METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 743, 1999
THE FINNISH FOREST RESEARCH INSTITUTE, RESEARCH PAPERS 743, 1999

Forest Condition Monitoring in Finland

National report 1998

Edited by
Hannu Raitio and Tuire Kilponen

PARKANON TUTKIMUSASEMA

METLA

The observation plot (Tammela, Plot no 12) of the Finnish programme for the intensive monitoring of forest ecosystems. Photo: Erkki Oksanen / Metla.

METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 743, 1999
THE FINNISH FOREST RESEARCH INSTITUTE, RESEARCH PAPERS 743, 1999

Forest Condition Monitoring in Finland

National report 1998

Edited by
Hannu Raitio and Tuire Kilponen

PARKANON TUTKIMUSASEMA

Forest Condition Monitoring in Finland

National report 1998

Editors:

Hannu Raitio and Tuire Kilponen

E-mail of editors:
hannu.raitio@metla.fi
tuire.kilponen@metla.fi

Publisher:

Finnish Forest Research Institute
Parkano Research Station

Approved by
research director Matti Kärkkäinen 18.6.1999

Printed in:

Tampereen Tekstifilmi Ky

For further information, please contact:

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54
FIN-39700 Parkano

Contents

Preface

Finland has been participating since 1985 in the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) established by the United Nations Economic Commission for Europe (UN/ECE) under its Convention on Long-range Transboundary Air Pollution (CLRTAP). In 1986 the European Union adopted the Scheme on the Protection of Forests against Atmospheric Pollution.

The Finnish Forest Research Institute (Metla) is responsible for monitoring the health and vitality of the forests in Finland by carrying out an annual survey of the overall condition of the trees on a permanent network of systematically selected sample plots (Level I, totalling 490 plots) using internationally standardised methods. A survey of needle chemistry on the Level I plots was started in 1987, and a soil survey carried out during 1985–89 (supplemented in 1995).

In order to gain a better understanding of the effects of air pollution and other stress factors on forests, a Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems (Level II) has been implemented in 1995. By the end 1997, 31 intensive monitoring plots had been established in different parts of Finland.

The present report describes the results of the Level I and II surveys in Finland in 1997/98.

Summary

Since 1985, Finland has been participating in the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), which was established by the United Nations Economic Commission for Europe under its Convention on Long-range Transboundary Air Pollution. In 1986 the European Union adopted the Scheme on the Protection of Forests against Atmospheric Pollution (Council Regulation (EEC) No 3528/86).

The Finnish Forest Research Institute (Metla) is responsible for monitoring the health and vitality of the forests in Finland by carrying out an annual survey of the overall condition of the trees on a permanent network of systematically selected sample plots (Level I, totalling 490 plots) using internationally standardised methods.

In order to gain a better understanding of the effects of air pollution and other stress factors on forests, a Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems (Level II) has been implemented in 1995. By the end 1997, 31 intensive monitoring plots had been established in different parts of Finland.

The weather conditions in 1997 were rather exceptional compared to the long-term mean values. In January, polar clouds associated with ozone depletion in the nothern hemisphere were observed even in southern Finland. Wintertime ozone depletion is normally observed only in Lapland. The winter was mild, and the spring rather cold. In contrast, the summer was exceptionally warm and dry. The autumn until December was mild, except for October, which was relatively cold. The amount of precipitation varied spatially and temporarily more than normally. Compared to long-term averages, precipitation was close to normal, but areal differences were noticeable.

As a result of effective emission reductions, the concentrations of acidifying deposition compounds and gaseous air pollutants have decreased during the past few years. However, ozone concentrations have increased, and ozone now appears to pose the most serious threat to the state of health of forests. Acidification is no longer the serious problem that it was a few years ago, although the critical load of S deposition is still being exceeded in certain areas. Relative high concentrations of air pollutants pass into Finland from industrial areas in Central Europe, St Petersburg and the Kola Peninsula in NW Russia.

The forests in Finland are less defoliated than those in most of the other European countries. Crown defoliation on all tree species in Finland increased during 1986–1989. During the 1990's, however, tree crown condition has improved and remained relatively stable. In 1998 the average degree of defoliation on Scots pine was 9 %, on Norway spruce 18 %, and on broad-leaved tree species 11 %. Needle or leaf loss was not found at all on 50 % of the conifers and 65 % of the broadleaves. The proportion of trees suffering from over 25 % defoliation increased compared to the situation in 1997 by 1 % on pine, 12 % on spruce and 4 % on broadleaves.

In Finland, stand age and unfavourable climatic and weather conditions primarily cause defoliation. No clear connections have been found between air pollution and tree crown condition at the national level. On the plots in the IM programme, on the other hand, there has been an improvement in the condition of the forest ecosystems along with an increase in air quality.

The weather conditions in summer 1998 promoted the occurrence of fungal diseases. Damage caused by rust fungi was widely reported in the southern parts of the country. Relatively extensive needle and leaf damage caused by insects also occurred on pine and birch in some localities. The main area of vole damage was moving from eastern to northern Finland. Seedling stand damage caused by moose increased in the southern and central parts of the country. Local heavy storms

(trombis) also occurred during the summer in connection with thunderstorms, and windthrow was reported e.g. in South Savo. A considerable amount of snow damage again occurred in North Karelia.

The causal effect relationships between forest condition and environmental factors have been studied since 1995 in 17 Scots pine and 14 Norway spruce stands. Tree defoliation in the stands on these intensively monitored observation plots was slightly more severe than that on the 490 plots in the extensive monitoring plot network. The difference appears to be due to differences in the structure of the stands. The nutrient status of the trees also differed to a small extent from each other. The stands were characterised by a lack of nitrogen and low phosphorus concentrations, and potassium deficiencies were apparent on peatlands in the south. No clear differences were found between the nutrient concentrations of needles collected in 1995 and in 1997. Relationships were found between the concentrations of many nutrients in the tree needles and the organic layer of the soil.

S and N deposition in the open area were clearly lower in 1996 and 1997 on the Level II sample plot network than the long-term values in the 1970s and 1980s. Thus, the reduction in S emissions is reflected in deposition, and has strongly decreased the potential stress to the forest ecosystems. The reasons for the low N deposition may be partly meteorological, because the reduction in N emissions from anthropogenic sources has not been as strong as that for sulphur. Although the S and N depositions were relatively low in 1996-97 compared to the situation earlier, the deposition loads reaching the forest floor within the stand, as well as in the open area, were higher in southern Finland and decreased on moving to the north.

The loads of base cations and DOC were higher in stand throughfall than in the open area and the increase in the loads of these components was higher in the spruce than in the pine stands.

The strong S-N climatic gradient in Finland appears to be the main reason for the S-N gradients in the total N and S concentrations and C/N ratio in the organic layer. There is also a strong decreasing S-N gradient in the deposition of N and S compounds, and an increasing gradient in the average pH of bulk precipitation. It is very difficult to separate, with any degree of certainty, the effects of deposition on the soil chemical status from those attributable to climatic conditions. However, the strong correlations between the geographical location of the plots and the deposition and soil parameters indicate that both the climatic conditions and deposition should be taken into account when estimating the chemical properties of forest soil.

According to the change in soil water acidity as it passes down through the soil profile, the buffering capacity of the soil on six of the ICP Forests (level II) monitoring plots is relatively high. The S concentrations in bulk deposition, stand throughfall and percolation water were the highest on the plots located in southern Finland. The nitrate concentrations in percolation water on all the plots were extremely low as a result of efficient nitrogen uptake, and the risk of nitrate leaching into the groundwater appears to be negligible.

The acidity and base saturation of the organic and uppermost mineral soil layers on the monitoring plots indicate that these sites have not suffered from the adverse effects of acidifying deposition, and that their capacity to buffer and neutralise acidifying deposition in the future is relatively high. The results of soil water studies carried out on 6 of the plots also support this conclusion. The annual deposition of N and S compounds is equivalent to only a very small proportion of the total amount of total N and S in the organic layer on the plots.

A relatively large number of pilot and integrated studies have been carried out in conjunction with the national ICP Forests intensive monitoring programme in order to facilitate and improve interpretation of the results and the development of monitoring methods and techniques.

Yhteenveto

Suomi on vuodesta 1985 lähtien osallistunut yleiseurooppalaiseen metsien terveydentilan seurantaohjelmaan, joka pohjautuu kansainväliseen ilman epäpuhtauksien kaukokulkeutumista koskevaan sopimukseen. Euroopan Unionin jäsenmaissa metsien terveydentilan seuranta nojautuu vuosina 1986 ja 1994 vahvistettuihin säädöksiin ja niihin myöhemmin tehtyihin täydennyksiin. Metsäntutkimuslaitos (Metla) inventoi puiden kunnon vuosittain kansainvälisesti sovituin menetelmin noin 490 pysyvällä havaintoalalla. Metsien kunnon ja ilman epäpuhtauksien sekä muiden stressitekijöiden välisiä vuorosuhteita tutkitaan 31 metsikössä eri puolilla Suomea sekä ympäristön yhdennetyn seurannan neljällä valuma-alueella.

Vuoden 1997 säätila oli varsin poikkeuksellinen pitkäaikaisiin keskiarvoihin verrattuna. Tammikuussa polaariset pilvet ja otsonikato ulottuivat Etelä-Suomeen saakka, normaalisti otsonikatoa havaitaan ajoittain vain Lapissa. Talvi oli leuto ja kevät puolestaan melko kylmä. Sen sijaan kesä oli poikkeuksellisen lämmin ja kuiva. Samoin syksy aina joulukuulle saakka oli leuto lokakuuta lukuun ottamatta, joka oli varsin kylmä. Kesän sademäärä oli varsin normaali pitkän ajan keskiarvoon verrattuna, sateet vaihtelivat kuitenkin ajallisesti ja paikallisesti normaalia enemmän.

Päästövähennysten seurauksena happamoittavan laskeuman komponenttien sekä kaasumaisten ilman epäpuhtauksien pitoisuudet ilmassa ovat viime vuosina laskeneet. Ilman otsonipitoisuudet ovat kuitenkin kohonneet ja otsoni lieneekin tällä hetkellä pahin uhka metsiemme terveydentilan kannalta. Happamoituminen ei enää ole yhtä vakava ongelma kuin menneinä vuosina, vaikkakin rikkilaskeuman kriittinen kuormitus ylittyy vielä paikoin. Keski-Euroopan, Pietarin ja Kuolan niemimaan teollisuusalueilta kulkeutuu ajoittain Suomeen ilman epäpuhtauksia hetkellisesti suhteellisen korkeina pitoisuuksina.

Kansainvälisessä vertailussa Suomen metsät ovat vähemmän harsuuntuneita kuin useimmissa muissa Euroopan maissa. Vuosina 1986–1989 kaikkien puulajien latvusten harsuuntuminen lisääntyi Suomessa. 1990-luvulla puiden latvusten kunto on kuitenkin parantunut ja säilynyt viime vuodet melko vakaana. Vuonna 1998 mäntyjen keskimääärinen harsuumisaste oli 9 %, kuusten 18 % ja lehtipuiden 11 %. Neulas- tai lehtikatoa ei tavattu lainkaan 50 %:lla havupuista ja 65 %:lla lehtipuista. Yli 25 % harsuuntuneiden puiden osuus kasvoi mäntyjen osalta edellisestä vuodesta prosentilla, kuusella 12 %:lla ja lehtipuilla 4 %:lla.

Harsuuntuminen johtuu Suomessa pääasiassa puuston ikääntymisestä sekä epäedullisista ilmasto- ja säätekijöistä. Koko maata tarkasteltaessa ei ole havaittu selvää yhteyttä ilman epäpuhtauksien ja puiden latvuskunnon välillä. Sen sijaan ympäristön yhdennetyn seurannan valuma-alueilla on havaittu metsäekosysteemien tilan kohentuneen ilman laadun parantumisen myötä.

Kesän 1998 sääolot edistivät sienitautien esiintymistä. Ruostesienien aiheuttamia tuhoja tavattiin yleisesti maan eteläosissa. Männiköissä ja koivikoissa esiintyi paikoin myös laajahkoja hyönteisten aiheuttamia neulas- ja lehvästötuhoja. Myyrätuhojen painopiste oli siirtymässä Itä-Suomesta Pohjois-Suomeen. Hirvien aiheuttamat taimikkotuhot lisääntyivät maan etelä- ja keskiosissa. Kesällä ilmeni myös ukkosten yhteydessä paikallisia pyörremyrskyjä eli trombeja, jotka kaatoivat puita mm. Etelä-Savossa. Lumituhoja ilmeni edelleen runsaasti Pohjois-Karjalassa.

Vuodesta 1995 lähtien metsien kunnon ja ympäristötekijöiden välisiä vuorosuhteita on tutkittu 17 männikössä ja 14 kuusikossa eri puolilla Suomea. Näissä intensiivisen seurannan metsiköissä puiden harsuuntuminen oli hieman voimakkaampaa kuin laaja-alaisen seurannan havaintometsiköissä. Ero aiheutunee metsiköiden rakenteen välisistä eroista. Ilmeisesti samasta syystä myös metsiköiden ravinnetilat poikkesivat hieman toisistaan. Metsiköille oli tyypillistä typen puute ja alhaiset fosforipitoisuudet, eteläisillä suokohteilla ilmeni kaliumin puutosta. Vuonna 1995 ja 1997 kerättyjen neulasten ravinnepitoisuuksien välillä ei havaittu sanottavia eroja. Neulasten ja humuksen ravinnepitoisuuksien välillä havaittiin yhteisvaihtelua monien ravinteiden osalla.

Rikki- ja typpilaskeuma metsäekosysteemien intensiivisen seurannan havaintoaloilla oli selvästi pienempi vuosina 1996 ja 1997 verrattuna pitkän ajan keskiarvoihin 1970- ja 1980-luvuilla. Rikkipäästöjen vähennykset heijastuvat myös laskeumassa. Syyt typpilaskeuman vähäisyyteen voivat olla osittain meteorologisia, sillä antropogeenisten typpipäästöjen vähennykset eivät ole olleet yhtä suuria kuin rikkipäästöjen vähennykset. Vaikka rikin ja typen laskeumat olivat koko maassa suhteellisen alhaisia vuosina 1996–97 aiempaan tilanteeseen nähden, avoimen paikan ja metsikkösadannan laskeumakuormat olivat korkeimmillaan Etelä-Suomessa ja vähenivät pohjoista kohti.

Metsikkösadannan liuenneen orgaanisen hiilen ja emäskationien laskeumat olivat suurempia kuin avoimella paikalla, ja kuusikot lisäsivät näiden aineiden metsikkösadannan kuormaa enemmän kuin männiköt.

Voimakas etelä-pohjoissuuntainen ilmastogradientti Suomessa lienee syynä humuskerroksen kokonaisrikin ja -typen sekä C/N-suhteen etelä-pohjoissuuntaiselle gradientille. Myös rikin ja typen laskeumat vähenevät ja laskeuman keskimääräinen pH kohoaa pohjoista kohti. Näin ollen on hyvin vaikea erottaa laskeuman vaikutuksia metsämaan kemialliseen tilaan ilmastoon liittyvistä vaikutuksista. Voimakas korrelaatio havaintoalojen maantieteellisen sijainnin, laskeuman ja maaperätunnusten välillä indikoi, että sekä ilmasto-olot että laskeuma tulee huomioida arvioitaessa metsämaan kemiallisia ominaisuuksia.

Kuuden tutkitun havaintoalan maaperän puskurikapasiteetti happamoitumista vastaan oli suhteellisen korkea, mikä heijastui vajoveden happamuuden vähenemisenä veden vajotessa maannosvyöhykkeen läpi. Laskeuman, metsikkösadannan ja vajoveden rikkipitoisuudet olivat korkeimpia Etelä-Suomen näytealoilla. Vajoveden nitraattipitoisuudet olivat hyvin alhaisia kaikilla näytealoilla, koska kasvillisuus käyttää nitraattia tehokkaasti hyväkseen. Nitraatin huuhtoutumisriski pohjaveteen on siten pieni.

Humuskerroksen ja kivennäismaan happamuus ja emäskyllästysaste osoittivat, etteivät metsäekosysteemien intensiivisen seurannan näytealat ole kärsineet happamasta laskeumasta, ja että niiden puskurikyky hapanta laskeumaa vastaan on jatkossakin suhteellisen korkea. Myös maavesitutkimukset kuudella näytealalla tukivat tätä johtopäätöstä. Vuosittainen typpi- ja rikkilaskeuma vastaa vain hyvin pientä osaa typen ja rikin kokonaismäärästä humuskerroksessa.

Yleiseurooppalaisen metsien terveydentilan seurantaohjelman yhteydessä on tehty myös lukuisia erillistutkimuksia tulosten tulkinnan parantamiseksi ja tutkimusmenetelmien kehittämiseksi.

1 Forest condition monitoring in Finland during 1985–1998

Hannu Raitio

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Introduction

The Finns have always been extremely interested in their forests, and for good reason since Finland is an industrialised country that is economically dependent on its forests. A national forest programme to develop the management, use and protection of the country's forests is currently being adopted. We want to maintain the forests in a vital, diverse condition while, at the same time, ensuring that the forests provide as much work and income as possible, and act as a source of spiritual and physical well-being for all Finns.

The national forest inventory

Finland has for long been concerned about the sufficiency of its forest resources. During the 1980's considerable concern was expressed about the state of health of the forests, and interest has recently shifted, for instance, to forest biodiversity and climate change. An attempt has been made to address these concerns by establishing monitoring systems that provide an accurate picture of the situation in our forests.

The first national forest inventory (NFI) covering all the forests in the country was carried out during 1921–24, and the 9th NFI is currently underway. The Finnish forest inventories thus form a time series that is unique throughout the world.

The NFI is a system for monitoring the forests and forest reserves. It produces reliable and repeatable information on a national scale about 1) the forest reserves, i.e. the volume, growth and quality of the standing stock, 2) forms of land use and ownership of the forests, 3) forest damage, and 4) forest biodiversity. The information produced by the NFI is based on over 70 000 observation plots on forest land, over 150 measured or estimated parameters, and on thousands of intensively measured sample trees (Tomppo & Tonteri 1998, Reinikainen et al. 1998). The Finnish statistical yearbook of forestry, which is published annually, contains up-to-date information about the Finnish forests and forestry, as well as international forest statistics (Sevola 1998).

Monitoring the state of health of the forests

Concern about forest damage caused by air pollutants increased considerably in Europe during the 1980's. The continuous monitoring of forest condition in Finland first started in connection with the ILME (Effect of Air Pollutants on Forests) Project, carried out during 1983–1990 by the Finnish Forest Research Institute (Metla) as part of the national Acidification Project, 1985–1990. The final report of the Acidification Project was published in 1990 (Kauppi et al. 1990) and the ILME Project in 1993 (Hyvärinen et al. 1993).

In 1985 about 3 000 permanent sample plots were established to supplement the 8th national forest inventory. The tree stand was measured, the ground vegetation analysed, and moss and epiphytic lichen samples were collected for a survey of heavy metal deposition. The stand measurements and moss sampling and heavy-metal analyses have since been repeated at 5-year intervals (Kubin et al. 1998). The survey of heavy-metal concentrations in mosses has simultaneously developed into a Pan-European project.

Metla annually inventories crown condition of trees, using internationally standardised methods, on a representative sample of tree stands. The inventory is carried out on about 450 permanent sample plots selected from the permanent NFI sample plots established in 1985. A number of different parameters are measured on the trees. In addition, soil samples have been collected and analyzed from all the plots, as well as needle samples for elemental analysis on part of the plots. The extensive monitoring of forest condition (Level I) in Finland has, ever since it was first started, been part of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) of the United Nations Economic Commission for Europe (UN/ECE).

Forest condition in European Union has been monitored by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) of UN/ECE and under the Scheme on the Protection of Forests against Atrmospheric Pollution of the European Union (EU). The monitoring work carried out in the EU countries is based on regulations issued in 1986 and 1994, and on subsequent modifications made to them.

When Finland joined the European Union in 1995, some modifications were made to the national monitoring of forest condition (Level I) and, at the same time, the intensive monitoring of forest ecosystems (Level II) was also started.

Since 1987, Metla has participated, together with other research institutes and universities, in the International Co-operative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (IM). Starting in 1989, the programme was initially carried out on a trial basis until, in 1992, it attained an official position under the UN ECE Convention on Long-Range Transboundary Air Pollution. The IM monitoring programme is studying the state of the environment in small catchments in a natural state, of which there are four in Finland. The national summary of the first results of the programme was published in 1995 (Bergström et al. 1995).

Regional projects

Lapland was for long considered to be a clean background area, which was one of the reasons why a monitoring network of lower density than the rest of the country, was established in Lapland in 1985. However, the idea of clean air in Lapland started to be questioned as a result of the reports of serious environmental damage in the Kola Peninsula, NW Russia, and the outbreaks of forest damage observed in Lapland (Tikkanen & Raitio 1990). The 5-year Lapland Forest Damage Project was started at the instigation of Metla in May 1989. Four universities and five research institutes also participated in the project. The final report of the project, entitled "Kola Peninsula Pollutants and Forest Ecosystems in Lapland", was published in 1995 (Tikkanen 1995).

A couple of years after the start of the Lapland Forest Damage Project, Metla initiated a joint Russian–Finnish investigation into forest condition and air pollutant deposition in the Karelian Isthmus (NW-Russia) and SW Finland, as well as in the Kostamus and Kainuu areas. The results of the project were published in 1997 (Lumme et al. 1997).

On the instigation of the Provincial Government of Turku and Pori, a 5-year research project was started in 1992 to investigate the state of health of Scots pine stands on sites susceptible to soil acidification in the region. A 3-year project to survey the condition of Norway spruce stands in the Merenkurkku area, and to investigate the factors affecting stand condition, was started by the Merenkurkku Council and the provincial governments of Vaasa and Västerbotten at the same time. The final report on the condition of Norway spruce stands in the Merenkurkku area was published in 1996 (Raitio 1996).

Bioindicator surveys

Finland has a long-established tradition of bioindicator research on air quality in forest environments. Bioindicator monitoring was carried out in Finland already in the 1970's in areas subjected to air pollution loads. During the 1980's bioindicator monitoring became more systematic and, during the past decade, it has also been extended to cover background areas away from point emission sources (Jussila 1997).

The representatives of the pollution emitters, the state, the environmental authorities, local municipalities and the parties responsible for carrying out the work, are usually involved in forest bioindicator studies. The obligation set on industrial enterprises to carry out environmental monitoring is usually based on decisions made by the authorities in accordance with the Air Protection Law. The municipalities can actively participate in the monitoring work, but they are also obliged under the law to be aware of the state of the environment in their area. The task of the state environmental authorities, on the other hand, is to direct the content and implementation of the monitoring work. In Finland, bioindicator surveys have mainly been carried out in the western and southern parts of the country, which have the highest densities of population and industry (Jussila et al. 1999). The main emphasis in bioindicator monitoring has been placed on estimating tree condition and the condition of epiphytic lichen species growing on tree trunks, as well as on the elemental composition of the needles.

References

Bergström, I., Mäkelä, K. & Starr, M. (Eds.). 1995. Integrated Monitoring Programme in Finland. First national report. Ministry of the Environment, Environment Policy Department, Report I. 138 p.

Hyvärinen, A., Jukola-Sulonen, E.-L., Mikkelä, H. & Nieminen, T. (Eds.). 1993. Metsäluonto ja ilmansaasteet. Finnish Forest Research Institute. Research Papers 446. 221 p. (In Finnish).

Jussila, I. 1997. Porin-Harjavallan ja Pohjois-Satakunnan alueen ilman laadun seuranta bioindikaattorien avulla vuosina 1996–1997. Sykesarja B 12. 78 p. (In Finnish).

