutkija)
Kari Mikkola, FK
Kari Mäkitalo, MH
Arto Naskali, TTM
Ari Nikula, MMK
Kaarina Niska, MMK
Yrjö Norokorpi, MMT (erikoistutkija)
Timo Penttilä, MH
Aulis Ritari, MML
Hannu Salminen, MMK
Pentti Sepponen, FT
Marja-Liisa Sutinen, FL
Eero Tikkanen, FL
Mauri Timonen, MH

Rovaniemen tutkimusasemalla ilmestyneet Metsäntutkimuslaitoksen tiedonantoja-sarjan julkaisut:

N:o 6 Metsäntutkimuspäivät Rovaniemellä 1981. 1981.

N:o 35 Päivi Hänninen. Sammalen kemiallinen torjunta taimitarhalla. 1981.

N:o 58 Pohjois-Lapin metsät. Metsäntutkimuspäivät Rovaniemellä 1982. 1982.

N:o 65 Yrjö Norokorpi ja Pentti Sepponen (toim.). Kilpisjärven alueen maankäytön yleissuunnitelma. 1982.

N:o 71 Päivi Hänninen. Alustavia päätelmiä kivivillan käytöstä männyntaimien kasvualustana muovihuoneessa. 1982.

N:o 77 Pohjois-Lapin metsien uudistaminen. 1982.

N:o 95 Jarmo Nieminen. Varttuneet kontortametsiköt Kivalon kokeilualueella. 1983.

N:o 105 Metsäntutkimuspäivät Rovaniemellä 1983. 1983.

N:o 148 Pentti Sepponen, Vuokko Pitkänen ja Helena Poikajärvi (toim.). Metsien kasvupaikkaluokitus. Metsäntutkimuspäivät Rovaniemellä 1984. 1984.

N:o 157 Erkki Kaila ja Markku Taipale. TUTKA-tiedonhallintaohjelmisto. Tietokannan muodostus ja käyttö. 1984.

N:o 165 Eero Tikkanen ja Hannu Raitio. Pohjois-Suomen aurausalueiden männyntaimien epänormaali kehitys ja olettamus sen syystä. Summary: A hypothesis on the cause of abnormal development of Scots pine saplings on ploughed sites in Northern Finland. 1984.

N:o 186 Eero Tikkanen. Aurausalueen heikkokuntoisten männyntaimien ravinnetaloudesta Pohjois-Suomessa. Abstract: Nutrient metabolism of weakened Scots pine saplings on a ploughed site in Northern Finland. 1985.

N:o 190 Erkki Kaila, Hilkka Kinnunen ja Tapio Timonen. BIB-viitetietokantaohjelmisto. Tietokannan muodostus ja käyttö. 1985.

N:o 196 Olli Saastamoinen ja Helena Poikajärvi (toim.). Tietojärjestelmien kehittäminen metsäalalla. Ajankohtaista tutkimuksesta. Metsäntutkimuspäivät Rovaniemellä 1985. 1985.

N:o 226 Timo Penttilä ja Mikko Honkanen. Suometsien pysyvien kasvukoealojen (SINKA) maastotyöohjeet. 1986.

N:o 242 Esa Taskinen ja työryhmä. Metsäkanalintujen elinympäristövaatimukset - kirjallisuuskatsaus. 1986.

N:o 243 Timo Penttilä ja Martti Varmola (toim.). Lapin kolmion puuntuotannolliset mahdollisuudet. 1987.

N:o 253 Helena Poikajärvi (toim.). Metsäntutkimuspäivät Rovaniemellä 1986. 1987.

N:o 278 Hannu Saarenmaa ja Helena Poikajärvi (toim.). Korkeiden maiden metsien uudistaminen. Ajankohtaista tutkimuksesta. Metsäntutkimuspäivät Rovaniemellä 1987. 1987.

N:o 345 Anna-Liisa Sippola. Suojelualuetyypit ja kansallispuistojen suojelun toteuttaminen - kahdeksan esimerkkiä. 1989.

N:o 347 Martti Varmola ja Pertti Palviainen (toim.). Lapin metsien terveys. Metsäntutkimuspäivät Rovaniemellä 1989. 1990.

N:o 362 Martti Varmola ja Tuija Katermaa (toim.). Metsänparannus. Metsäntutkimuspäivät Rovaniemellä 1990.1990.

ISBN 951-40-1144-9
ISSN 0358-4283