Jussila, I., Joensuu, E. & Laihonen, P. 1999. Ilman laadun bioindikaatioseuranta metsäympäristössä. Ympäristöopas 59. Ympäristöministeriö/Ilmansuojeluosasto. 57 p. (In Finnish).

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

Kubin, E., Lippo, H. & Poikolainen, J. 1998. Raskasmetallikuormitus. In: Mälkönen, E. (Ed.). Ympäristömuutos ja metsien kunto. Metsien terveydentilan tutkimusohjelman loppuraportti. Finnish Forest Research Institute. Research Papers 691: 55–61. (In Finnish).

Lumme, I., Arkhipov, V., Fedorets, N. & Mälkönen, E. (Eds.) 1997. Männiköiden kunto Karjalan kannaksen – Kaakkois-Suomen ja Kostamuksen – Kainuun alueilla. Suomalais-venäläisen tutkimushankkeen loppuraportti. Finnish Forest Research Institute. Research Papers 665. 75 p. (In Finnish).

Raitio, H. (Ed.). 1996. Kuusikoiden kunto Merenkurkun alueella. Granskogarnas hälsotillstånd i Kvarkenregionen. Merenkurkun Neuvosto. Gummerus Kirjapaino Oy, Jyväskylä. 145 p. (In Finnish).

Reinikainen, A., Mikkola, K., Vanha-Majamaa, I., Nousiainen, H. & Tamminen, M. 1998. metsä- ja suokasvillisuuden seuranta VMI:n yhteydessä. In: Annila, E. (Ed.). Monimuotoinen metsä. Metsäluonnon monimuotoisuuden tutkimusohjelman väliraportti. Finnish Forest Research Institute. Research Papers 705: 19–73. (In Finnish).

Sevola, Y. (Ed.) 1998. Metsätilastollinen vuosikirja 1998. Skogsstatistik årsbok. Finnish statistical yearbook of forestry.

SVT Maa- ja metsätalous 1998:3. 344 p. (In Finnish).
Tikkanen, E. (Ed.). 1995. Kuolan saastepäästöt Lapin metsien rasitteena. Gummerus Kirjapaino Oy, Jyväskylä. 232 p. (In Finnish).
Tikkanen, E. & Raitio, H. 1990. Nutrient stress in young Scots pines suffering from needle loss in a dry heath forest. Water, Air, Soil Pollution 54: 281–293.
Tomppo, E. & Tonteri, T. 1998. Luonnon monimuotoisuuden arviointi valtakunnan metsien inventoinnissa. In: Annila, E. (Ed.). Monimuotoinen metsä. Metsäluonnon monimuotoisuuden tutkimusohjelman väliraportti. Finnish Forest Research Institute. Research Papers 705: 7–17. (In Finnish).

2 Background air quality in Finland in 1997

Jari Waldén, Tuija Ruoho-Airola and Liisa Leinonen

Finnish Meteorological Institute
Air Quality Research
Sahaajankatu 20 E, FIN-00810 Helsinki, Finland

Stations and methods

The Finnish Meteorological Institute (FMI) carries out air quality measurements at background stations within several national and international networks. The first measurement station was founded at the beginning of 1970. In 1997 air quality measurements were conducted at 16 stations over Finland. The network of air quality measurement stations in the background area in Finland is presented in Fig. 1.

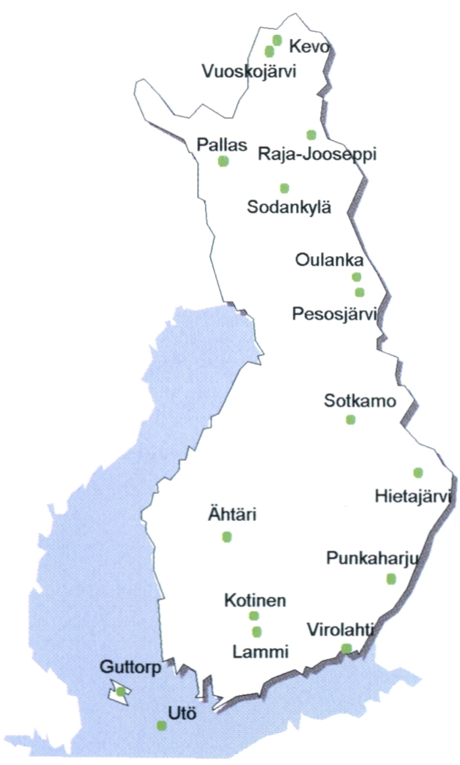

Figure 1. Finnish background air quality measuring stations in 1997.

The measurements and sampling at the stations and the analysis of samples in the laboratory are carried out with methods described in detail in the manuals for UN ECE EMEP (EMEP 1996), UN ECE IM (ENVIRONMENT DATA CENTRE 1989) and WMO GAW (Santroch 1994). Deposition samples have been collected using different types of bulk sampler for summer and winter. The bulk deposition includes the wet deposition and the part of dry deposition (gases and particles) that settles in the sampler. Sampling times range from 24 hours to 1 month. Further information on the background air quality measuring programmes and methods is available in the annual reports in Air Quality Measurements (Leinonen 1998).

The quality assurance of the results is based on guidelines given in the EMEP Data Quality Objectives (EMEP 1996) and GAW (Mohnen et al. 1992). The laboratory participates annually in intercomparisons within the EMEP and GAW programmes in order to achieve international comparability for the results. Such intercalibration events are not regularly employed, however, for gases and particles.

Weather in 1997

This review of the main features of the weather is based on the Finnish Meteorological Institute's meteorological data base and on the issues 1–12/97 of the Ilmastokatsaus (FMI 1997) published by the FMI.

The weather in 1997 was quite exceptional compared to the long-term averages of temperature and precipitation, with some very rare meteorological phenomena being observed. In January, polar clouds associated with ozone depletion in the northern hemisphere were observed even in southern Finland. Polar clouds are observed every now and then in Lapland, but are very rarely seen in other parts of the country. Funnel clouds associated with thunderstorms were observed quite frequently in late summer.

The winter was relatively mild with few heavy storms. At the end of January a storm swept over the country, being strongest in marine areas and in Lapland. The spring was quite cold, but the summer was one of the warmest, and long-term records were exceeded all over the country in every one of the summer months. The autumn until December was mild, except for October, which was relatively cold.

The amount of precipitation varied spatially and temporarily more than normally. Compared to long-term averages, precipitation was close to normal, but areal differences were noticeable. The highest amount of precipitation, over 700 mm, was reached in the south–west of Finland and also at Kilpisjärvi in the north. At Kilpisjärvi the annual amount of precipitation was 1.7 times the normal value. The summer was extremely dry due to the low precipitation. However, some local showers were observed, especially at Kuhmo, where 122 mm of rain was recorded. The low amount of precipitation in summer was a limiting factor on the growth of plants, in spite of the high temperature.

In Figs. 2–4 are shown some of the meteorological parameters (temperature, precipitation and global radiation) for the year 1997 compared to their long-term means.

Deposition

Annual deposition of acidifying components, comparison with mean values for the ten previous years

Annual depositions in 1997 at four stations representing different parts of the country are

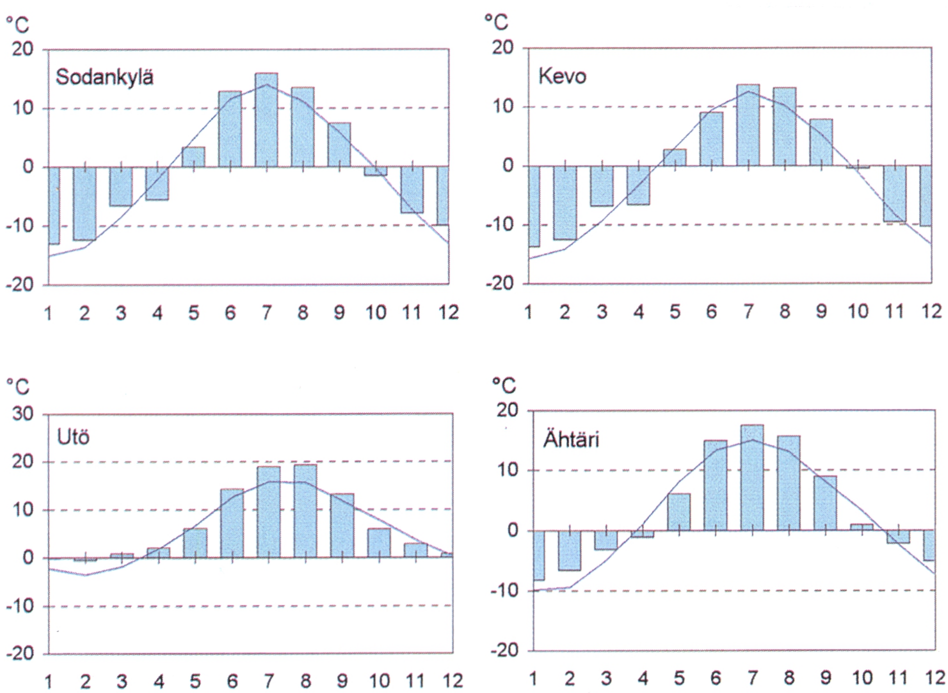

Figure 2. Mean monthly temperatures in 1997 (bars) and long-term (1961–1990) averages (line) at Utö, Ähtäri, Sodankylä and Kevo (See Fig. 1).

given in Fig. 5. The stations have been arranged along the abscissa from south to north.

A clear decreasing south–north gradient is observable in the deposition of the major components affecting acidification, the southern part of the country receiving 4–16 times the deposition of the northernmost part. The geographical difference is strongest for ammonium and weakest for hydrogen ion depositions.

For all components and stations, the annual depositions are lower in 1997 than the mean values for the years 1987–96; this result is in line with the downward acidification trend

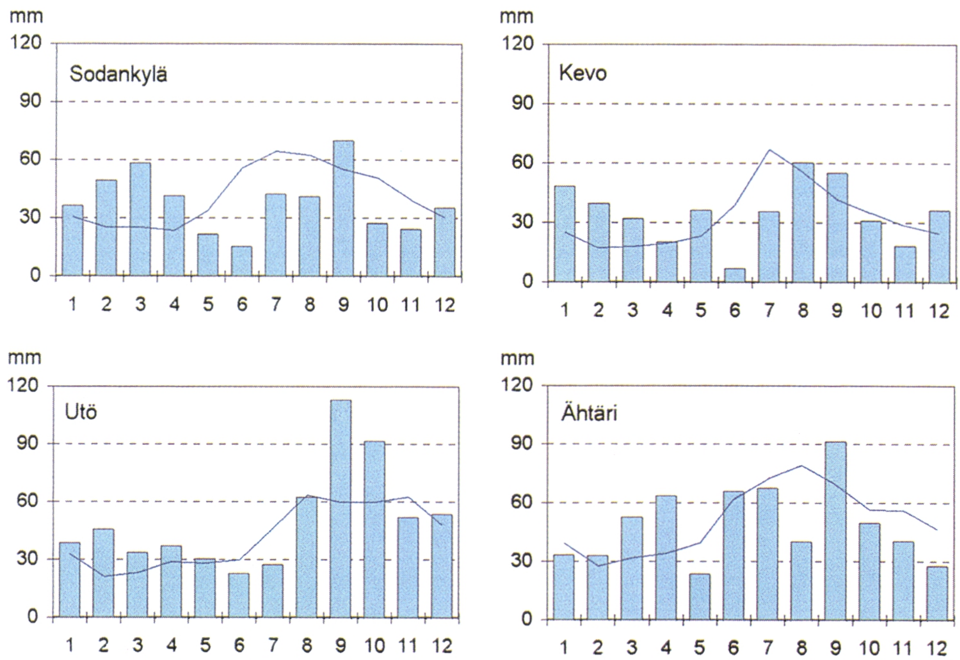

Figure 3. Monthly precipitation in 1997 (bars) and long-term (1961–1990) averages (line) at Utö, Ähtäri, Sodankylä and Kevo (See Fig. 1).

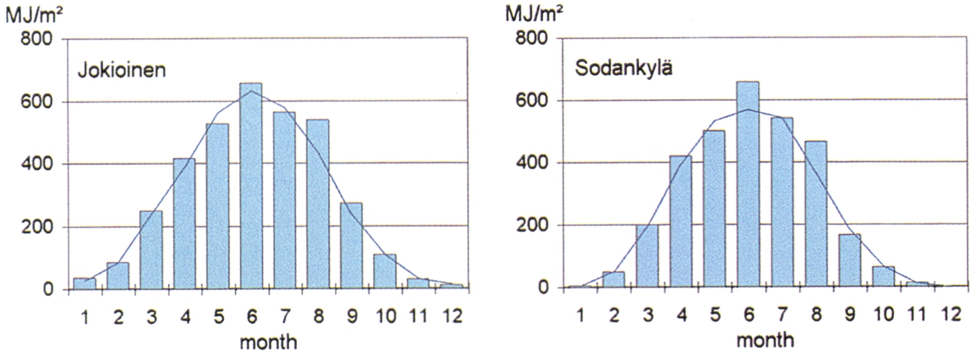

Figure 4. Monthly amounts of global radiation in 1997 (bars) and long-term (1961–1990) averages (line) at Jokioinen and Sodankylä (See Fig. 1).

observed during the last ten years in Finland (Kulmala et al. 1998). The decrease in 1997 from the previous decade is strongest for the sulphate and ammonium depositions: about 50 % at all other stations than Kevo in the far north. The decline for nitrate deposition was about 30 % in the same area. Hydrogen ion deposition decreased by 40 % in the southern part of Lapland and between 20 and 30 % at the other stations. Deposition of calcium, which neutralises the acidic deposition, has also declined during the last ten years. At the stations in southern and central Finland, the deposition in 1997 was about 50 % lower than the mean for 1987–96.

Annual deposition of some trace elements

Annual depositions of some trace elements in 1997 are presented in Fig. 6. The stations have been arranged along the abscissa from south to north.

The deposition decreases from south to north. The decreasing south–north gradient is quite similar for lead, cadmium and chromium: the far north receives only 10–15 % of the deposition measured on the south coast. For copper the geographical distribution of deposition is presumably affected by the huge copper emissions from the Kola Peninsula

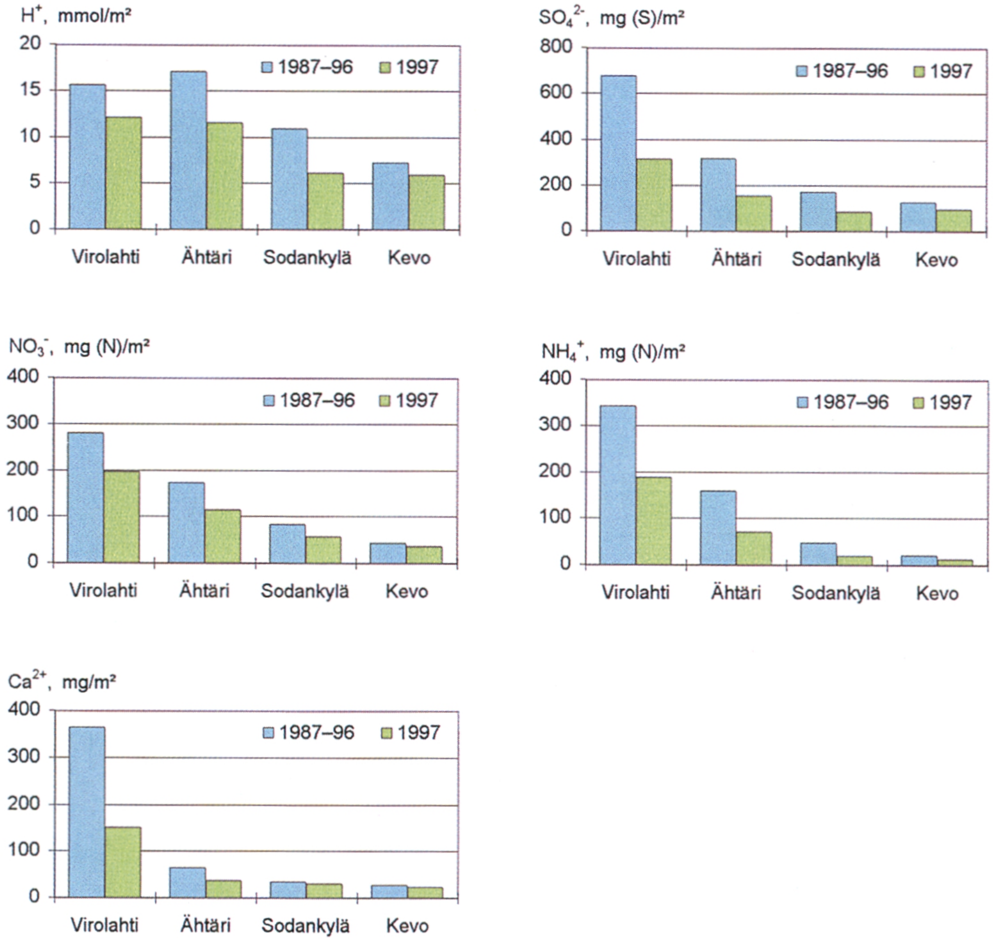

Figure 5. Deposition of H^+, SO_4^{2-}, NO_3^-, NH_4^+ and Ca^{2+} in 1997 compared with 1987–96 data.

(AMAP 1997), the northern and eastern stations having a relatively high copper deposition.

Seasonal variation of deposition

In Figs. 7a–f the seasonal variation of rain amount and depositions for acidifying components are given for 12 stations. They have been grouped according to the geographical location, stations in the northern part of the country being placed at the top of the figure, stations in central Finland in the middle, and stations in the south at the bottom. Results from the station of Kotinen differ from those of the three other southern stations, which are situated on the coast, and correspond better to the results of the central Finland stations, but in order to make the figures as clear as possible, four stations were chosen for each sub-figure.

The bulk deposition is highly dependent on rain amount (Fig. 7a). The summer of the year 1997 was exceptionally warm in Finland,

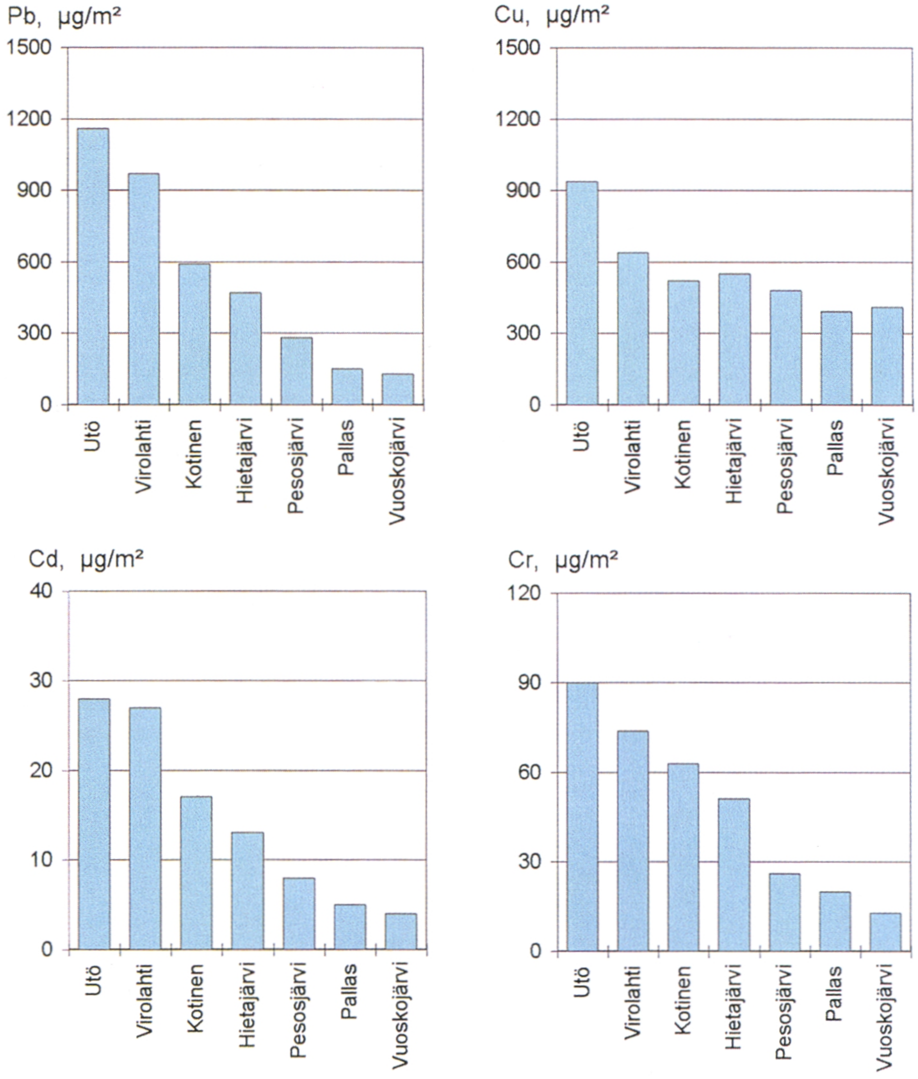

Figure 6. Deposition of lead, copper, cadmium and chromium in 1997.

rain amounts for many areas being lower than the normal values for 1961–90 (FMI 1991). In the north the first months of the year were rainy, but the summer months and October–November were dry. Most stations received much lower rain amounts than usual the whole year round. In the central parts of the country, March–April and July–August were in many places dry; at Punkaharju in the south–eastern part of central Finland, all the months of the year 1997 had less rain than in the normal period. In the south–western part of the country the rain amount was considerably higher than normal: February and September–November were especially rainy. Other parts of the south received low rain amounts in the summer and during the last months of the year.

The seasonal variation of hydrogen ion deposition (Fig. 7b) usually follows quite closely the variation in rain amount. The dry summer months in 1997 led to a weak summer deposition maximum. It can be seen from the figure that in the northern and central parts of the country the seasonal variation is quite low. In the south the deposition peaks in February and during the last months of the year, as is the case for sulphate and nitrogen deposition, too.

For sulphate (Fig. 7c), the normal maximum deposition in summer has moved some months later in 1997. Unusually high sulphur depositions were measured in February–March (Central Finland), May (Oulanka) and November (Southern Finland).

The overall seasonal variation for the nitrate deposition (Fig. 7d) did not differ much from the normal curve. High rain amounts in September caused the exceptional deposition peak in that month, whereas the values in March and November at Ähtäri and in November–December at Utö arose from high nitrate concentrations in the precipitation.

For ammonium (Fig. 7e) the overall seasonal variation was normal, especially in the north. The maximum in April at Ähtäri was exceptionally high and cannot be explained by the rain amount alone. The eastern stations of Punkaharju and Hietajärvi received an unusually large fraction of their annual ammonium load in February–March. Later, in August, when the rain amount was quite low in central and south Finland, heavy ammonium deposition was measured at many stations. Finally, high depositions of ammonium were found at the three southernmost stations on the coast of the Baltic Sea.

Finally, Fig. 7f shows the variation in the calcium deposition. The shifting of the summer maximum to later months is visible in this figure, too. The peak at Punkaharju in October might have its origin in dust from nearby soil, while high depositions at the south–eastern station of Virolahti, like those at the beginning and end of the year, are often brought about by transport from the southern coast of the Baltic Sea.

Episodicity of deposition

The annual deposition of the major components affecting acidification accumulates in a highly episodic manner. The percentile amount of the largest, five largest and ten largest daily depositions of the annual deposition are listed in Table 1 for the major components and the four stations with daily bulk deposition measurements. Samples for days with precipitation of more than 0.2 mm have been analyzed and are included in the calculations. The number of rainy days with a rain amount of more than 0.2 mm is given in brackets after the name of the station.

The episodicity is strongest for the ammonium deposition in the south–west, where the worst day of the year brings almost 20 % of the annual load and for the calcium deposition in the south–east, where the load of the ten worst days amounts to 50 % of the annual load.

The central and northern Finnish stations show weaker episodicity than those in southern areas. At Oulanka and Ähtäri, for all the components the load of the worst day is between 5 and 10 % of the annual total, the ten worst days bringing altogether 25–45 %.

For the hydrogen ion deposition, the largest daily fraction is deposited in the south–east. During the ten worst days, almost 40 % of the annual load is sampled in the south–east, 25–30 % in the rest of the country.

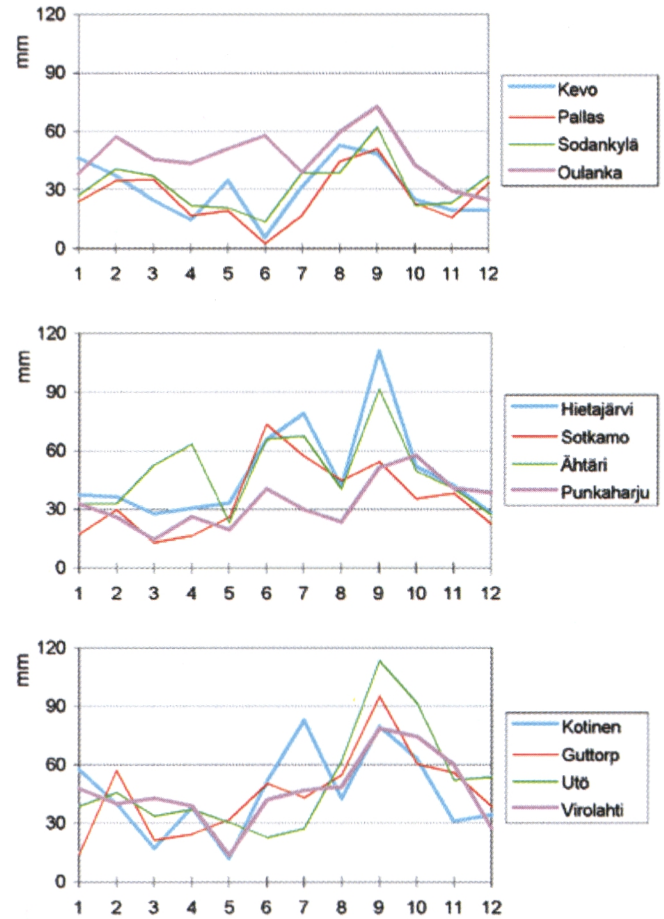

Figure 7a. Seasonal variation of precipitation amounts in 1997.

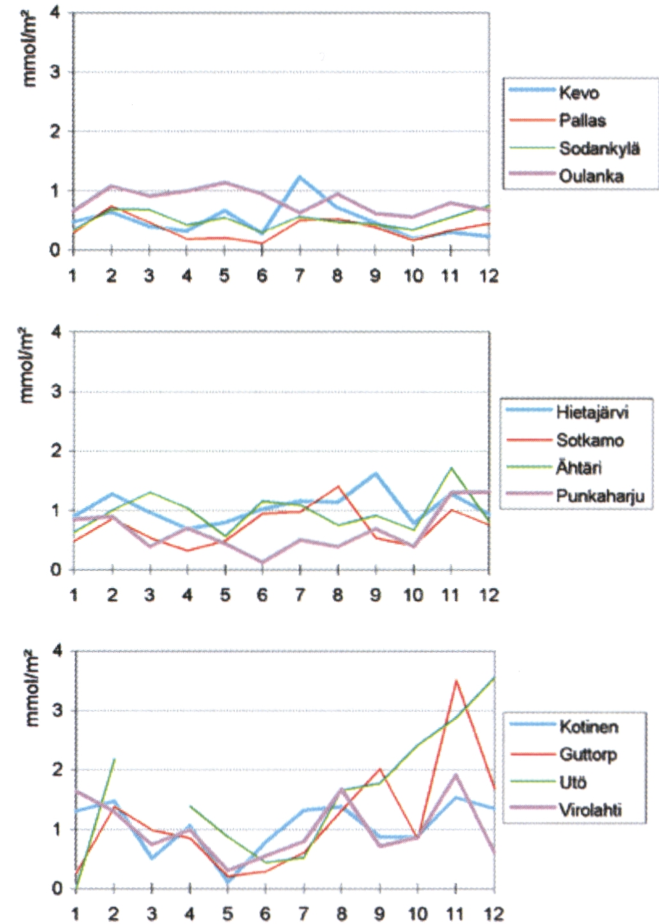

Figure 7b. Seasonal variation of hydrogen ion depositions in 1997.

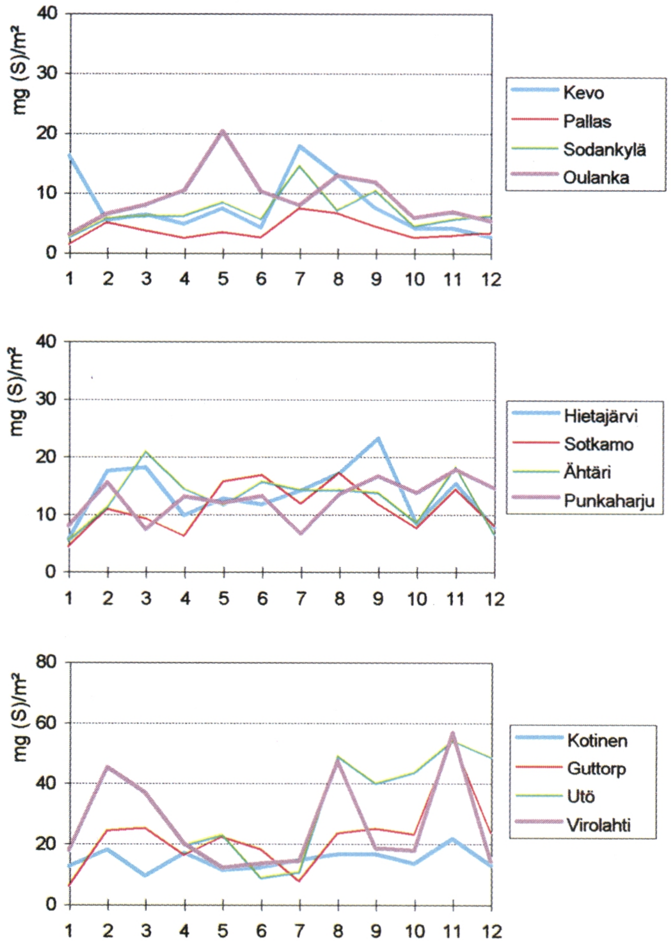

Figure 7c. Seasonal variation of sulphate (SO_4^{2-}) depositions in 1997.

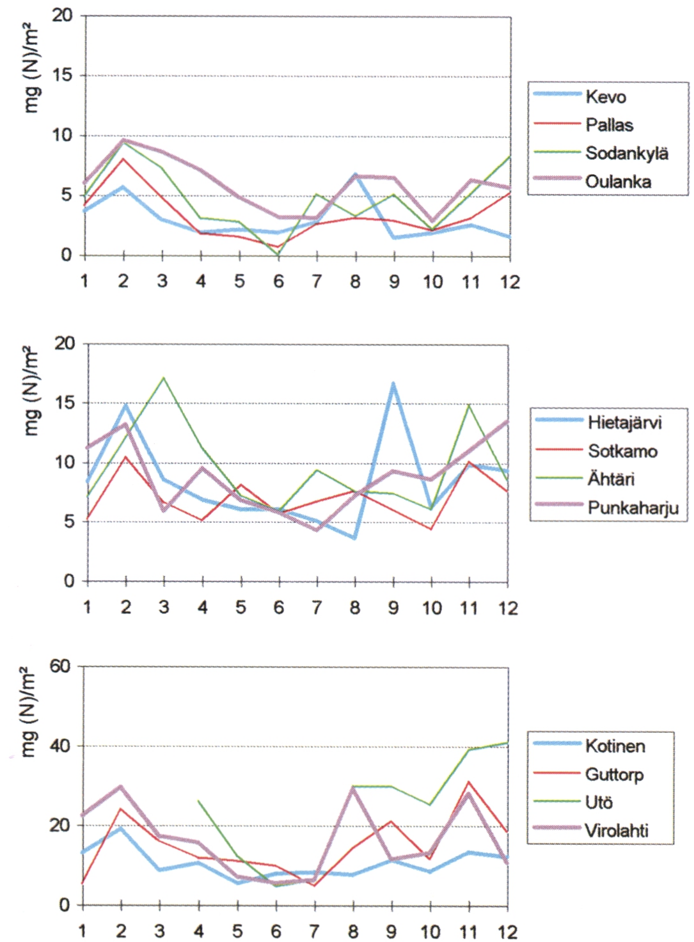

Figure 7d. Seasonal variation of nitrate (NO_3^-) depositions in 1997.

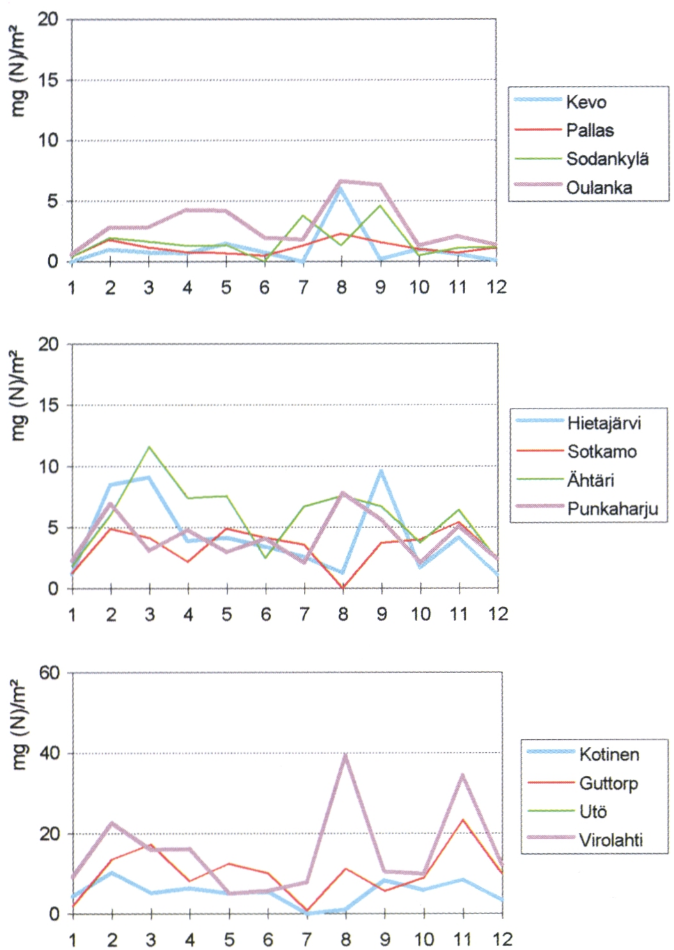

Figure 7e. Seasonal variation of ammonium (NH_4^+) depositions in 1997.

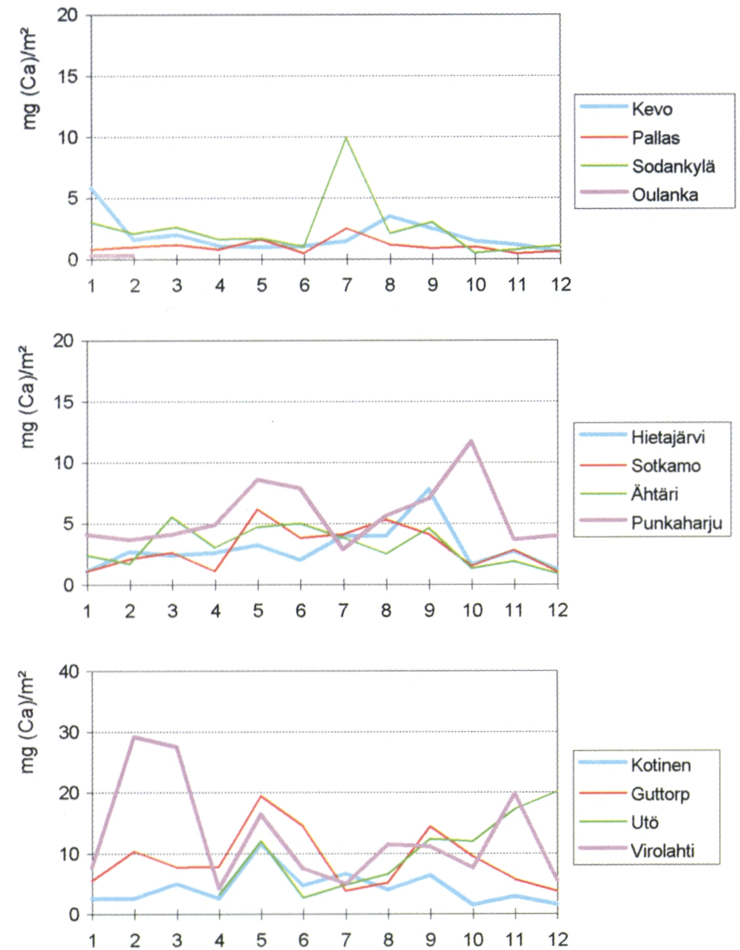

Figure 7f. Seasonal variation of calcium (Ca^{2+}) depositions in 1997.

The episodicity for nitrate deposition is similar to that for the hydrogen ion deposition, the worst rainy day being responsible for 5–10 % and the ten worst giving 25–40 % of the annual load.

Sulphate and ammonium depositions accumulate even more unevenly than nitrate depositions. The episodicity is weaker in the north, also. The largest daily fraction for sulphate deposition in the south is 10 %, and 45 % of the annual deposition being accumulated during the ten worst days.

At many of the stations the strongest episodicity is connected with calcium deposition. From the 138–167 days with precipitation only ten are needed to collect 40–50 % of the annual calcium load.

Gases

Sulphur dioxide

Main source of sulphur dioxide is industry and energy production. After emission, sulphur dioxide takes part in chemical processes in atmosphere, i.e. oxidation processes and a phase transition process, and it is affected by dry and wet deposition.

Sulphur dioxide emissions have decreased due to the Protocol on the Reduction of Sulphur Emissions at the European level, which was adopted in 1985 and came into force in 1987. Furthermore the Second Protocol of Further Reduction of Sulphur Emissions was adopted in 1994. Based on these protocols, the target

Table 1. The percentage fraction of the largest, 5 largest and 10 largest daily depositions of the annual deposition.

	H^+	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}
Oulanka (167 days with precipitation amount > 0.2 mm)					
largest, %	4.0	7.2	3.9	9.4	9.2
5 largest, %	16.4	24.1	15.5	31.3	25.5
10 largest, %	25.5	35.6	25.5	42.0	42.2
Ähtäri (162 days)					
largest, %	4.5	4.8	5.1	5.9	9.0
5 largest, %	19.0	22.1	17.6	21.9	35.0
10 largest, %	29.8	35.2	28.5	37.6	46.7
Virolahti (140 days)					
largest, %	10.4	11.2	10.2	13.5	12.3
5 largest, %	28.9	32.7	25.4	32.8	35.8
10 largest, %	39.4	43.0	36.7	44.6	51.3
Utö (138 days)					
largest, %	6.8	9.6	8.0	18.4	6.8
5 largest, %	21.8	23.5	23.8	34.7	26.1
10 largest, %	33.3	34.8	35.8	46.2	38.0

emission limit in Finland is 116 kt/a as sulphur dioxide by the year 2000 (YM 1998). In 1995 emissions of sulphur dioxide were less than 100 kt/a (TK 1997), but a small increase of emissions since then has been observed due to increased economical activity. Nevertheless total sulphur emissions are still below the target limit. The largest industrial and energy production emissions of sulphur dioxide take place in south-western Finland and along the coastal areas (SYKE 1998).

In the atmosphere, sulphur dioxide is oxidized in moist conditions into sulphuric acid (H_2SO_4) mainly by hydroxyl radicals ($OH^{\cdot}$). The average oxidation rate by this process is about 1 % per hour (Seinfeld 1986), being greater during sunlight in daytime (photochemical production of OH radicals). Thus sulphate formation from sulphur dioxide is more of a transboundary problem than a local one, and is more rapid during summer-time than during winter-time.

In Finland, as well as all over Europe, sulphur dioxide concentrations in background areas have decreased quite dramatically since the 1980's (Kulmala et al. 1998). In Fig. 8 is presented the annual mean concentrations of sulphur dioxide at the stations of Utö, Virolahti and Ähtäri and at Oulanka, Sodankylä and Kevo. The decrease of sulphur dioxide is clearly seen in the figures, as is also the spatial difference across the country. There is an overall decrease of concentrations from the southern coast northwards. In the south-east of Finland sulphur dioxide concentrations are also relatively high. The high concentrations there originate from local sources and are also due to the influence of transboundary pollution from the St. Petersburg area and the Baltic countries.

Although the sulphur dioxide emissions are

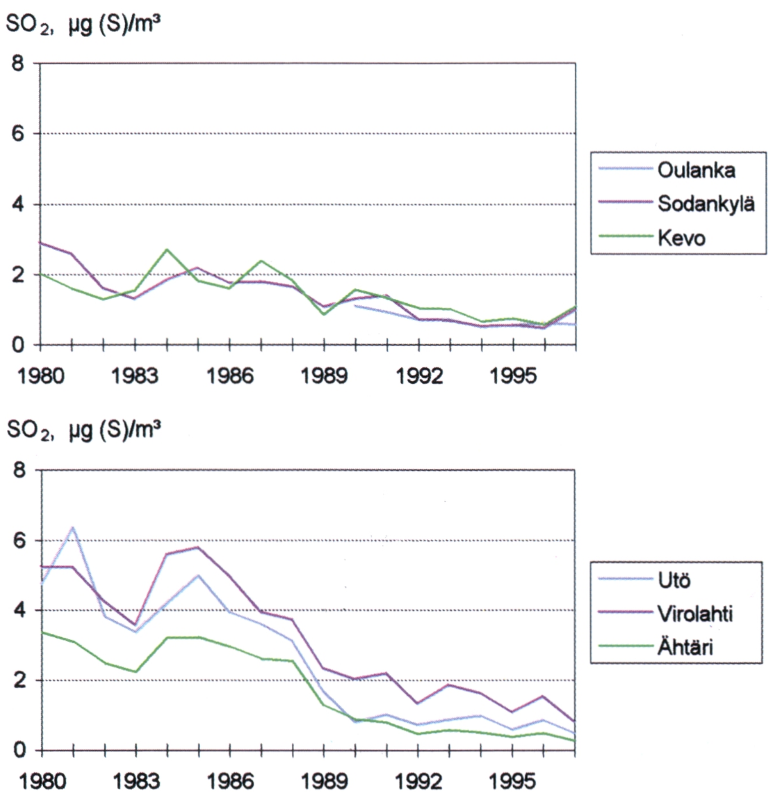

Figure 8. Mean annual concentrations of sulphur dioxide as sulphur.

at their highest during the heating period, the low temperature reduces transformation into sulphate to a great extent. The seasonal behaviour of sulphur dioxide is clearly shown in Fig. 9, although it is minor in the north as are also the concentrations there.

Nitrogen oxides and ozone

Nitrogen monoxide and nitrogen dioxide together form a group called the nitrogen oxides and expressed as $NO_x = NO + NO_2$. Nitrogen can form several other oxides with different oxidizing capacities. In the atmosphere, nitrogen oxides undergo several chemical reactions, some of which can be cyclic as well as reversible, before transforming into the nitric ion in clouds or in rain. Oxidized nitrogen compounds as a whole (NO_x, nitric acid, nitrous acid, PAN, nitrate ions, etc.) are commonly known as NO_y. We also address the fact that nitrogen oxides are the most important components in the photochemical production of ozone. In the atmosphere, nitrogen oxides can also undergo dry deposition directly onto vegetation or after forming aerosol they can be deposited onto the ground.

Emissions of nitrogen oxides from man-made sources in Finland have totalled less than 300 kt/a. Road traffic and other traffic account for more than half of the emissions. The Protocol concerning the Control of Emissions of Nitrogen Oxides was adopted in 1988 and came into force in 1991. The target level in Finland is 206 kt/a as nitrogen dioxide by the year 1998 (Happamoitumistoimikunta 1998). Thus, there is still a considerable gap between the actual emissions and the target limit. During the last few years, emissions have even slightly increased due to the improved economical situation. From a number of other than man-made sources the most important are soils, lightning, biomass burning, ammonia oxidation, and stratospheric fluxes from the reaction of the oxygen atom ($O^1(D)$) with nitrous oxide (N_2O).

The importance of nitrogen oxides in the atmosphere is not only associated with the generation of tropospheric ozone. Deposition of nitrogen from acidifying nitrogen oxides emissions is also becoming increasingly important (IPCC 1995).

At the beginning, measurements of nitrogen dioxide were performed by Saltzman-type monitors and more recently by chemiluminescence monitors. Difficulties in detecting low concentrations with acceptable accuracy and malfunctions of the monitors have been the main causes of missing data over the years.

In Fig. 10 the seasonal behaviour of nitrogen dioxide at EMEP stations is shown together with the monthly averages for the years 1990–96.

From the figure we can see that seasonal behaviour is also characteristic for the nitrogen oxides. However, especially during the summer-time, episodicity can be responsible for increased concentrations, as is the case with the summer averages in 1997 at Virolahti. Note that at Ähtäri nitrogen dioxide measurements were interrupted from the beginning of 1997 until June, when measurements were started at a new location with a chemiluminescence monitor. The change of location was made necessary by the influence of traffic emissions from a nearby road. The distance between the old and new locations is 5 km.

A homogeneous concentration behaviour is found with the ozone concentrations. In Fig. 11 the annual mean values of ozone concentration at the stations is shown. The increased trend for ozone concentration, reported in Kulmala et al. (1998), is here too seen at every station. There are also some spatial and temporal features. At Utö concentrations are slightly higher than in other parts of the country. This can be explained by the weaker deposition rate of ozone because of the marine location of the station. Elsewhere, deposition of ozone onto vegetation is more effective and also causes damage to crops.

The seasonal behaviour of ozone has some typical features, as is shown in Fig. 12. In spring-time there is often a so-called spring peak, which is mainly caused by increased sunlight and a smaller deposition rate onto vegetation. In late spring and summer, due to

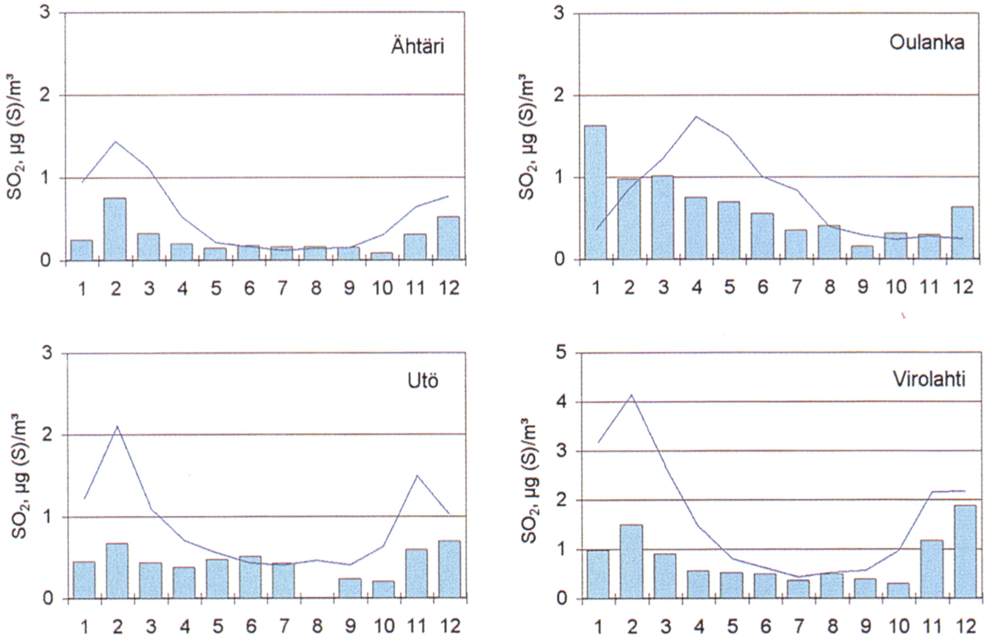

Figure 9. Monthly averages of sulphur dioxide as sulphur in 1997 (bars) compared with long-term (1990–96) averages (line) at Utö, Virolahti, Ähtäri and Oulanka. (See Fig. 1).

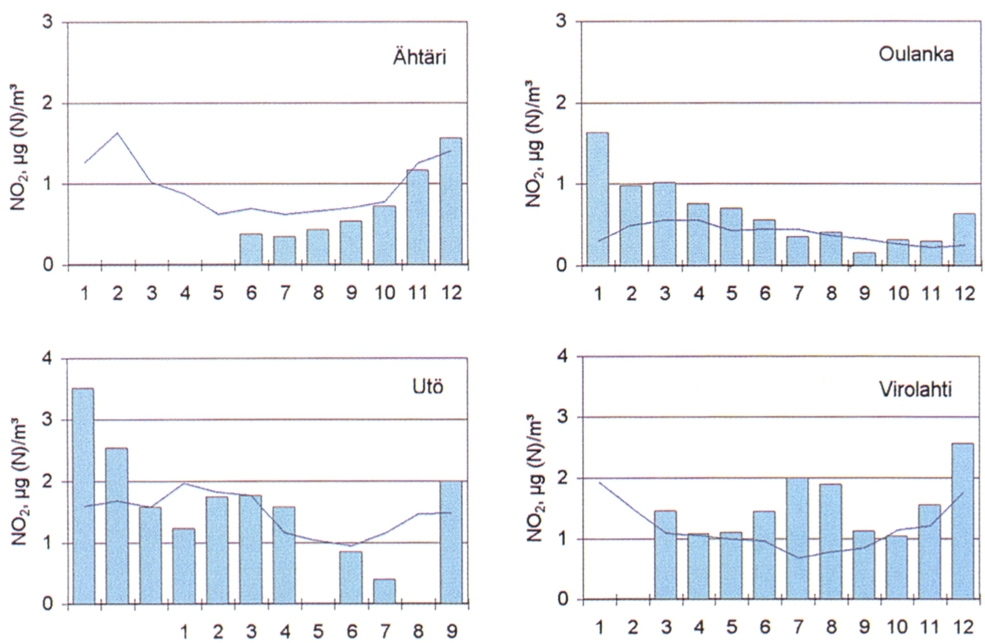

Figure 10. Monthly averages of nitrogen dioxide as nitrogen in 1997 (bars) compared with long-term (1990–96) averages (line) at Utö, Virolahti, Ähtäri and Oulanka. (See Fig. 1).

the growth of vegetation, the deposition of ozone is stronger, causing crop damage. The increased sunlight in spring and summer-time maintains the ozone concentrations relatively high, especially in anticyclonic weather systems, when polluted air-masses from Europe are transported to Finland.

Particulate matter

Particulate sulphate

The transformation of sulphur dioxide into sulphate is a reasonably well-known process under atmospheric conditions. Sulphate is a

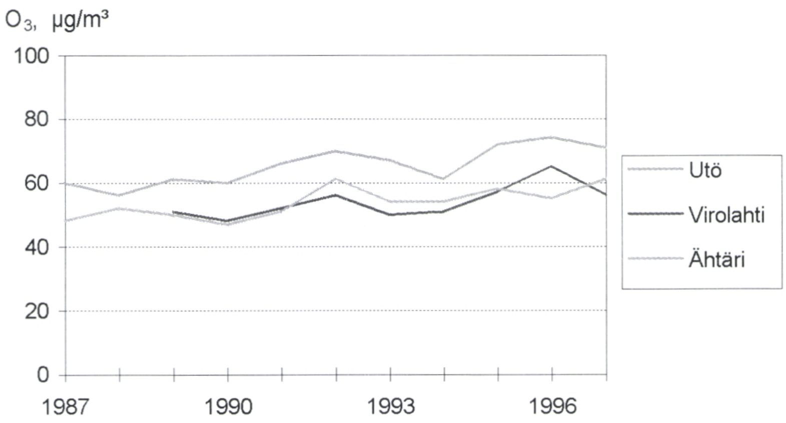

Figure 11. Mean annual concentrations of ozone.

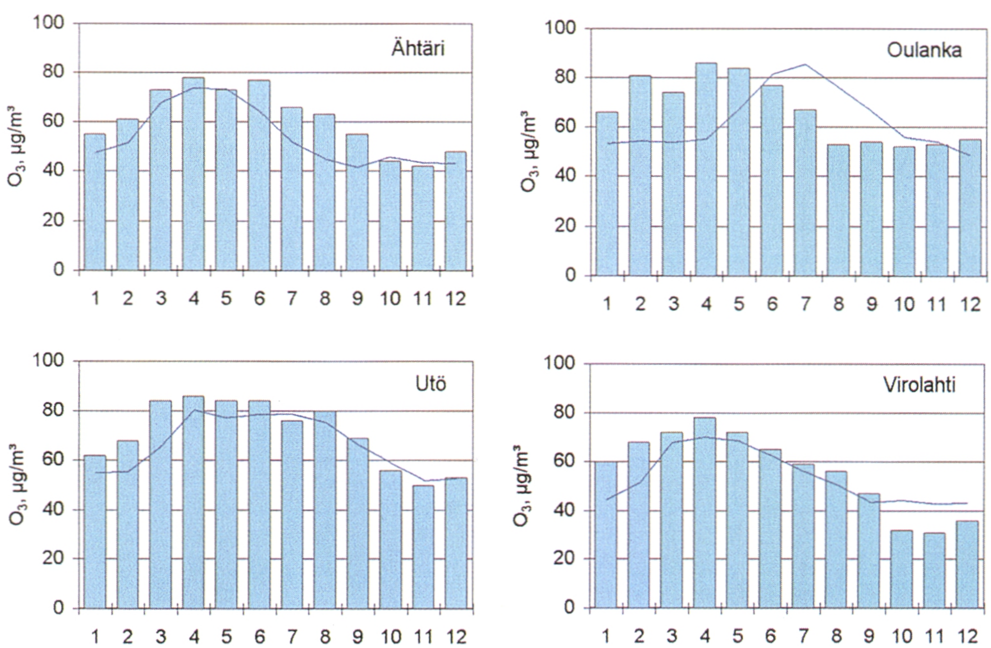

Figure 12. Monthly averages of ozone in 1997 (bars) compared with long-term (1990–96) averages (line) at Utö, Virolahti, Ähtäri and Oulanka. (See Fig. 1).

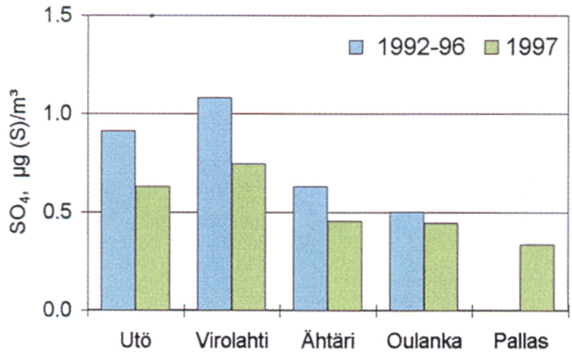

Figure 13. Aerosol sulphate concentrations as sulphur in 1997 compared with the period averages for 1992–96.

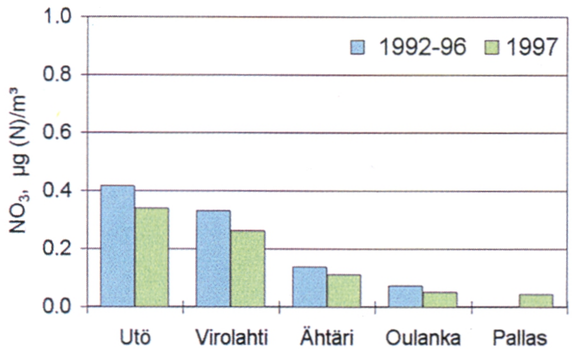

Figure 14. Aerosol nitrate concentrations as nitrogen in 1997 compared with the period averages for 1992–96.

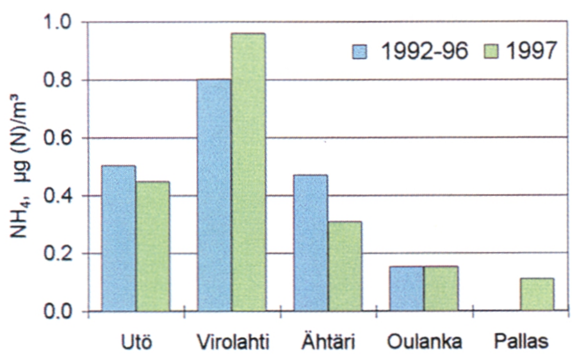

Figure 15. Aerosol ammonium concentrations as nitrogen in 1997 compared with the period averages for 1992–96.

product from the oxidation process of primarily-emitted sulphur dioxide. Particulate sulphate has a seasonal variation with a peak in late winter or early spring. The concentration of aerosol sulphate therefore behaves similarly to that of sulphur dioxide with a short time lag.

In Fig. 13 the annual mean concentration of particulate sulphate from stations in 1997 is shown in comparison with the mean values for 1992–96. On the south coast of Finland the concentrations of particulate sulphate are higher than that in other parts of the country. The spatial variation of particulate sulphate follows that of sulphur dioxide (Fig. 8) and the total deposition of sulphate (Fig. 5).

Particulate nitrate and ammonia

Nitrate particles are formed primarily from nitrogen monoxide and nitrogen dioxide. In the atmosphere nitrogen oxides undergo several chemical reactions before being transformed into nitrate ions in cloud or rain. The details of the different pathways for the formation of nitrate aerosols are described by Seinfeld (1986). Also note that the size of the nitrate particles is dependent on the process by which they are formed.

In Fig. 14 the annual concentration of nitrate aerosol together with that of nitric acid (HNO_3) is shown. Comparison of the results in 1997 is made with the period 1992–96. In Fig. 15 the same comparison is made with the ammonium ion.

Summary

Due to its northern location Finland has distinguished seasons, and moreover, there are frost and free from frost seasons as well. This makes the environment rather harsh for vegetation and for other living organisms.

The climatological circumstances give also rise to a clear seasonal behaviour of many of the pollutants in the atmosphere. Due to the abatement programmes, the concentrations of primary pollutants in the atmosphere and the deposition of acidifying components have decreased considerably over the years. Acidification is no longer a general problem in the country although there are still areas where the critical loads of sulphur are exceeded.

Episodicity is clearly a phenomenon which can locally cause serious problems to the vegetation. Air masses coming from the European industrial areas as well as from the St. Petersburg area or from the Kola peninsula account for a large fraction of the total deposition.

The concentrations of gaseous pollutants have decreased since 1985. The ambient concentration levels of ozone have, however, increased over the years indicating that ozone is becoming a major air pollution problem also in Finland.

Acknowledgements

This report is the work of a project group. The authors participated collectively in its production, and are specifically responsible for the following parts of it: Liisa Leinonen performed the calculations and produced the graphics, Tuija Ruoho-Airola wrote the text about deposition and Jari Waldén wrote the text about meteorological conditions, gases and particulate matter. The weather review in 1997 is based on the Finnish Meteorological Institute's monthly meteorological review *Ilmastokatsaus*. Precipitation samples and particulate samples were analyzed by the accredited chemical laboratory of the Air Quality Research Division. The operational work at the stations, including service and maintenance, was carried out by the field staff of different organizations and the staff of the Observational Services Division of the Finnish Meteorological Institute. The results were stored into the data base by Mr. Tapio Poutiainen.

References

AMAP 1997. Arctic Monitoring and Assessment Programme. Arctic Pollution Issues: A State of the Arctic Environment Report. Oslo. p. 97–102.

EMEP 1996. EMEP manual for sampling and chemical analysis. EMEP/CCC-Report 1/95. Rev. 1/96: 29 March 1996. Chemical Coordinating Centre, Norwegian Institute for Air Research, Kjeller. 199 p.

Environment Data Centre 1989. Field and Laboratory Manual for Integrated Monitoring. International Co-operative Programme on Integrated Monitoring National Board of Waters and the Environment, Helsinki. 127 p.

FMI 1991. Climatological Statistics in Finland 1961–1990. Finnish Meteorological Institute Helsinki 1991. 125 p.

FMI 1997. Ilmastokatsaus No. 1–12/1997, Finnish Meteorological Institute, Helsinki. (In Finnish).

IPCC 1995. Climate Change 1994. Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios. Cambridge University Press, Cambridge, UK.

Kulmala, A., Leinonen, L., Ruoho-Airola, T., Salmi, T. & Waldén, J. 1998. Air Quality trends in Finland. Ilmanlaatumittauksia – Air Quality Measurements.Finnish Meteorological Institute, Helsinki. 91 p.

Leinonen, L. (Ed.) 1998. Ilmanlaatumittauksia – Air Quality Measurements 1996. Finnish Meteorological Institute, Helsinki. 244 p. (In Finnish).

Mohnen, V. & Seiler, W. 1992. WMO (preparation by). Report of the WMO Meeting of Experts on the Quality Assurance Plan for the Global Atmosphere Watch (Garmisch-Partenkirchen, Germany, 26–30 March 1992). World Meteorological Organization, Global Atmosphere Watch No. 80. WMO, Geneva. 73 p.

Santroch, J. 1994. WMO (prepared by). Chemical Analysis of precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards. World Meteorological Organization, Global Atmosphere Watch No. 85. WMO, Geneva. 27 p.

Seinfeld, J. H. 1986. Atmospheric Chemistry and Physics of Air Pollution. John Wiley and Sons, New York. 738 p.

SYKE 1998. Happamoittavat päästöt. Ympäristö 3/1998, Fig. 3.9, p. 20. (In Finnish).

TK 1997. Energiatilastot 1996. Tilastokeskus, Helsinki. SVT Energia 1997:1. (In Finnish).

Happamoitumistoimikunta 1998. Happamoitumistoimikunnan mietintö. Suomen ympäristö 219, Ympäristöministeriö, Helsinki. 182 p. (In Finnish).

3 Results of the 1998 national crown condition survey (ICP Forests/Level I)

Martti Lindgren

Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

Concern about a large-scale decline in the vitality of forests in central Europe in the late 1970's and early 1980's led Finland to initiate an extensive national survey of forest condition. The Finnish Forest Research Institute has annually surveyed the crown condition since 1986. The surveys have been carried out in accordance with the methodology of the UN/ECE Convention on Long-Range Transboundary Air Pollution on International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Manual.... 1994, 1998) and, since 1995 also of Commission Regulations (EEC) No 3528/86 and 1398/95. According to the latest report on Forest Condition in Europe (Forest .. 1998) the forests in Finland were less defoliated than those in the majority of the European countries.

The aim of the study is 1) to survey the regional distribution of forest condition in Finland, 2) to monitor year-to-year variation in forest condition, and 3) to analyse, using a correlative approach, the factors which may explain the regional pattern and changes in forest condition.

Material and methods

The large-scale crown condition survey is carried out in Finland on a systematic network of permanent upland site sample plots (totalling 459 plots in 1998) that was established during 1985–1986 in connection with the 8th National Forest Inventory (NFI). The country was divided into a southern and a northern region (demarcation line 66° N) (Jukola-Sulonen et al. 1990). The network in the southern region is based on a 16 x 16 km grid (395 plots in 1998), and that in the northern region on a 32 x 24 km grid (64 plots in 1998). The total forest area covered by the plots is approximately 15 million ha.

According to the Commission regulation (EC no: 1398/95), the minimum number of sample trees per plot must be 20 in southern Finland and 10 in northern Finland. Because a fixed plot-size was used in Finland during 1986–1994, the number of sample trees on many of the plots was insufficient to fulfil the minimum criteria for tree number. During summer 1995 over 4000 new trees and 82 new sample plots were added to the sample (Table 1). The new trees were added systematically to the sample by increasing the radius of the plot. Five sample plots were terminated owing to cuttings, and four new plots were added to the sample in 1998.

In 1998, the total number of sample trees was 8758, of which 4584 were Scots pine (*Pinus sylvestris*), 2829 Norway spruce (*Picea abies*) and 1345 broadleaves (mainly *Betula spp.*). The number of common sample trees (cst) in 1997/1998 was 8576.

Defoliation and discoloration of Scots pine and broad-leaved trees were estimated on the upper 2/3 of the living crown and Norway spruce on the upper half of the living crown, in 5 % classes (Jukola-Sulonen et al. 1990, Salemaa et al. 1991, Lindgren & Salemaa 1998). However, the average defoliation degree was calculated by using the same defoliation-

Table 1. The number of assessed trees, sample plots and observers during 1986–1998.

Year	Number of trees	Scots pine	Norway spruce	Broad-leaves	Number of plots	Trees/ plots	Number of observers
1986	3982	2233	1445	304	378	11	4
1987	3971	2171	1432	368	376	11	4
1988	3870	2129	1391	347	370	10	4
1989	3807	2032	1355	500	360	11	4
1990	3746	2002	1329	415	358	10	4
1991	3764	2004	1272	488	356	11	4
1992	4391	2377	1367	647	409	11	4
1993	4276	2347	1307	622	399	11	4
1994	4180	2301	1265	614	392	11	4
1995	8754	4520	2838	1396	455	19	7
1996	8732	4522	2851	1359	455	19	7
1997	8779	4582	2814	1383	460	19	7
1998	8758	4584	2829	1345	459	19	8

class mid-point values as in previous years (0–10 % defoliation = 5 %, 11–20 % def. = 15 %, 21–30 % def = 25 % etc.). A tree is classified as discoloured when 10 % of its leaf or needle mass has abnormal coloration (e.g. needle yellowing). The degree of easily identifiable damage was also assessed and grouped into three categories: 1) slight, 2) moderate and 3) severe. The survey was carried out by eight forest technicians during the period June 30 to August 26.

Training and check survey

Before starting the field work the observers undergo a one-week training course. The reliability of the visual estimations is studied in the field. The test material consists of Norway spruces, Scots pines and birches that are not growing on actual sample plots. According to the comparison of defoliation estimates between the observers and the check survey team, 86 % of the Scots pines, 76 % of the Norway spruces and 88 % of the broadleaves were assessed uniformly (±5 % tolerance).

Results

No marked changes in the defoliation level of any of the tree species were observed between the years 1997 and 1998 (Fig. 1). Of the 8758 trees examined in 1998, 59 % of the conifers and 65 % of the broadleaves were not defoliated (needle loss 0–10 %). The proportion of conifers in class 1 (warning stage) was 29 %, and in classes 2–3 (notably defoliated) 12 %. For the broadleaves the corresponding proportions were 26 % and 9 %, respectively. 17 trees (0.2 %) died during 1997–1998 (Table 2). The average, tree-specific degree of defoliation was 9 % in Scots pine, 18 % in Norway spruce and 11 % in broadleaves. The proportion of over 25 % defoliated trees (cst) increased by 1 %-units in Scots pine (n = 1612), 12 %-units in Norway spruce (n = 976) and 4 %-units in broadleaves (n=150) since 1986.

The proportion of defoliated trees was higher in older (= 60 years) than in younger stands (under 60 years) (Table 2). The proportion of over-25 % defoliated stands was 0.3 % in Scots pine, 27 % in Norway spruce and 6 % in broadleaves (Fig. 2). These

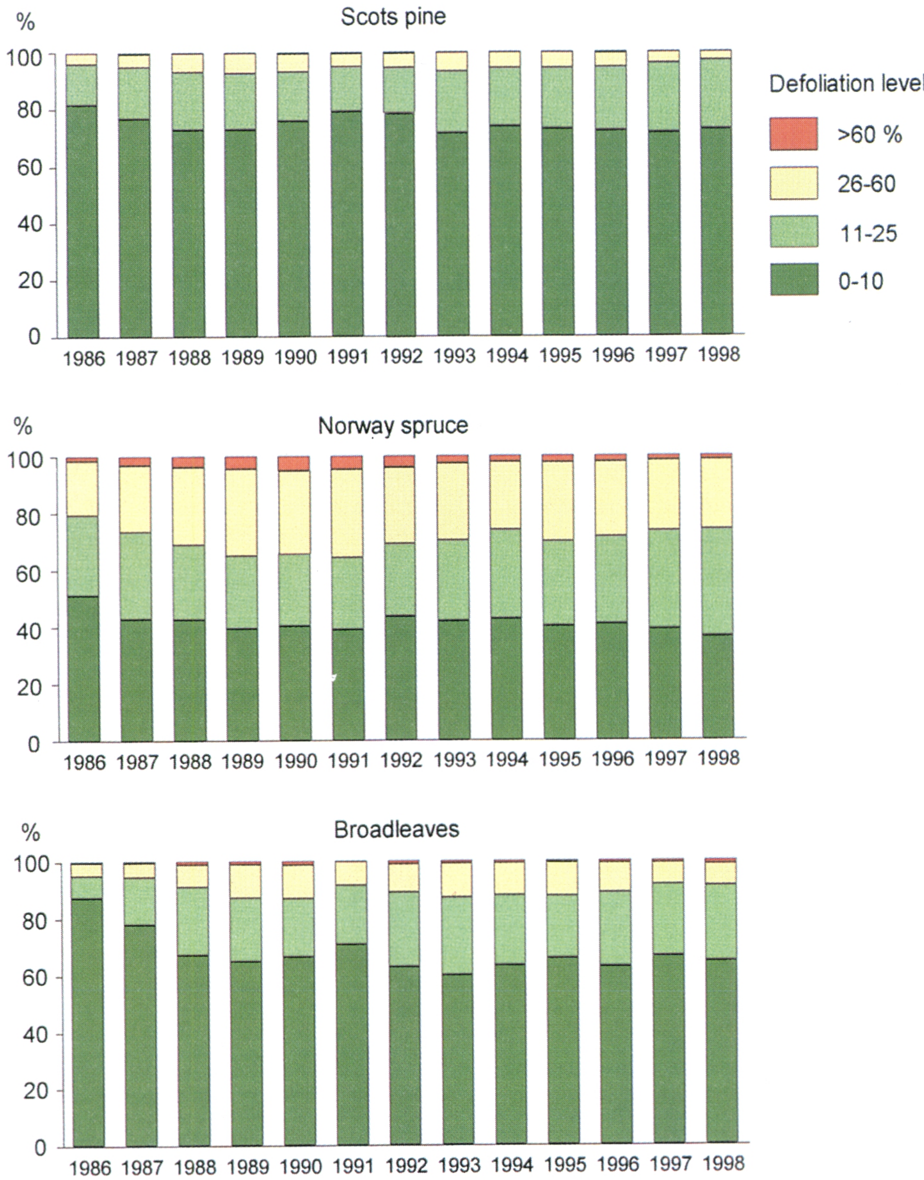

Figure 1. Defoliation frequency distribution for Scots pine, Norway spruce and broadleaves during 1986-1998.

defoliated stands were mainly situated in the district of Kainuu (eastern part of central Finland) and in Northern Finland. However, a number of isolated, defoliated sample plots occurred in all parts of the country. Extensive needle or leaf discoloration was rare in Scots pine (0.2 %) and in broadleaves (1 %) (Fig. 3). Furthermore, the proportion of discoloured Norway spruces decreased from 8 % in 1997 to 4 % in 1998.

Altogether 32 % of the Scots pines, 35 % of the Norway spruces and 33 % of the broadleaves had some kind of abiotic or biotic damage symptom. 4 % of all the Scots pines were classified as moderately or severely damaged. For Norway spruce and broadleaves,

Table 2. Proportion (%) of trees in different defoliation classes in stands under 60 years old and in those more than 59 years old.

Defoliation class	Scots pine < 60 yrs	>=60 yrs	Norway spruce < 60 yrs	>=60 yrs	Broadleaves < 60 yrs	>= 60 yrs
0–10 %	91.9	56.8	75.7	20.5	82.0	43.7
11–25 %	7.4	37.3	19.5	44.6	15.1	39.2
26–60 %	0.4	5.3	4.2	32.6	2.2	14.5
61–100 %	0.1	0.4	0.6	2.2	0.1	2.1
Dead	0.1	0.2	0	0.1	0.6	0.5

the corresponding proportions were 10 % and 9 %, respectively. The most common biotic agents on Scots pine were insects (*Tomicus spp.*) and scleroderris pine canker (*Gremmeniella abietina*), on Norway spruce fungal pathogens, and on broadleaves insects.

No correlation was found between the defoliation or discoloration pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 1998 (deposition data for 1993 are based on the HILATAR model, Hongisto 1998).

Conclusions

A large number of natural factors, of which the most important are connected with stand age, climate, and weather, affect forest condition in Finland. In the northern parts of the country especially, the harsh climate has a strong effect on forest development. At the beginning of the monitoring period the increase in defoliation coincided with the extremely cold winter of 1987, and defoliation increased in all tree species during 1986 to 1989. Since then the tree crowns have recovered. Defoliation in broadleaves again increased in the years 1992–93. A slight increase in Scots pine defoliation was also observed in 1993. No essential changes have been observed in the defoliation level of any of the tree species during the past few years. An epidemic of Scleroderris pine canker (*Gremmeniella abietina*), which broke out in western Finland in the latter half of the 1980's, has also had a detrimental influence on crown condition (Nevalainen & Yli-Kojola 1990). Local outbreaks of scleroderris damage were also found during the 1990's.

Although no clear relationship was found between deposition levels and the average defoliation degree at the national level, some effects of air pollutants (gaseous pollutants) on vegetation have been detected in the vicinity of point sources. Recent results from the epiphytic lichen survey indicate that the number of species and the abundance of sensitive species (e.g. *Usnea* and *Bryoria sp.*) have increased particularly in Central Finland, which is a reflection of the decreasing trend in sulphur deposition (Poikolainen et al. 1998). On the other hand, green algae and lichen (*Scoliciosporum chlorococcum)* complexes growing on tree stems has widened its range to the north during the last years. This, together with the increase of some other nitrophilous lichen species (e.g. *Hypogymnia physodes*), may be a response to the cumulative effect of nitrogen deposition in forest ecosystems.

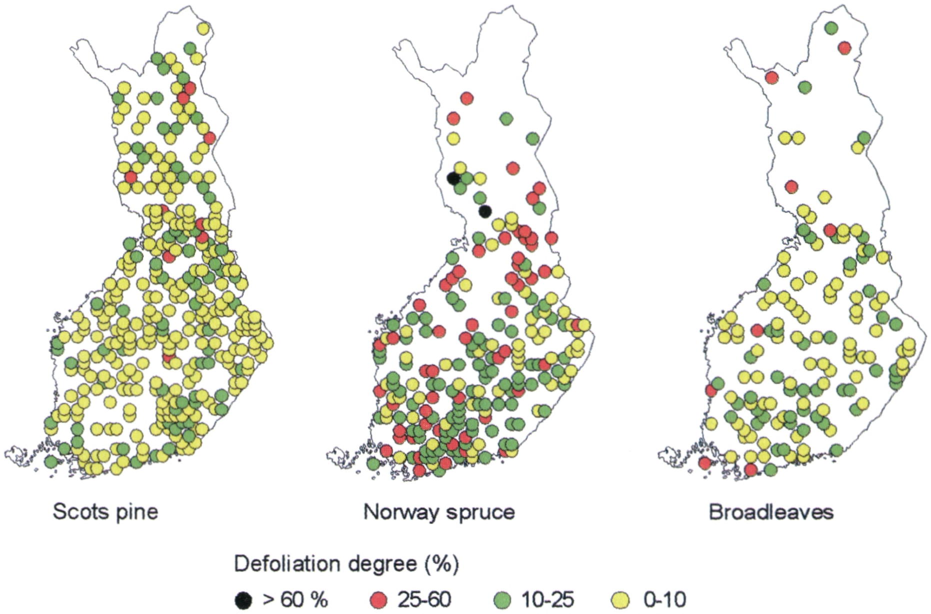

Figure 2. Average defoliation degree of Scots pine, Norway spruce and broadleaves in 1998. The colour of the circle indicate the plot specific values.

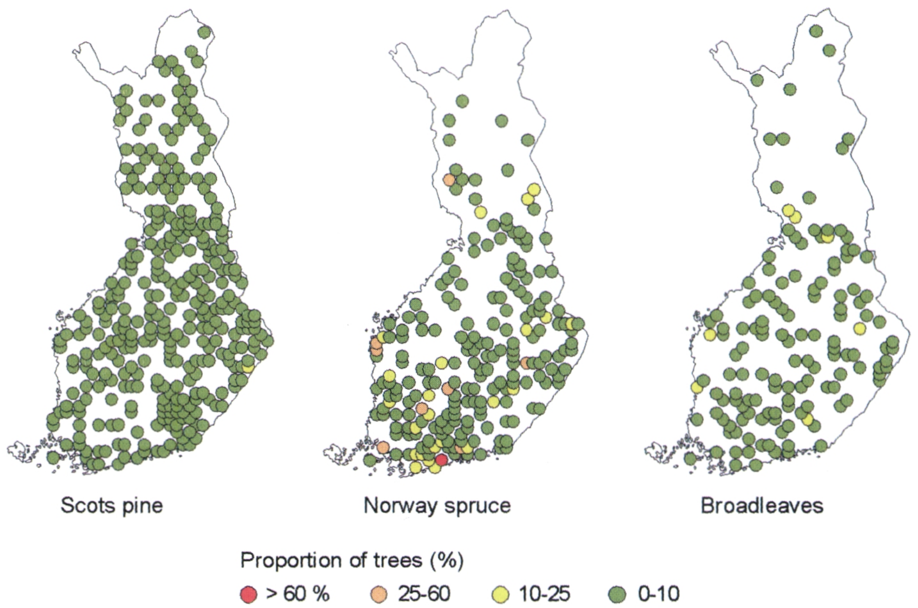

Figure 3. Proportion of discoloured Scots pines, Norway spruces and broadleaves in 1998. The colour of the circle indicate the plot specific values.

References

Council Regulation (EEC) No. 3528/86 on the protection of forest in the Community against atmospheric pollution. Brussels: 1986. Official Journal of the European Communities, N. L362/2 of Nov. 1986. 3 p.

Commission Regulation (EC) No. 1398/95 amending Regulation (EEC) No. 1696/87 (inventories, network, reports). Brussels: 1995, Official Journal of European Communities No. L139/4 of 22 June 1995. 2 p.

Forest condition in Europe. Report on the 1997 survey. Geneva, Brussels: UN/ECE, CEC 1998. 118 p. ISSN 1020–3729.

Hongisto, M. 1998. Hilatar, a regional scale grid model for transport of sulphur and nitrogen compounds. Description of the model. Finnish Meteorological Institute Contributions No. 21. Helsinki 1998. 152 p. ISBN 951–697–479–1.

Jukola-Sulonen, E.-L., Mikkola, K. & Salemaa, M. 1990. The vitality of conifers in Finland, 1986–88. In: Kauppi, P., Anttila, P. & Kenttämies, K. (Eds.). Acidification in Finland. Springer Verlag, Berlin. pp. 523–560.

Lindgren, M & Salemaa, M. 1998. Metsäpuiden elinvoimaisuusden arviointi. Vuotuisen seurannan (ICP level I) ja ympäristön yhdennetyn seurannan koealat 1998. The Finnish Forest Research Institute, Vantaa Research Centre. 43 p. (In Finnish).

Manual on methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forest. Hamburg/Geneva: Programme Co-ordinating Centres, UN/ECE 1994. 177 p.

Manual on methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forest. Hamburg/Geneva: Programme Co-ordinating Centres, UN/ECE 1998, 4th edition.

Nevalainen, S. & Yli-Kojola, H. 1990. The occurrence of abiotic and biotic damage and its relation to defoliation (needle loss) of conifers in Finland (1985–1988). In: Kauppi, P., Anttila, P. & Kenttämies, K. (Eds.). Acidification in Finland. Springer Verlag, Berlin. pp. 561–582.

Poikolainen, J., Kuusinen, M., Mikkola, K. & Lindgren, M. 1998. Mapping of the epiphytic lichens on conifers in Finland in the years 1985–86 and 1995. Chemosphere 36(4/5): 1073–1087.

Salemaa, M., Jukola-Sulonen, E.-L. & Lindgren, M. 1991. Forest condition in Finland, 1986–1990. Silva Fennica: 25(3): 147–175.

4 Biotic and abiotic forest damage in 1998

Katriina Lipponen, Martti Varama and Risto Heikkilä

Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

This report are based on forest damage samples and field inspections carried out at damage sites by Metla researchers, and on information about the occurrence of forest damage provided by researchers, representatives of the practical forestry sector and forest owners.

The most conspicuous and extensive forest damage in 1998 was that caused by rust fungi, which were common throughout Finland from the southern parts of the country right up to the southern parts of Lapland (area 19 in Fig. 1). Insects caused relatively extensive needle and leaf damage on a local scale in Scots pine and birch stands. The main area of vole damage was moving into the eastern and northern parts of the country. Moose damage increased in seedling stands in high-density, winter-range areas in the southern and central parts of the country.

Snow caused damage in North Karelia (area 12), as has earlier been the case in a number of years during the 1990's. Localised heavy storms (trombis) occurred at a number of places in connection with thunderstorms. An exceptionally severe trombi felled trees in June in the southern parts of South Savo (area 10). At the end of the summer a storm also felled trees in North Savo (area 11).

Fungal diseases

Precipitation during the past summer in Finland generally ranged from 250 mm to almost 400 mm. The mean, three-monthly precipitation in normal years varies from 180 to 220 mm which means that, taking the country as a whole, it rained 1.3 to 2 times more than normal. According to the Finnish Meteorological Institute, such wet summers occur in Finland only 4 or 5 times every century. A wetter summer than the last one occurred in 1981. Owing to the wet weather, there were only rather a few hours of sunshine in August especially.

The wet summer promoted the spread of fungal diseases caused by rust fungi especially, because the complicated development cycle of rusts and the successful transfer from one host plant to another requires periods of wet weather lasting for a number of days during certain stages of the development cycle. Rust fungi were a problem on all the economically important tree species (*Pinus sylvestris, Picea abies, Betula spp.*), as well as on e.g. willow (*Salix spp.*) and goat willow (*Salix caprea*). Of the rust fungi that periodically cause severe epidemics in Finland, the only one that was absent was pine twisting rust (*Melampsora pinitorqua*), the transfer of which from aspen leaves to pine shoots normally takes place at the beginning of June in Finland.

The most noticeable fungal disease on Norway spruce was *Chrysomyxa ledi*, which was abundant in spruce stands growing on sites with *Ledum palustre* ground vegetation throughout the whole of the country from the central parts of Pirkanmaa (area 6) up to the southern parts of Lapland (area 19). An outbreak of *Chrysomyxa abietis* continued for the third consecutive year in Satakunta, the coastal region of Vaasa and South Ostrobothnia (areas 4, 14 and 15). *Thekospora areolata* was also exceptionally abundant on Norway spruce in different parts of the country. *Melampsoridium betulinum* caused leaf yellowing in birch stands over extensive areas throughout almost the whole country. Premature yellowing of birch leaves was also partly caused by e.g. *Pyrenopeziza betulicola* and *Marssonina betulae.*

Severe rust infections, apart from those on small seedlings, do not cause the death of whole trees, but rust diseases can cause growth losses and increase the susceptibility of trees to secondary damaging agents. If the amount of precipitation in summer 1999 is normal, extensive outbreaks of rust damage are not likely to occur. However, if the summer is wet then the damage next summer will be more extensive and severe than that during summer 1998.

For a number of years in succession there have been light local epidemics of needle cast (*Lophodermella sulcigena*) in seedling and young Scots pine stands growing on fertile sites in North Savo and Lapland (areas 11 and 19). The epidemic in North Savo appears to have died down. In summer 1998 there were signs of an epidemic in the northern parts of Central Finland (area 13). Taking into account the weather conditions in summer and autumn, it is highly likely that the epidemic will continue to spread in these areas.

A number of years have already passed since the last serious epidemic of Scleroderris canker (*Gremmeniella abietina*). The last report of a Scleroderris canker outbreak that reached damage proportions was in Scots pine seedling stands in Lapland in 1994. Following the wet

1 Uusimaa
2 Varsinais-Suomi
3 Itä-Uusimaa
4 Satakunta
5 Häme
6 Pirkanmaa
7 Päijät-Häme
8 Kymenlaakso
9 Etelä-Karjala
10 Etelä-Savo
11 Pohjois-Savo
12 Pohjois-Karjala
13 Keski-Suomi
14 Etelä-Pohjanmaa
15 Vaasan rannikkoseutu
16 Keski-Pohjanmaa
17 Pohjois-Pohjanmaa
18 Kainuu
19 Lappi
20 Ahvenanmaa

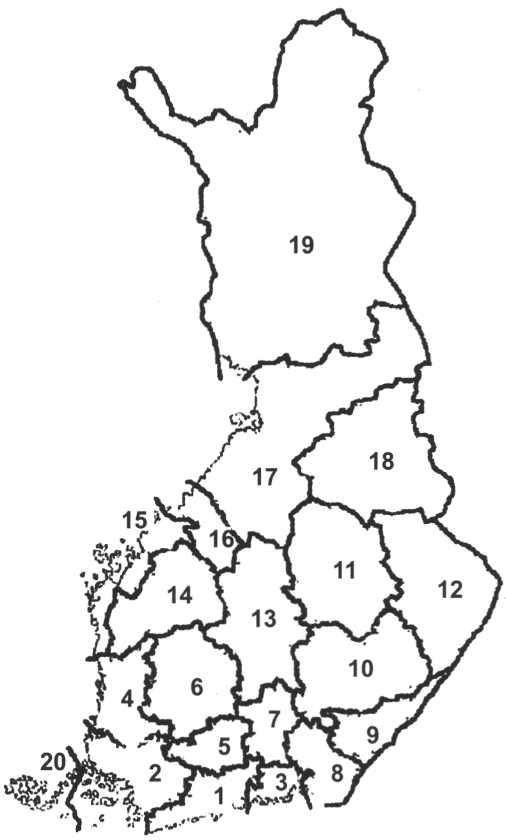

Figure 1. The provinces of Finland.

summer of 1996, Scleroderris canker increased to some extent in young Scots pine stands in various parts of the country in spring 1997, especially in South Karelia and in Savo (areas 9, 10 and 11). In the western parts of the country, Scleroderris canker was observed on the lower branches of mature pines. On such sites, Scleroderris canker also killed the crowns of understorey spruces. The warm dry summer in 1997 appeared to have stopped the progress of the epidemic. Taking into account the weather conditions last summer and autumn, it is highly likely that Scleroderris canker will again be abundant in spring 1999.

Merica laricis started to cause needle yellowing on larches in seedling nurseries at the beginning of August. Needle rusts were also reported on older larches. As a result of the wet summer, grey mould (*Botrytis cinerea*) destroyed the tops of seedlings in almost every nursery from southern Finland up to the southern parts of Lapland (area 19). Grey fungi on trees in parks drew considerable attention in southern Finland, e.g. on oak and maple. Grey fungi form a covering of light "grey" specks on the surface of leaves in late summer and early autumn. In Finland, however, these fungi do not usually have any harmful effect on trees. Poplars shed their leaves prematurely as a result of rusts and leaf-speckling fungi. *Pollacia radiosa* killed the growing shoots of aspen in August. Small seedlings and sprouts were most sensitive to the disease.

Insect damage

Damage caused by pine sawfly (*Diprion pini*) larvae continued in the central parts of North and South Ostrobothnia (areas 14 and 17) and in the western parts of Satakunta (area 4). According to forecasts made on the basis of cocoon samples, however, the risk of damage is not expected to require control measures in the areas in question, and neither has complete defoliation of whole stands been reported. However, the appearance of fresh defoliation, together with old signs of damage, give the impression that damage is on the increase in some areas. Development into adults and the abundance of pine sawflies were monitored in 20 stands in the damage area using a new method based on pheromone traps. New localised reports of pine sawfly larvae were made in the eastern parts of North Karelia (area 12).

The European pine sawfly (*Neodiprion sertifer*) population again increased slightly in the eastern parts of South Savo (area 10), and elsewhere in the country localised larvae observations were reported. In some areas larch was affected by larvae of the small larch sawfly (Pristiphora spp.). In some localities larch was also damaged by aphids.

Mass outbreaks of the northern winter moth (*Operophtera fagata*) and the winter moth (*O. brumata*) continued locally for the third year running in the coastal region of Varsinais-Suomi and Satakunta (areas 2 and 4) up to the Vaasa coastal region (area 15). Birches were almost completely defoliated over extensive areas in early summer, but in most cases the trees were able to produce new leaves in late summer. The wet summer presumably helped the trees to recover. Glue bands were painted on the trunks of birches in autumn to try to prevent the flightless female moths from ascending the trees.

Larvae of the satin moth (*Leucoma salicis*) defoliated a number of hectares of aspen and goat willow (*Salix caprea*) stands in the southern parts of North Ostrobothnia (area 17). Moths (*Argyresthia goedartella* and *A. brockeella*) living in the catkins of birch were abundant in Uusimaa (area 1)at least; the white, cobweb-covered trunks when the larvae moved down from the tree crowns in the spring to encapsulate resulted in numerous enquiries to Metla's entomologists.

Larvae of *Croesus septentrionalis* defoliated young planted birches in the eastern parts of South Savo and North Ostrobothnia (areas 10 and 17).

The larvae of a number of different Hymenoptera and butterflies damaged both coniferous and deciduous seedlings in seedling nurseries in many areas. The exceptionally high numbers were obviously a result of the warm summer in 1997, which promoted the reproduction of insects.

Vole damage

The field vole (*Microtus agrestis*), which causes damage in seedling stands, was abundant in autumn in South and North Savo (areas 10 and 11). The field vole was also abundant along the southern coast to the west of Helsinki. The field vole populations were only starting to increase in the southern parts of North Karelia and Kainuu (areas 12 and 18) in the east, but the common red-backed vole (*Clethrionomys glareolus*) was already abundant. The vole populations in almost the whole of Lapland were abundant or on the increase. Elsewhere in Finland the vole populations were mainly low.

5 Finnish programme for the intensive monitoring of forest ecosystems
(ICP Forests/Level II)

5.1 Description of the programme

Hannu Raitio

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Observation network

The Finnish programme for the intensive monitoring of forest ecosystems (Level II) started in 1995. The organisation of the Finnish programme is presented in Fig. 1. By 1997, 31 intensive monitoring plots had been established in different parts of the country: 27 of the plots on mineral soil sites and 4 on peatlands (Fig. 2). 17 of the plots have stands comprising Scots pine and 14 Norway spruce. All the plots, except the four Integrated Monitoring (IM) plots, are located in commercially exploited forest. The IM plots represent natural stands in catchment areas. A number of the plots are located close to background, air quality monitoring stations primarily run by the Finnish Meteorological Institute.

Four peatland sites were originally wet and sparsely stocked pine mires that represent the most typical drained peatland site types in Finland. The peat in these site types can have low concentrations of mineral nutrients but usually relatively high nitrogen concentrations. This may result in unbalanced nutrient regime for trees.

The effect of acidic deposition on the total amount of base cations and base saturation in peat soils seems to be negligible. The K balance in a stand, and changes in this balance, are more important than the total balance of base cations. Phosphorus is also an important growth-limiting nutrient on drained peatlands. Because of the limited amount of mineral nutrients in peat soils, it was of utmost important to establish plots where nutrient inputs and outputs, as well as nutrient fixation by the soil and plants, can be followed. The monitoring of runoff is seldom carried out on mineral soils, whereas on peat soils it is highly important in order to understand changes in the nutrient balance of the tree stands. The observation plots on peatlands were therefore established in separate catchment areas. This requires border ditches that lead external water flows past the observation plots, and also means that the amounts and nutrient concentrations of the runoff water flowing from the observation plots must be measured. This monitoring work is being carried out with national resources. The runoff is monitored continuously using data-loggers. Water samples for chemical analysis are collected weekly starting at snow-melt in the spring.

The design of the observation plot and location of the sub-plots

The observation plots proper consist of three sub-plots and a surrounding mantle (sub-plot 4) (Fig. 3). The sub-plots are square in shape (30 x 30 m). A 5–10 m wide strip has been left between the sub-plots for possible future use

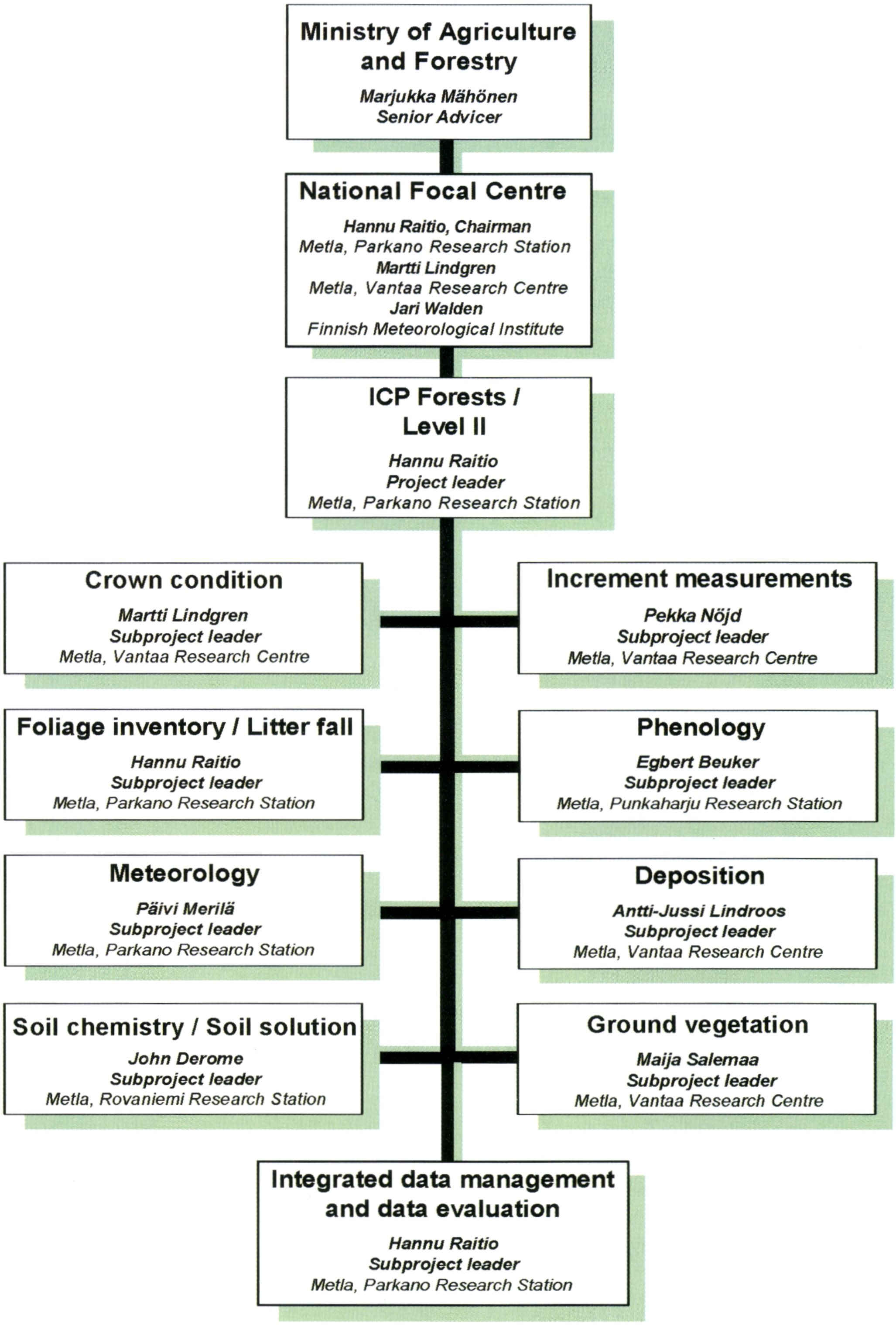

Figure 1. Organisation of Finnish programme for the intensive monitoring of forest ecosystems / ICP Forests, Level II.

in special studies and for additional sampling. Sampling methods that may have a detrimental, long-term effect on the soil or stand, e.g. soil sampling, deposition and soil water collection, needle and litter sampling etc., are concentrated on one sub-plot. One of the other two sub-plots is reserved for vegetation studies, and the other for tree growth measurements.

The centre point of the observation plot, the corners of the sub-plots and the outer edge of the mantle area have been marked with wooden posts. The mantle is surrounded by a buffer zone. The width of the mantle and buffer zones varies from 10–30 m.

Basic stand measurements and mapping

All the trees on the observation plot have been numbered at a height of 1.3 m on the side of each tree facing the centre point.

The following parameters have been recorded or measured on each tree: tree species, canopy layer, diameter at 1.3 m, tree height, and length of the living crown. The measurements have been performed on the trees on sub-plots 1–3 and those located in the mantle area (sub-plot 4). In addition to the above

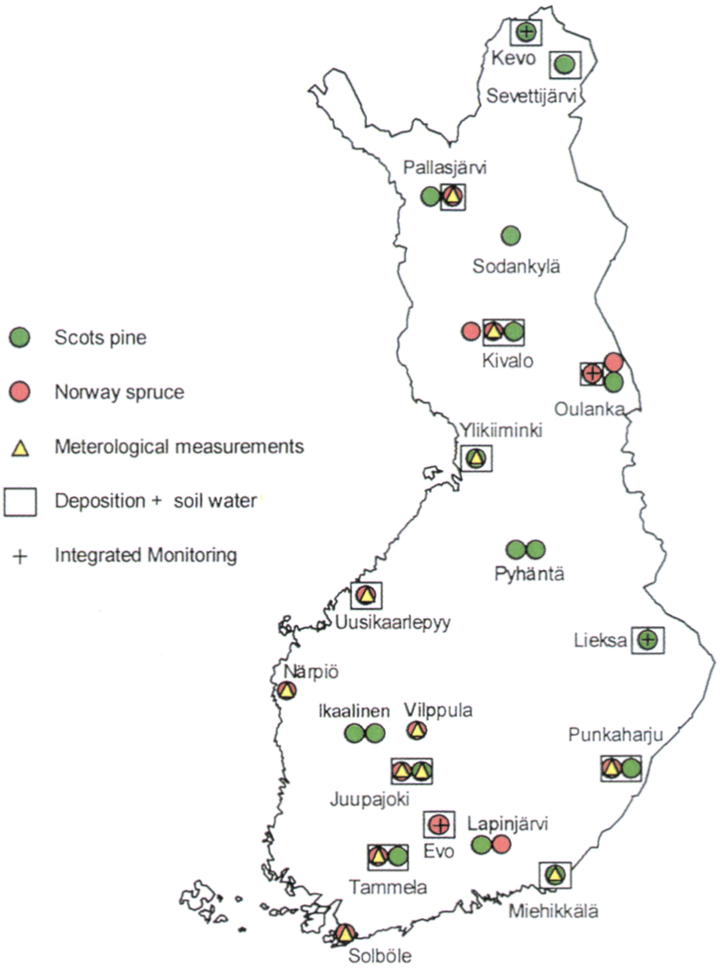

Figure 2. The intensive monitoring network of forest ecosystems in Finland in 1997.

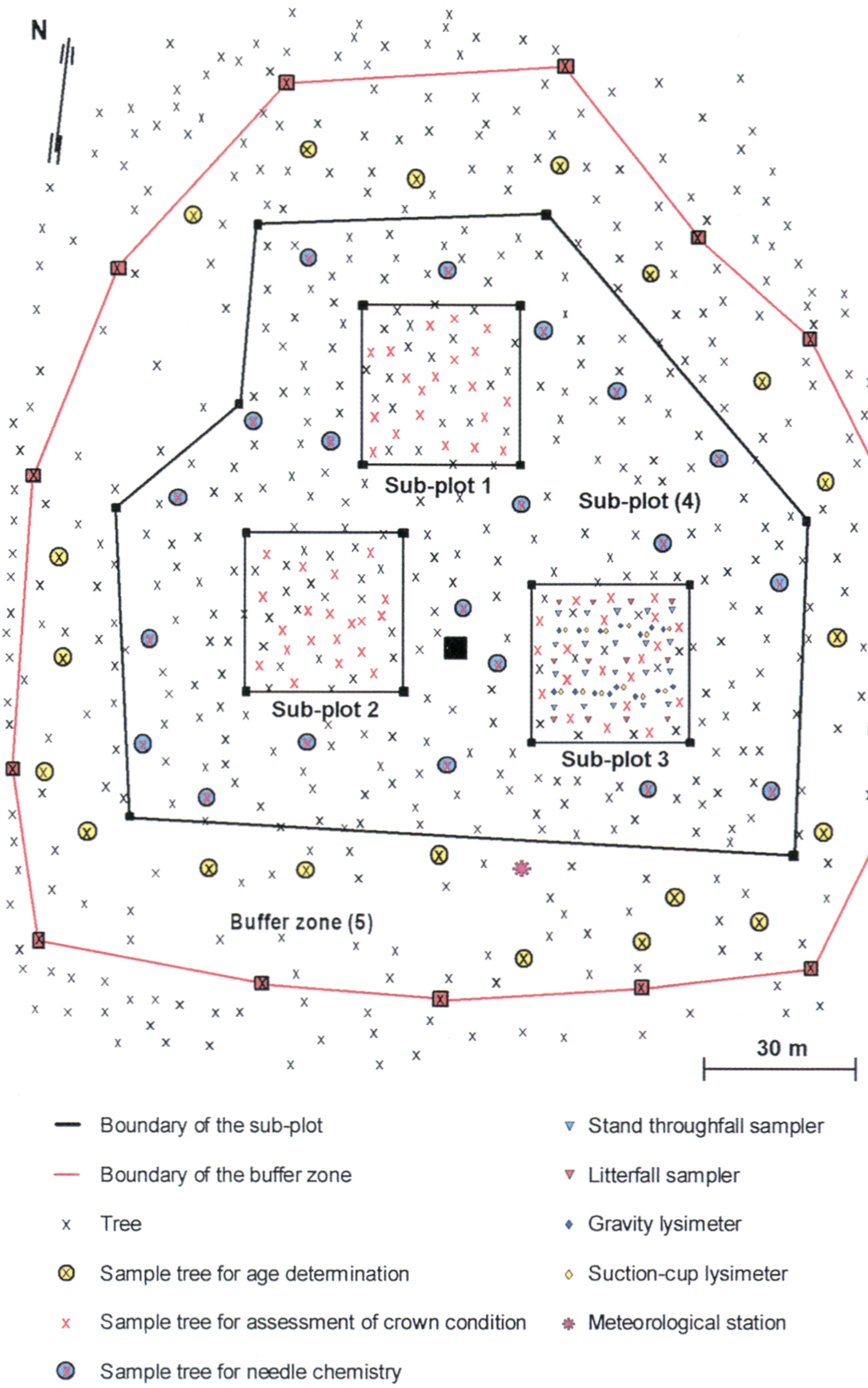

Figure 3. The design of the observation plot and location of the sub-plots.

Monitoring activities

Survey	*No of plots*	*Frequency of assessments*
Crown Condition	31	Annual
Soil condition	31	Every 10 years
Needle chemistry	31	Every 2 years
Tree growth	31	Every 5 years
Stem diameter growth	12	Hourly
Deposition	16	Every 4 weeks, but every 2 weeks during summer
Soil solution		
– gravity lysimeter	16	Every 2 weeks during the snowfree period
– suction-cup lysimeter	16	Every 2 weeks during the snowfree period
Meteorology	12	
– air temperature (13 m & 20 m)		Hourly
– relative humidity		Hourly
– soil temperature (-10 cm & -20 cm)		Hourly
– precipitation		Hourly
– wind speed		Hourly
– wind direction		Hourly
– photosynthetically active radiation (PAR)		Hourly
– solar radiation		Hourly
– soil frost (-10, -20, -30, ... -100 cm)		Hourly
Ground vegetation	31	Every 5 years
Litterfall	13	Every 2 weeks

measurements, bark thickness has been measured and increment cores taken at 1.3 m height for determining earlier growth and tree age. The forest site type of the observation plot has also been determined.

The location and elevation of all the trees on the observation plots have been mapped using a tachymeter. The exposition and gradient of each sub-plot have also been determined. Care has been taken during the field work to avoid causing unnecessary trampling of the ground vegetation or other forms of damage. Wooden walkways have been laid on the sub-plot used for collecting deposition and soil water.

Database and data evaluation

The database of the Finnish Programme for the Intensive Monitoring of Forest Ecosystems consists of four subsidiary databases: data base I (original data and measurements), data base II (data forwarded to FIMCI), an infobase and a photobase.

A review of the results of the individual surveys and the summaries of the pilot projects will be presented each year in the national report. In-depth scientific evaluations of the results will be presented every fifth year.

Co-operation

In 1993, five international organisations – FAO, ICSU, UNEP, UNESCO and WMO – decided to co-sponsor the planning process for a Global Terrestrial Observing System (GTOS). GTOS is intended to provide the data basis and observational framework needed to understand and address the impacts of global change on terrestrial, including freshwater, ecosystems. The Terrestrial Ecosystem Monitoring Sites (TEMS) database, which is an international directory of meta-data about monitoring stations and their activities, has been established to document existing long-term monitoring sites that may be suitable for inclusion in the GTOS network once it has been established. The Finnish ICP level II monitoring plots are included in the TEMS database.

The data collected on the monitoring plots in northern Finland will be regularly submitted for inclusion in the database of the Arctic Monitoring and Assessment Programme (AMAP).

5.2 Results of the individual surveys in 1997

5.2.1 Mandatory monitoring

Crown Condition

Martti Lindgren

Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN- 01301 Vantaa, Finland

Introduction

The 1997 annual crown condition assessment was carried out on the 13 Scots pine (*Pinus sylvestris*) and 14 Norway spruce (*Picea abies*) plots situated on mineral soil and on the 4 Scots pine plots on peatland. Defoliation, needle discoloration and easily identifiable causes of damage were assessed on 20 trees from each sub-plot, as well as on the 20 needle sampling trees. The total number of trees assessed was 980 (mineral soil) and 320 (peatland) Scots pines and 1000 Norway spruces. However, the trees for needle sampling or trees growing on peatland are not included in the results presented here. The results for 1997 are therefore based on 720 Scots pines and 740 Norway spruces growing on Level II upland site plots.

Defoliation of Scots pine was estimated from the upper 2/3 of the living crown, and of Norway spruce from the upper half of the living crown in 5 % classes. A one-week training course was held before the survey period. During the course, the observers underwent theoretical and practical training in assessment procedures and filling out the forms. The reliability of the observations based on visual estimation was also studied in the field. The test material consisted of trees which were not growing on the actual sample plots. The check survey on real sample plots was carried out by two experts. According to the comparison of defoliation levels between the observers and the check survey team, 89 % of the Scots pines and 81 % of the Norway spruces were assessed uniformly (±5 % tolerance) (Table 1).

Table 1. Difference in the defoliation assessment between the check survey team and the observers. 0 = no difference, minus sign = observer's assessment was lower than that of the check survey team, plus sign = observer's assessment higher than that of the check survey team.

Difference (%)	Scots pine % of trees	Norway spruce % of trees
-10	2.5	3.1
-5	15.6	7.5
0	38.8	33.8
+5	34.4	39.4
+10	6.9	15.0
+15	1.8	1.2
number of trees	160	160

Results

In 1997, 75 % of the Scots pines and 45 % of the Norway spruces were not defoliated (needle loss 0–10 %). The corresponding proportions for trees growing on similar site types in the Level I survey was 70 and 38 %, respectively. The proportion of slightly defoliated Scots pines (11–25 %) was 22 % (25 %, Level I), moderately or severely defoliated (over 26 %) 3 % (4 %, Level I) and severely defoliated (over 60 %) 0 (0.4 %, Level I). The corresponding proportions for Norway spruces were 40 % (35 %, Level I), 14 % (25 %, Level I) and 0.7 % (2 %, Level I), respectively. For both tree species, the proportion of defoliated trees clearly increased with stand age at both Level I and II (Fig. 4). The average defoliation degree of Scots pine at Level II was 9 % (10 %, Level I), and that of Norway spruce 16 % (21 %, Level I). No marked changes in defoliation were observed either on Scots pine or Norway spruce between the years 1996 and 1997 at Level II.

In 1997, 0.3 % of the Scots pines and 5 %

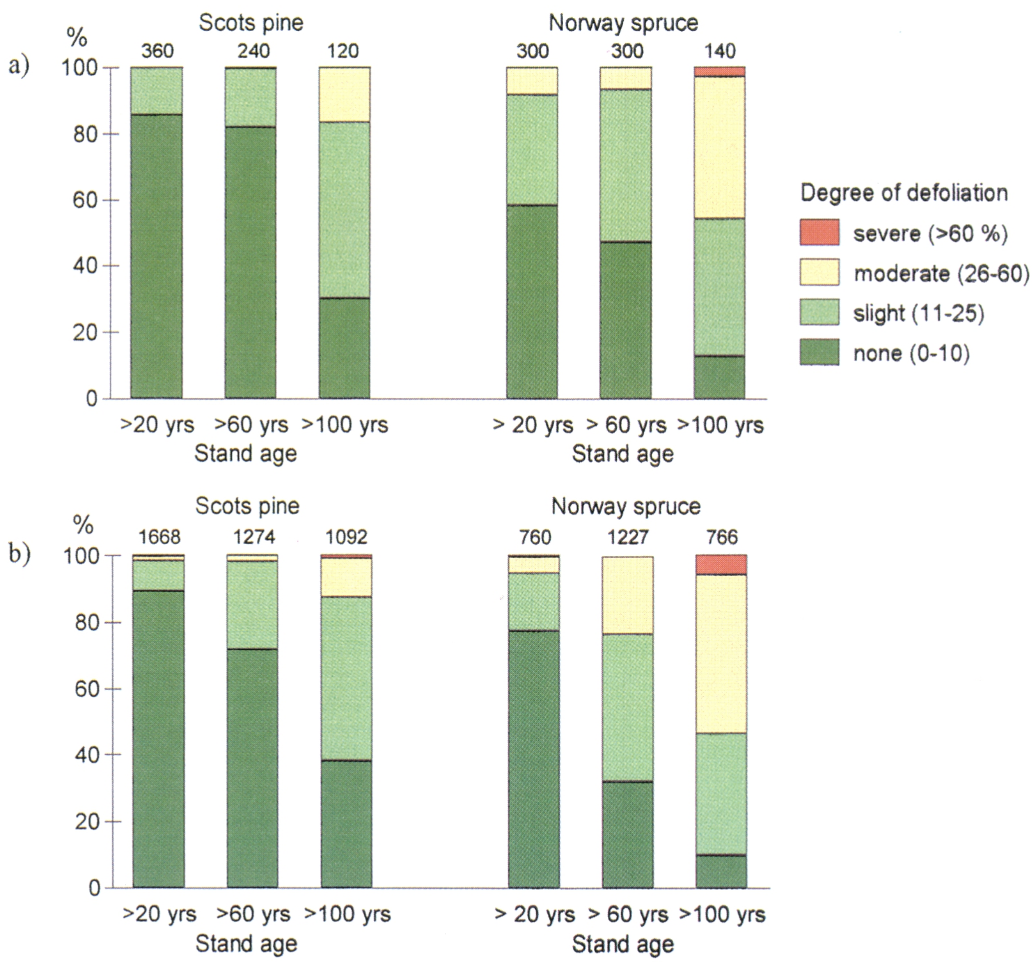

Figure 4. Defoliation frequency distribution for Scots pine and Norway spruce in three stand age classes in Level II (a) and Level I (b) in 1997. The number of trees is given above the column.

of the Norway spruces were discoloured. The corresponding proportions for Level I were 0.3 % and 8 %, respectively. The discoloration of Norway spruce increased with age (Fig. 5). The most abundant discoloration symptom on Norway spruce was needle yellowing.

Altogether 37 % (45 %, Level I) of the Scots pines and 44 % (36 %, Level I) of the Norway spruces had some kind of damage symptom. About 90 % of the damage on Scots pine was classified as slight and on spruce 80 %. The most common biotic agents on Scots pine were insects (*Tomicus spp.*, 11 % of damaged trees) and scleroderris pine canker (*Gremmeniella abietina,* 10 % of damaged trees), and on Norway spruce fungal pathogens (*Chrysomyxca spp.* 33 % of damaged trees). The distribution of easily identifiable causes of damage in 1997 is presented in Fig. 6.

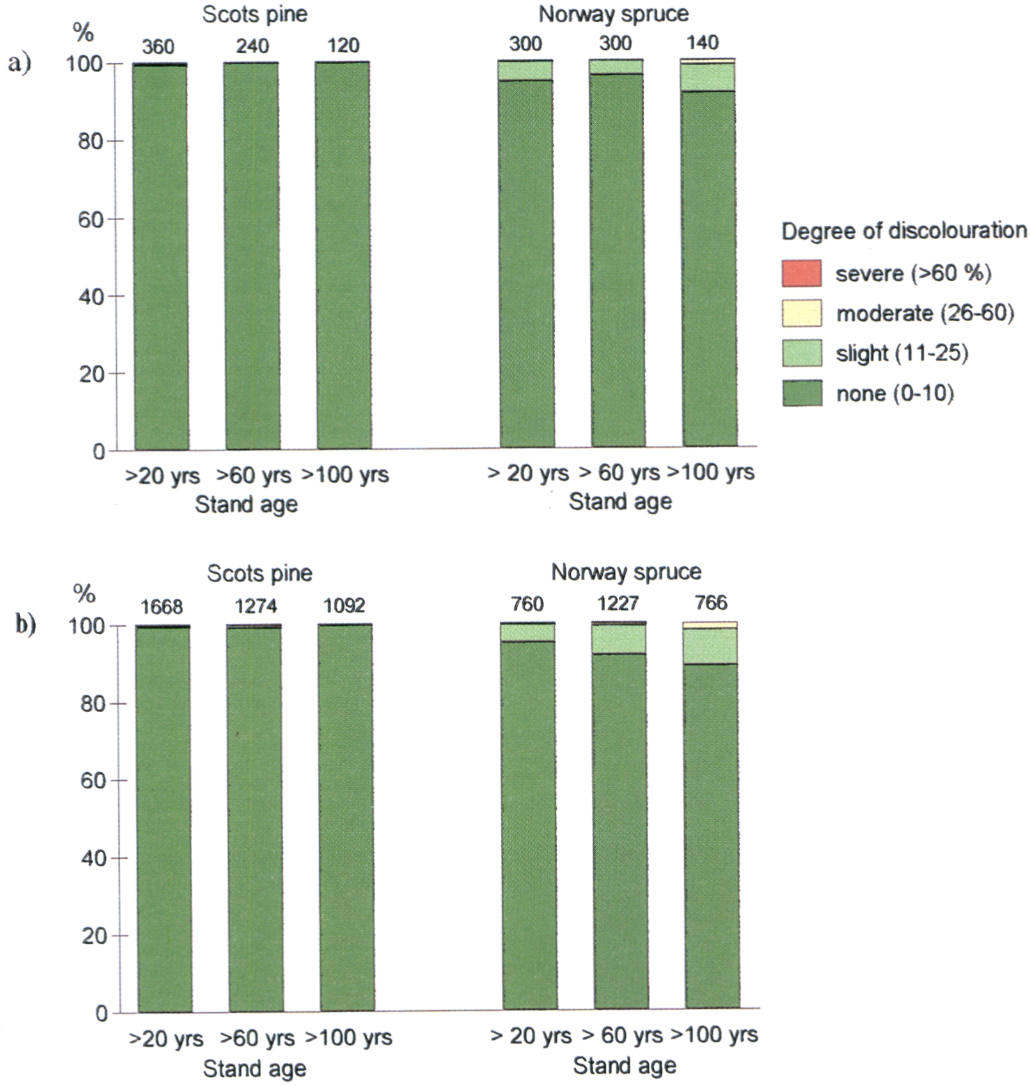

Figure 5. Proportion of discoloured Scots pine and Norway spruce in three stand age classes in Level II (a) and Level I (b) in 1997. The number of trees is given above the column.

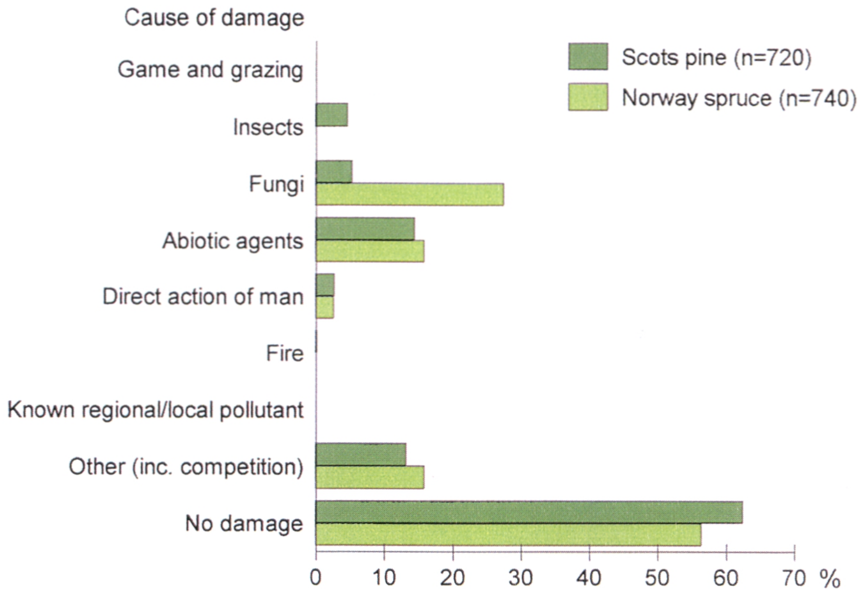

Figure 6. The proportion of Scots pine and Norway spruce in easily identifiable damage classes in Finland 1997.

Conclusions

Defoliation increased with stand age, and discoloration was more common on Norway spruce than on Scots pine at both Level I and Level II. However, the proportion of defoliated trees was slightly higher in all age classes at Level I compared to Level II. Moreover, the proportion of defoliated trees was clearly higher in 60- to 100-year-old Norway spruce stands at level I. The same kind of pattern was also seen in the discoloration frequencies for Norway spruce. The reason for the differences in the defoliation or discoloration distributions between these two levels may be due to the sampling design. The level II (under 100 years old) sample plots were subjectively selected and established (mainly) in homogeneous, single-species, managed stands, whereas the sampling design at Level I was based on a systematic sampling that leads to more varying stands characteristics, e.g. species composition etc.

Needle chemistry

Hannu Raitio

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Introduction

The Finnish Forest Research Institute has systematically monitored the nutritional status of the trees on 29 of the Level I plots (15 Scots pine and 14 Norway spruce stands) since 1987 (Fig. 7) (Raitio 1994). Chemical foliar analysis is also widely used in other national projects and studies (Raitio 1992, 1995, Lumme et al. 1994, Merilä et al. 1996).

The monitoring of the nutritional status of the trees on the Level II plots started in Finland in 1995, and the first results were presented in the 1996 national report (Raitio et al. 1996). Sampling for the chemical foliar analysis on the Level II plots was repeated in 1997 (Fig. 7).

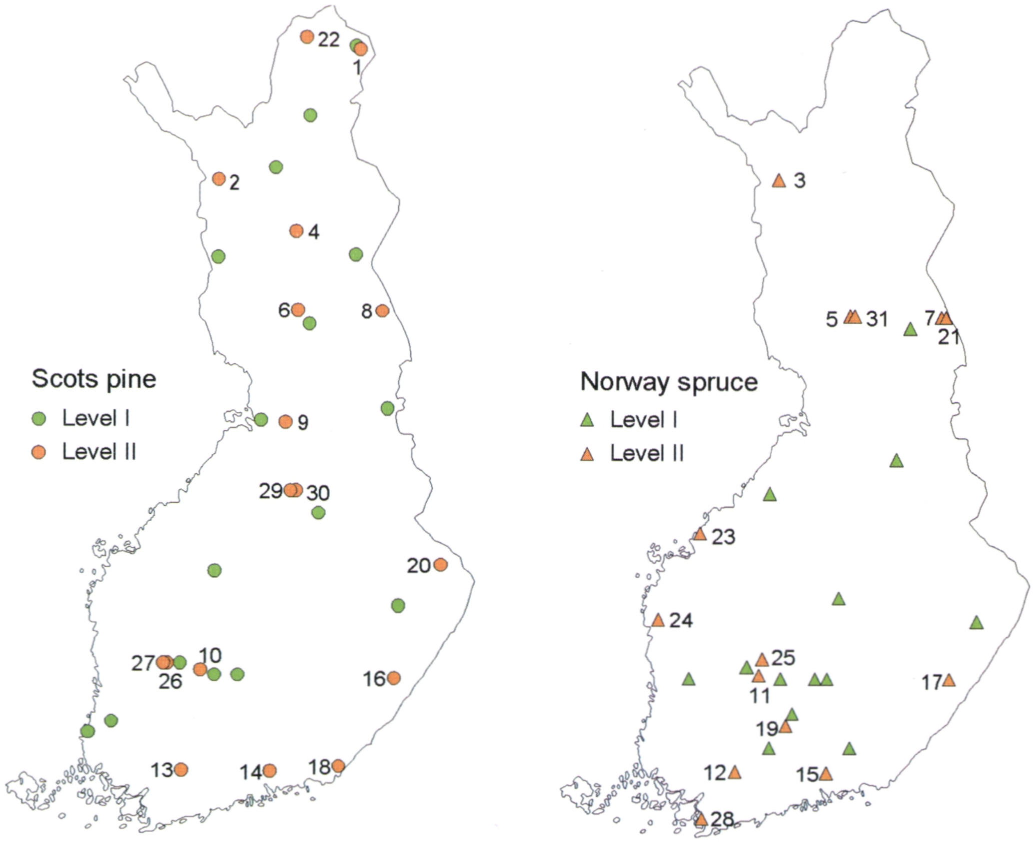

Figure 7. Location of sample plots for foliar chemical determination at Level I and II of ICP Forests. Level II plots are numbered.

Sampling

Two sets of 10 predominant or dominant sample trees have been selected for needle chemistry analysis on the sub-plot 4 of each Level II plot (Fig. 3, p. 44). Sample branches are taken from 10 of these trees every second year. The two tree sets are sampled in rotation, i.e. each set is sampled every 4 years. This arrangement is being employed in order to minimise damage to the trees as a result of branch removal. The first tree set (18 plots) was sampled in 1995 (supplemented by two plots in 1996) and the second tree set (31 plots) was sampled in 1997.

The sample branches with the current (C) and previous year's needles (C+1) have been collected from the uppermost third of the living crown with a pruning device during October and November each year.

Transport, storage and pre-treatment

The branches were transported in paper bags to the laboratory as soon as possible and the dry mass of 50 needles determined. During pre-treatment, i.e. after drying, the needles were separated from the stems. The dry, unwashed needles were milled using a Retsch ultra-centrifugal mill type (Zm 1). The mesh size of the sieve was 1 mm. The dry needle powder was stored in polyethylene bags in cartons at room temperature. Composite samples for chemical analysis were prepared by mixing an equal amount of needle powder from each of the 10 trees.

Analyses

Total nitrogen concentration was determined on a CHN analyser (LECO CHN-600). The concentrations of P, K, Ca, Mg, Fe, Cu, Zn and Mn were determined, following wet digestion (HNO_3+H_2O_2), by inductively coupled plasma atomic emission spectroscopy (ICP/AES). The boron concentration was determined spectrophotometrically using azomethine H. Duplicate analyses were not carried out. The concentrations are expressed on a dry mass basis (105 °C).

Each of the sample batches for wet digestion comprised 45 actual samples, 1–3 zero samples, and one non-certified control sample. The non-certified control sample was used to monitor the repeatability of the wet digestion procedure. The reliability of the wet digestion method was controlled by analysing three certified samples during 1995 and 1996; the results of these analyses are presented in Table 2. In addition, our laboratory has participated in inter-laboratory comparison, e.g. the 2nd and 3rd Needle/Leaf Interlaboratory Tests of ICP Forests (Bartels 1996, 1998). Our results in these interlaboratory tests have been very good.

The analysis result has been corrected if the mean value of the zero sample exceeds the detection limit of the ICP/AES instrument. The corrected result has been obtained by subtracting the result of the zero analysis from the analysis result. This procedure had to be employed mainly for sulphur and iron, and less frequently for the other elements.

Defoliation and discoloration of trees selected for foliar analysis in 1997

In 1997, 80 % of the pines and 47 % of the spruces selected for needle chemistry analysis were not suffering from defoliation. The corresponding proportions for trees selected for crown condition estimation on the subplots were 75 % and 45 %, respectively. The proportion of slightly defoliated pines was 16 % (22 %, the estimation of the crown condition on the subplots), moderately defoliated 5 % (3 %) and severely defoliated zero (0 %). For spruce the corresponding proportions were 41 % (40 %), 13 % (14 %) and zero (1 %),

Table 2. Results of the analysis of certified reference materials.

Reference material	N mg/g	P mg/g	K mg/g	Ca mg/g	Mg mg/g	S mg/kg	B mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg
Own result		1.23	4.01	4.20	1.17			693	181	2.60	
NIST 1547		1.20	3.70	4.10				675	200	3.00	
		± 0.2	± 0.2	± 0.2				± 15	± 10	± 0.3	
Own result	18.5	1.78		4.47	0.63	1792		940			34.4
CRM 101	18.9	1.69		4.28	0.62	1700		915			35.3
	± 0.18	± 0.04		± 0.08	± 0.01	± 40		± 11			± 2.3
Own result	29.0						27.7				
NIST 1547	29.4						29.0				
	± 1.2						± 2				
National reference	16.8 ± 0.2	2.06 ± 0.07	7.03 ± 0.36	3.65 ± 0.13	1.05 ± 0.08	1181 ± 59	7.02 ± 0.28	316 ± 18	36 ± 3	3.47 ± 0.32	45.3 ± 2.63

respectively. There were no statistical differences in the defoliation of trees between the years 1995 and 1997.

In both species, trees over 100 years old were more defoliated than those under 100 years (Fig. 8). None of the pines selected for needle chemistry analysis had discoloration symptoms. In contrast, the spruces showed some needle discoloration symptoms (Fig. 8). Symptoms of biotic and abiotic damage in trees selected for needle chemistry analysis were also similar to the symptoms observed on the trees on the Level II plots. According to the results, the average state of health of the trees selected for needle chemistry analysis in the buffer zone was similar to that of the trees on the Level II plots.

Nutrient status of the trees

The foliar chemical composition of the trees on mineral soils were rather similar on the Level I and II plots in 1997 (Fig. 7). However, the foliar N, Fe and Cu concentrations of the pines were statistically higher and the K concentrations lower on the Level I plots. The foliar S, Mg and K concentrations of the spruces were statistically lower and the Cu concentrations higher on the Level I plots. This could be due to differences in the stand structure; the Level I plots are more heterogeneous than the Level II plots. A high proportion of the Level I spruce plots are also located in southern Finland. The Level I and II pine plots are rather evenly distributed throughout the country (Fig. 7).

The differences in the foliar chemical composition of both tree species between the two samplings were small on the Level II plots (Figs. 9 and 12). However, the N and K concentrations of current needles of Scots pines were statistically lower and the P concentrations of previous-year needles were higher in 1995/96 than in 1997. The Fe concentrations of both current and previous-year needles of spruces were statistically lower in 1995/96 than in 1997. The differences could be due to the sampling. The 1995/96 sampling is based on the first tree set, and the 1997 sampling on the second tree set. Figures 9–12 show the average element concentrations of Scots pine and Norway spruce needles on the observation plots in 1995 and 1997.

The foliar S, P and Mn concentrations of current needles and the P, Mg and Mn concentrations of previous-year needles of pine were lower on mineral soils than on peatlands. However, there were differences in the nutrient status of the trees between the southern and

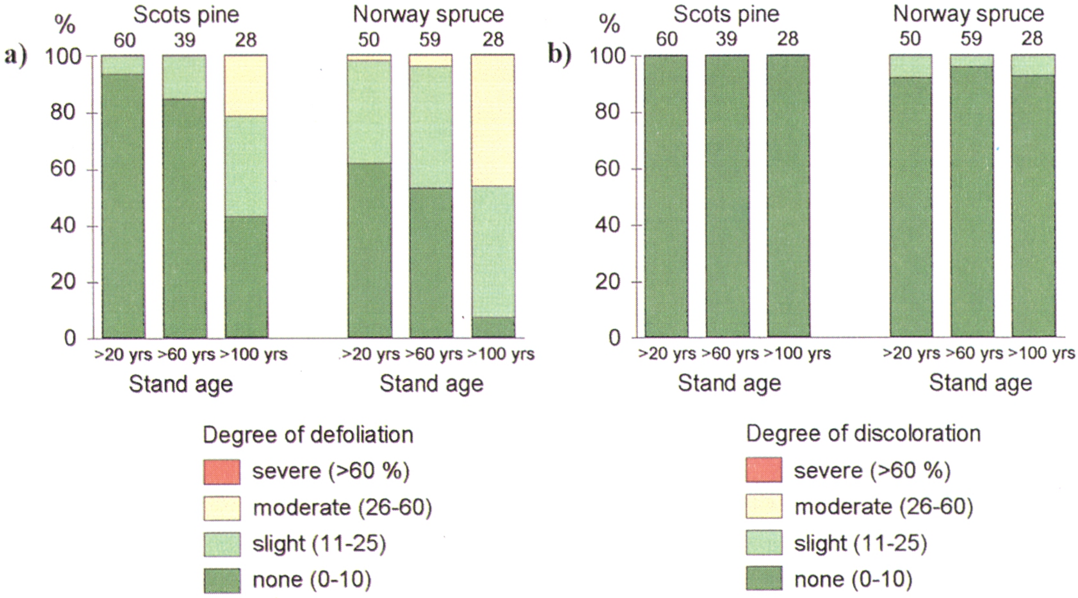

Figure 8. Defoliation (a) and discoloration (b) frequency distribution for Scots pine and Norway spruce selected for needle chemistry determination in three stand age classes.

northern peatland plots. The N, S, Mg and Cu concentrations were higher and the P, K and B concentrations lower on the southern plots than on the northern plots (Fig. 9 and 10, plot no. 26, 27, 29 and 30). The foliar K and B concentrations were rather low compared to the critical concentrations (Jukka 1988) on Plot no. 26 and 27. Nutrient deficiencies, e.g. P, K and B deficiency, are relatively common in peatland forests in Finland (Kolari 1983, Kaunisto 1992).

The effect of stand age on the foliar chemical composition was stronger in spruce than in pine (Fig. 13). However, there were few statistical differences between the stand age classes due to the low number of observations in the individual age classes. The N, Mg and K concentrations of the spruce needles were statistically higher in the youngest trees than in the oldest ones. The effects of spruce stands on the nutrient status of the soil may be stronger, due to the different tree and stand structure, than the effects of pine stands.

Table 3 shows the average element concentrations calculated from the 1997 data representing current-year and previous-year needles of coniferous species on Level I observation plots. The foliar N, S, B and Fe concentrations of both tree species, and the Ca concentrations of pine, were slightly lower than the corresponding concentrations on the Level I plots during 1987–1995 (Raitio 1998). There were also differences between the observation plots. Figures 14–17 show the statistical dependences of the foliar nutrient concentrations on the nutrient concentrations of the organic matter layer on Level II plots.

The lowest foliar boron concentrations occurred on the plots in the most continental part of Finland. However, the foliar boron concentrations elsewhere in Finland are normally very low (3–20 mg/kg). The effect of a maritime climate was also seen in the Mg concentrations of pine needles e.g. on plot No. 1 (Figs. 9 and 10). Cu deposition from the Cu-

Table 3. The average element concentrations in the current-year (C) and the previous-year (C+1) needles of Scots pine and Norway spruce on the Level I observation plots in 1997.

Element	Scots pine Mineral soil, n = 13		Peatland, n = 4		Norway spruce n = 14	
	C	C + 1	C	C + 1	C	C + 1
N mg/g	11.8	11.5	12.8	12.3	11.3	10.1
P mg/g	1.46	1.29	1.61	1.45	1.67	1.33
K mg/g	5.42	4.76	5.16	4.63	6.69	5.11
Ca mg/g	1.93	3.26	2.01	3.21	3.56	6.10
Mg mg/g	1.09	0.95	1.28	1.09	1.21	1.13
S mg/kg	931	925	1006	1023	914	905
Fe mg/kg	30	43	30	44	30	36
B mg/kg	11.0	10.0	11.7	9.4	10.6	11.0
Cu mg/kg	2.60	2.29	2.25	2.26	1.95	1.69
Zn mg/kg	40.8	50.2	39.6	44.8	32.1	36.0
Mn mg/kg	431	706	253	370	658	999

Ni smelter complex at Nikel on the Kola Peninsula could explain the slightly higher copper concentrations of the pine needles on plot No. 1 compared to comparable sites elsewhere in Finland (Fig. 10). This plot is located at a distance of only about 70 km from the smelter at Nikel and, according to the national moss survey, signs of Cu, Ni and S deposition are clearly evident in this part of Finnish Lapland (Kubin et al. 1998).

Conclusions

The deficiency of plant-available N and P within the boreal coniferous zone are the most common factors limiting growth, and hence forest condition (Tamm 1991). Deficiencies of K, Mg, Ca or micronutrients, especially on mineral soil forest sites, are much less common.

Potassium and phosphorus are the most important growth-limiting nutrients on drained peatlands whereas the peat in the most typical drained peatland site types can have usually relatively high nitrogen concentrations. This may result in unbalanced nutrient regime for trees. Micronutrient deficiencies, e.g. B and Cu deficiency, are also quite common on peatland sites in Finland (Kolari 1983, Kaunisto 1992).

These conceptions are also supported by regional Finnish surveys and by the Level I and II monitoring programme in Finland.

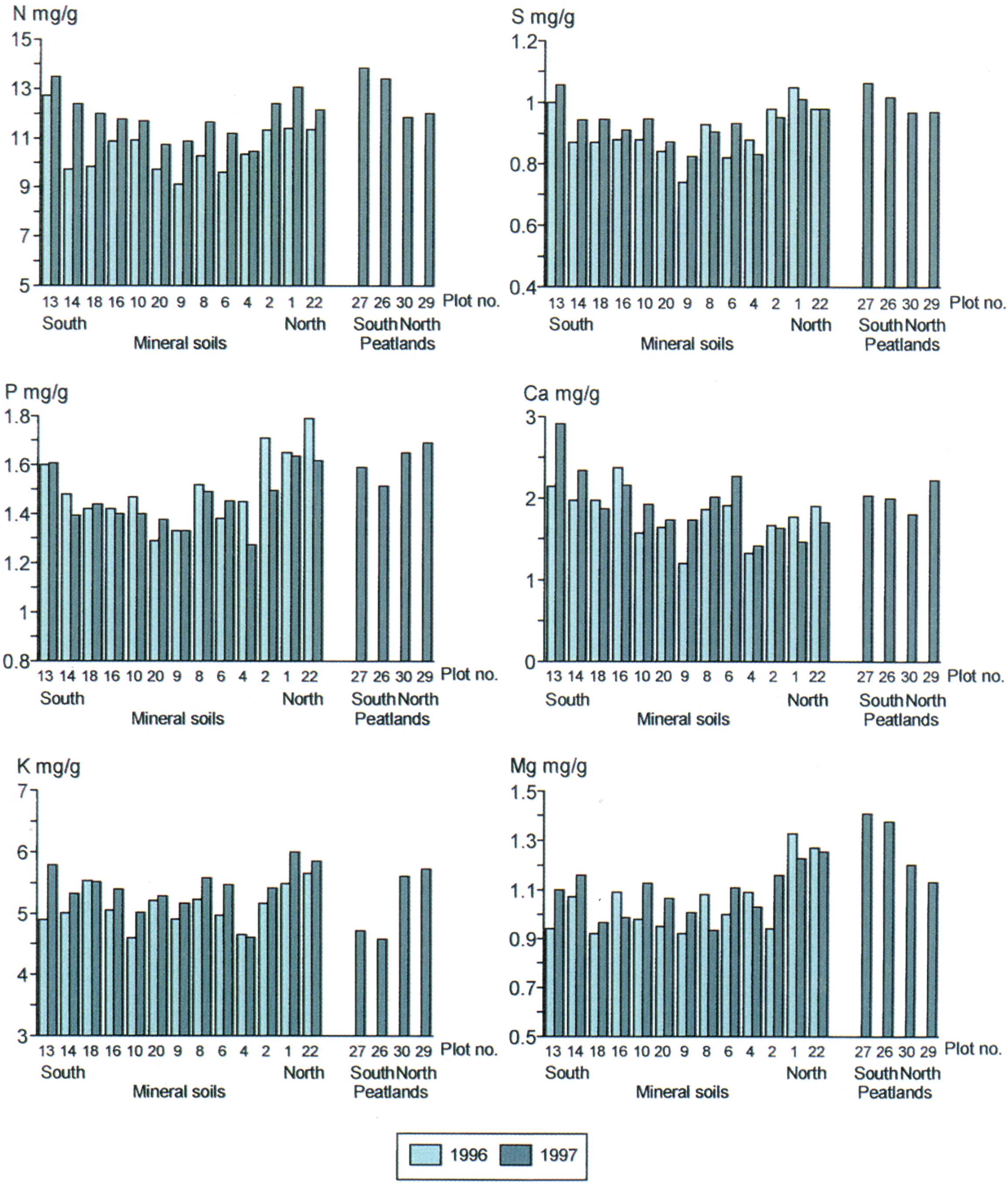

Figure 9. Average element concentrations of Scots pine current needles on the observation plots in 1995/96 and 1997. Plot no. 26, 27, 29 and 30 are locating on peatlands.

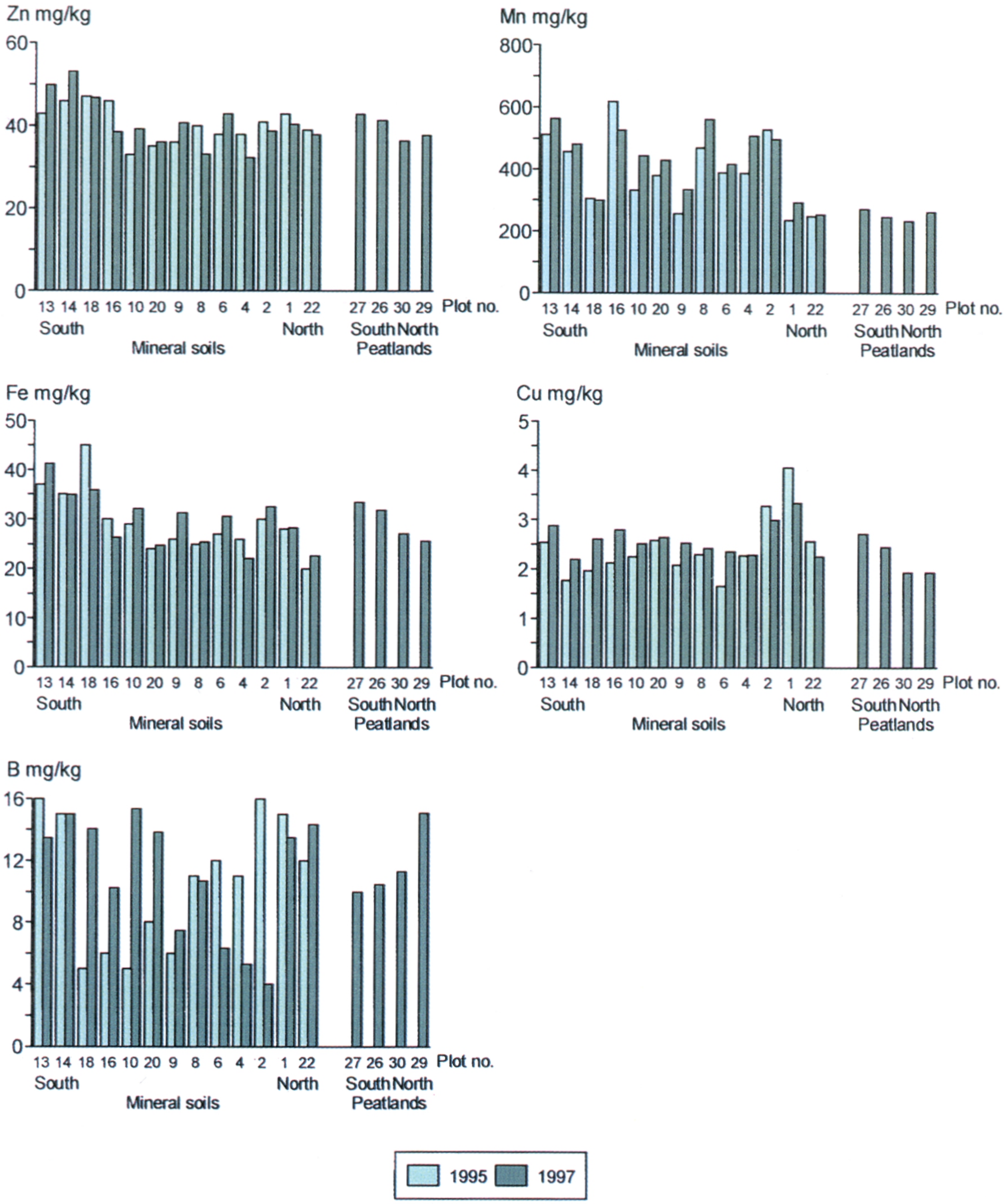

Figure 9. Continues.

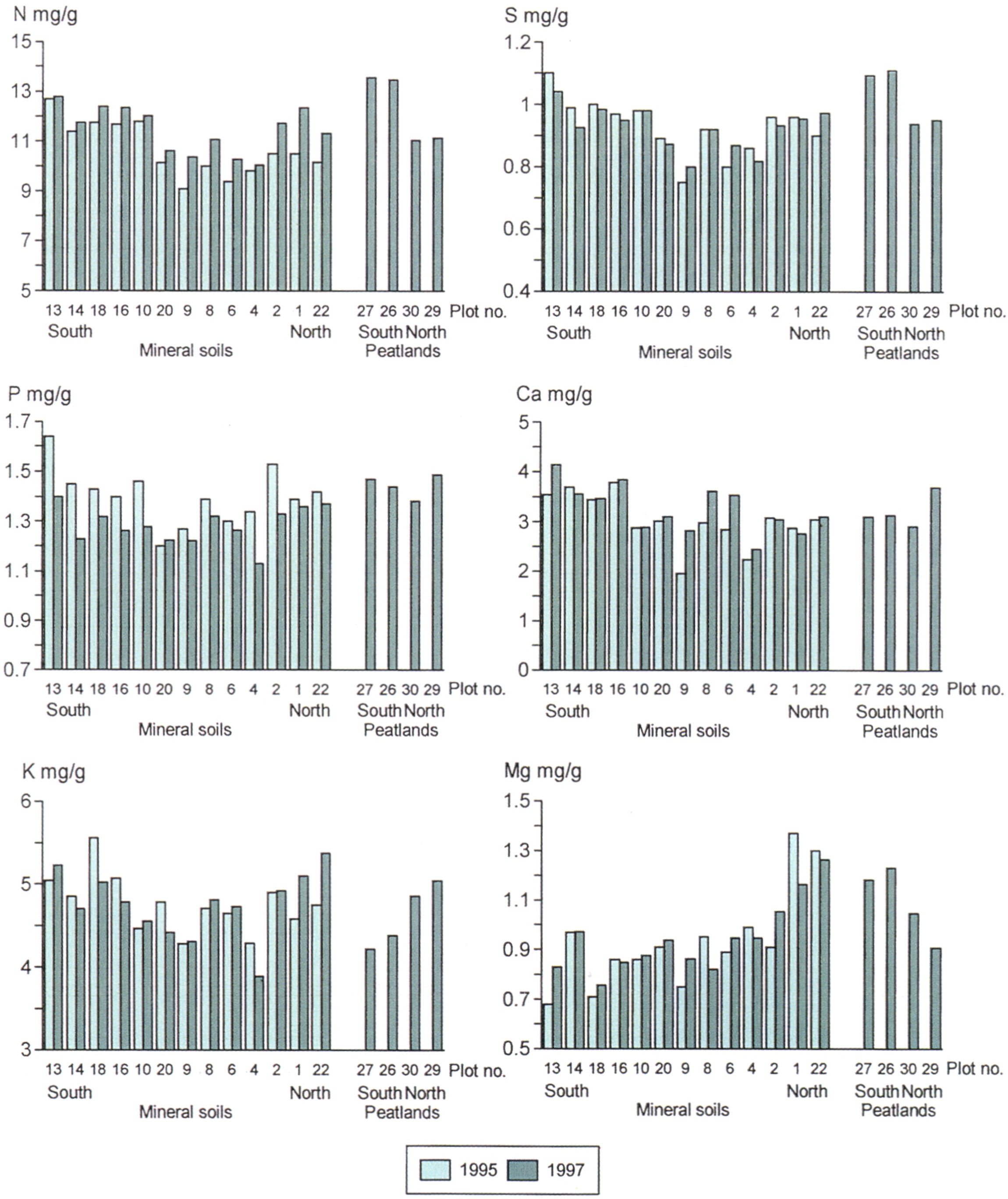

Figure 10. Average element concentrations of Scots pine previous-year needles on the observation plots in 1995/96 and 1997. Plot no. 26, 27, 29 and 30 are locating on peatlands.

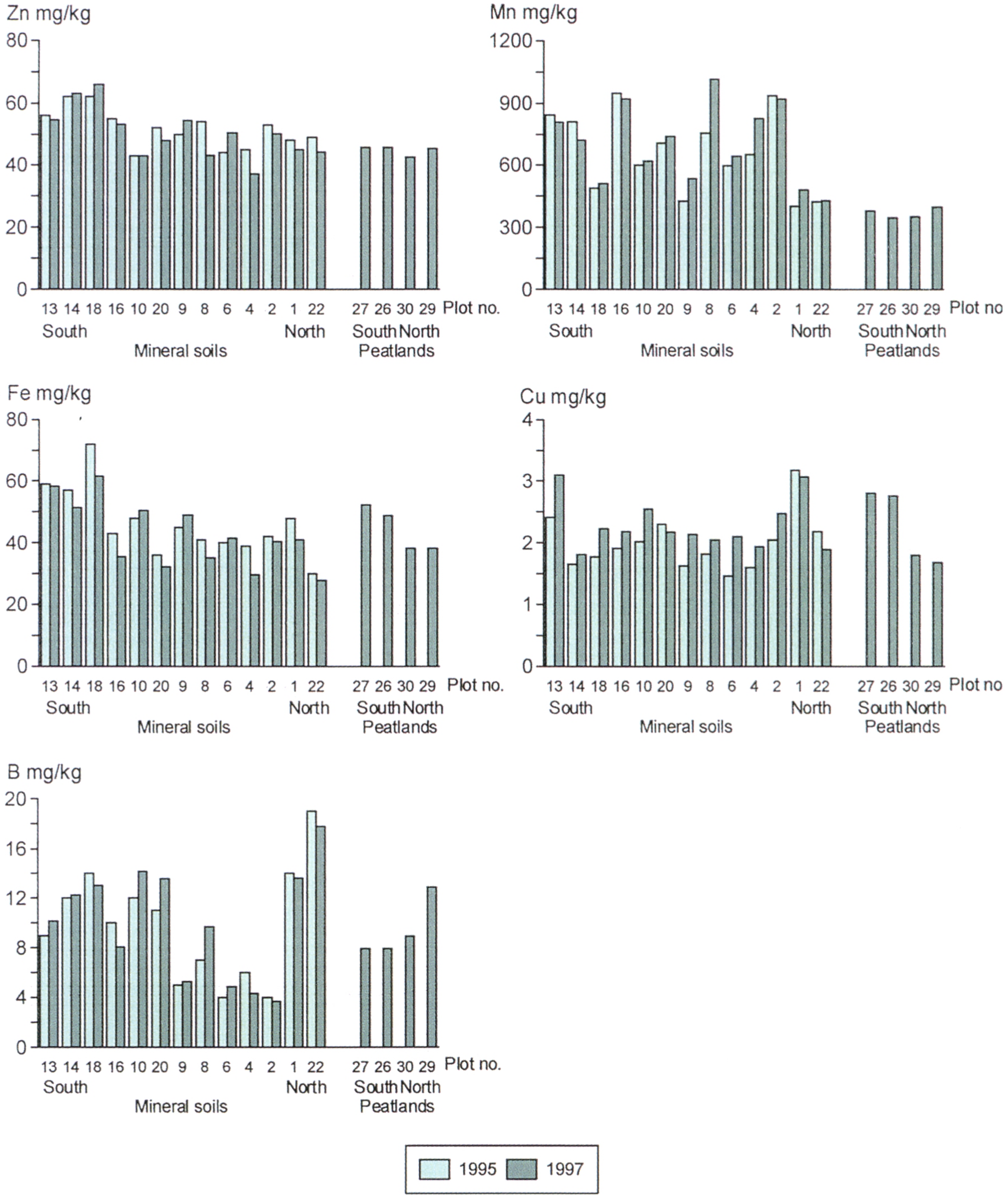

Figure 10. Continues.

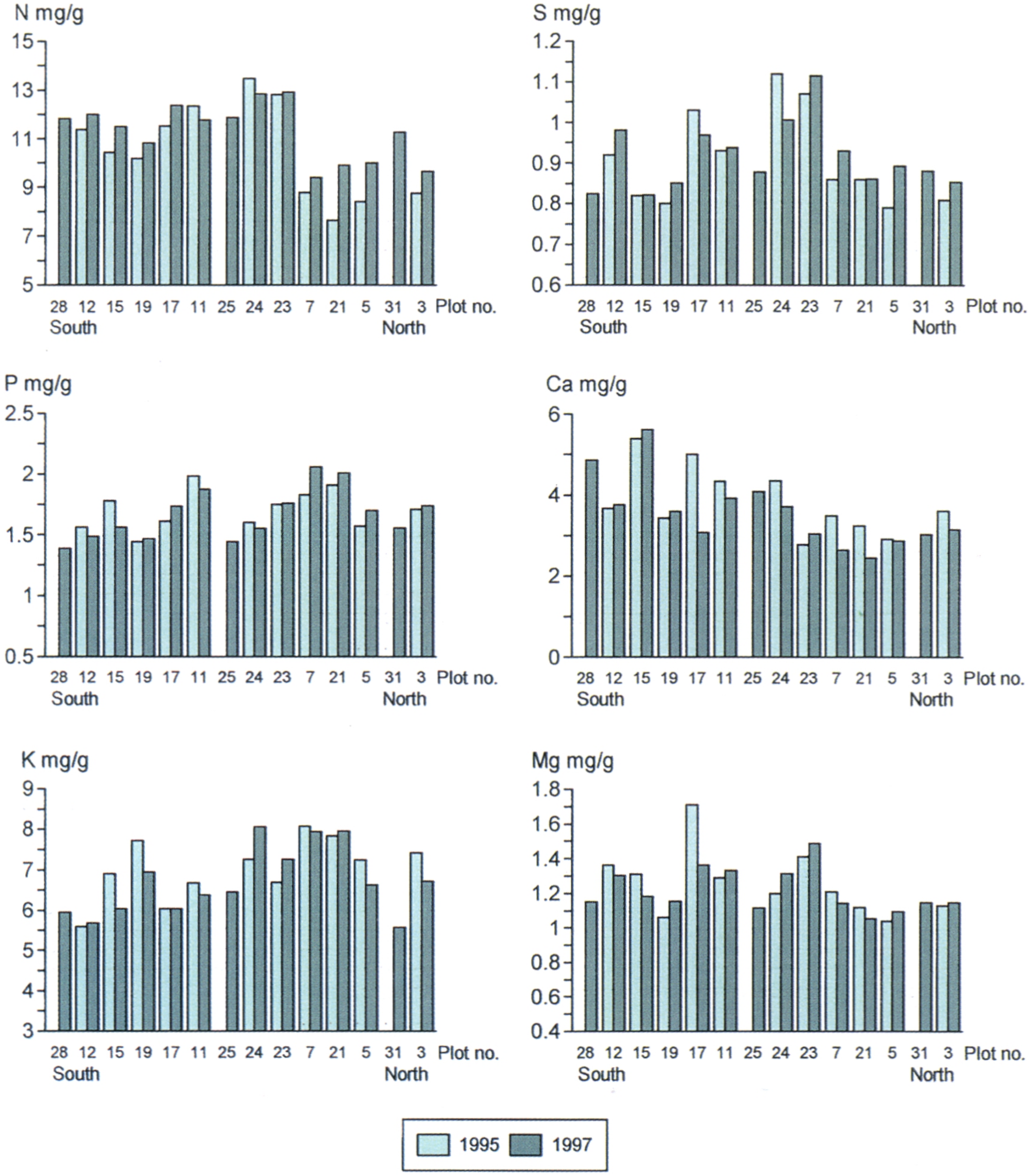

Figure 11. Average element concentrations of Norway spruce current needles on the observation plots in 1995/96 and 1997.

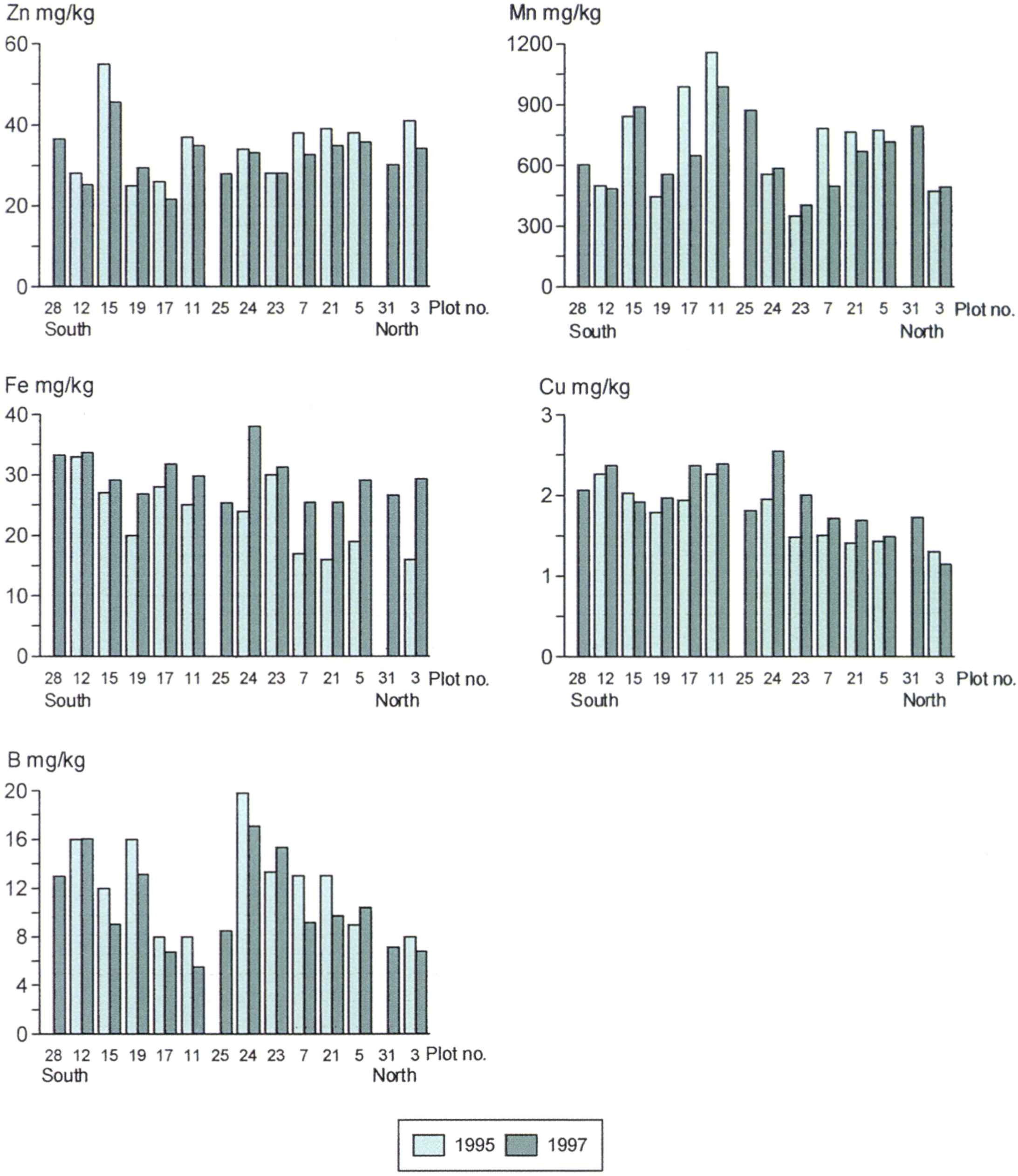

Figure 11. Continues.

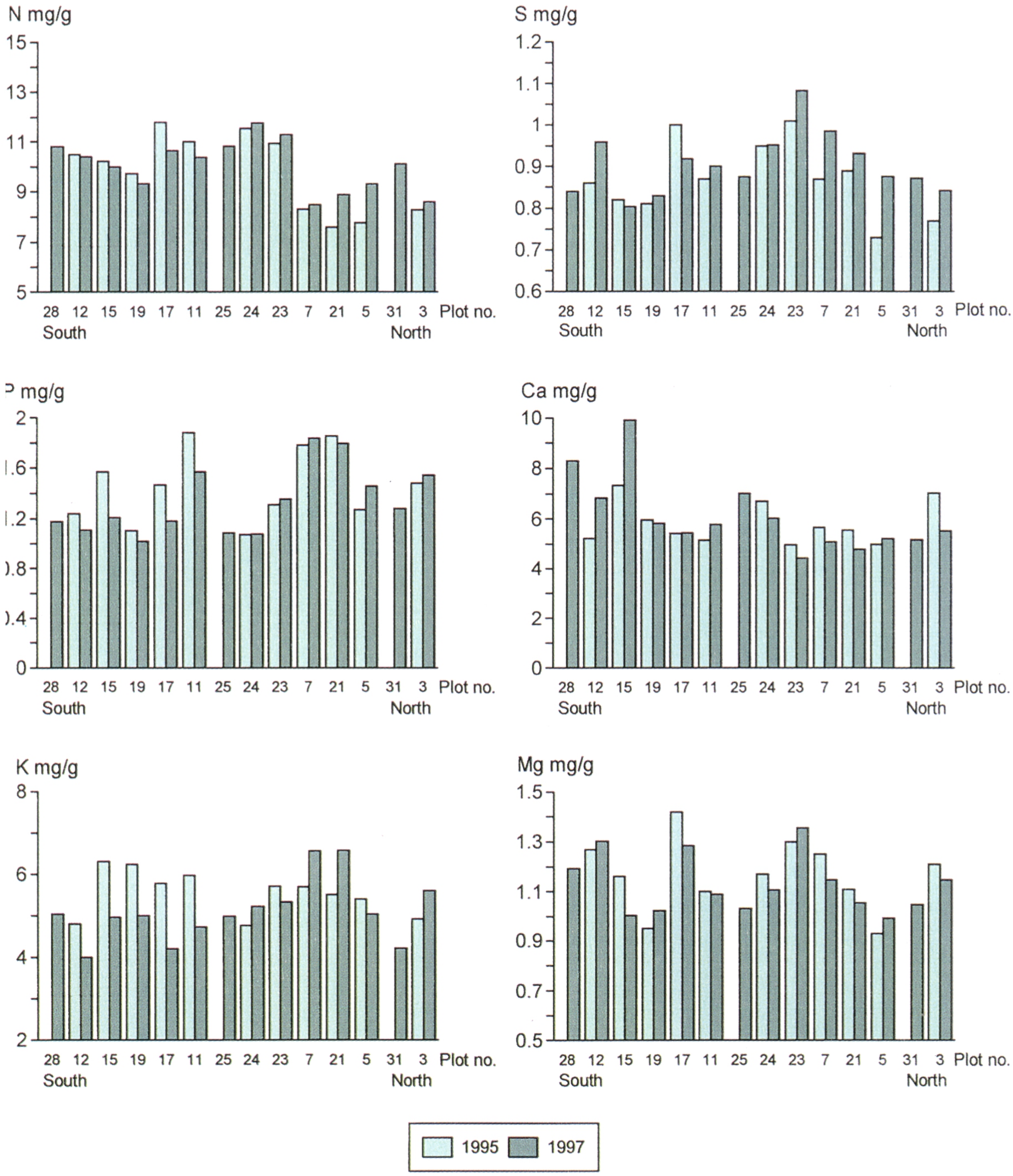

Figure 12. Average element concentrations of Norway spruce previous-year needles on the observation plots in 1995/96 and 1997.

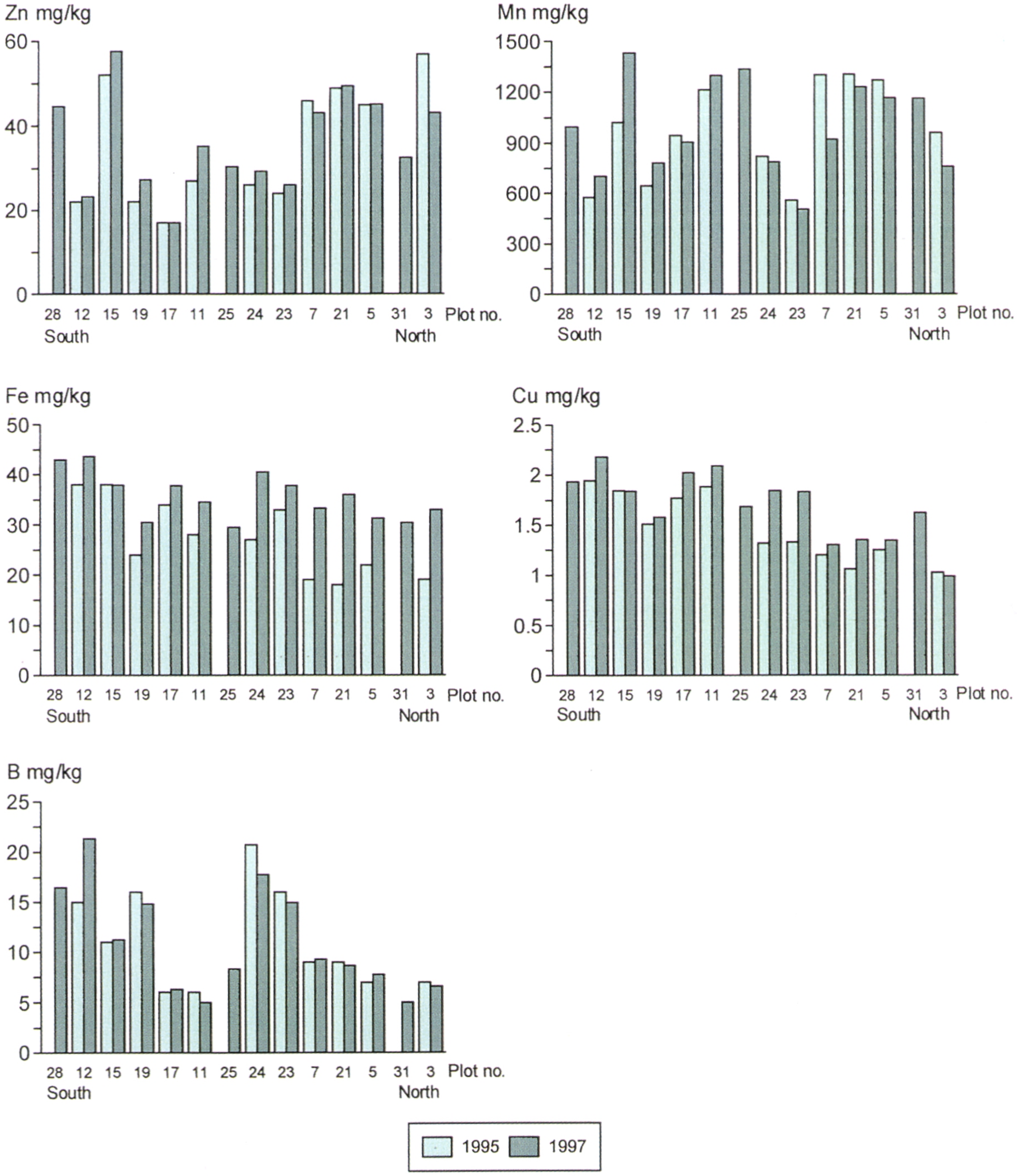

Figure 12. Continues.

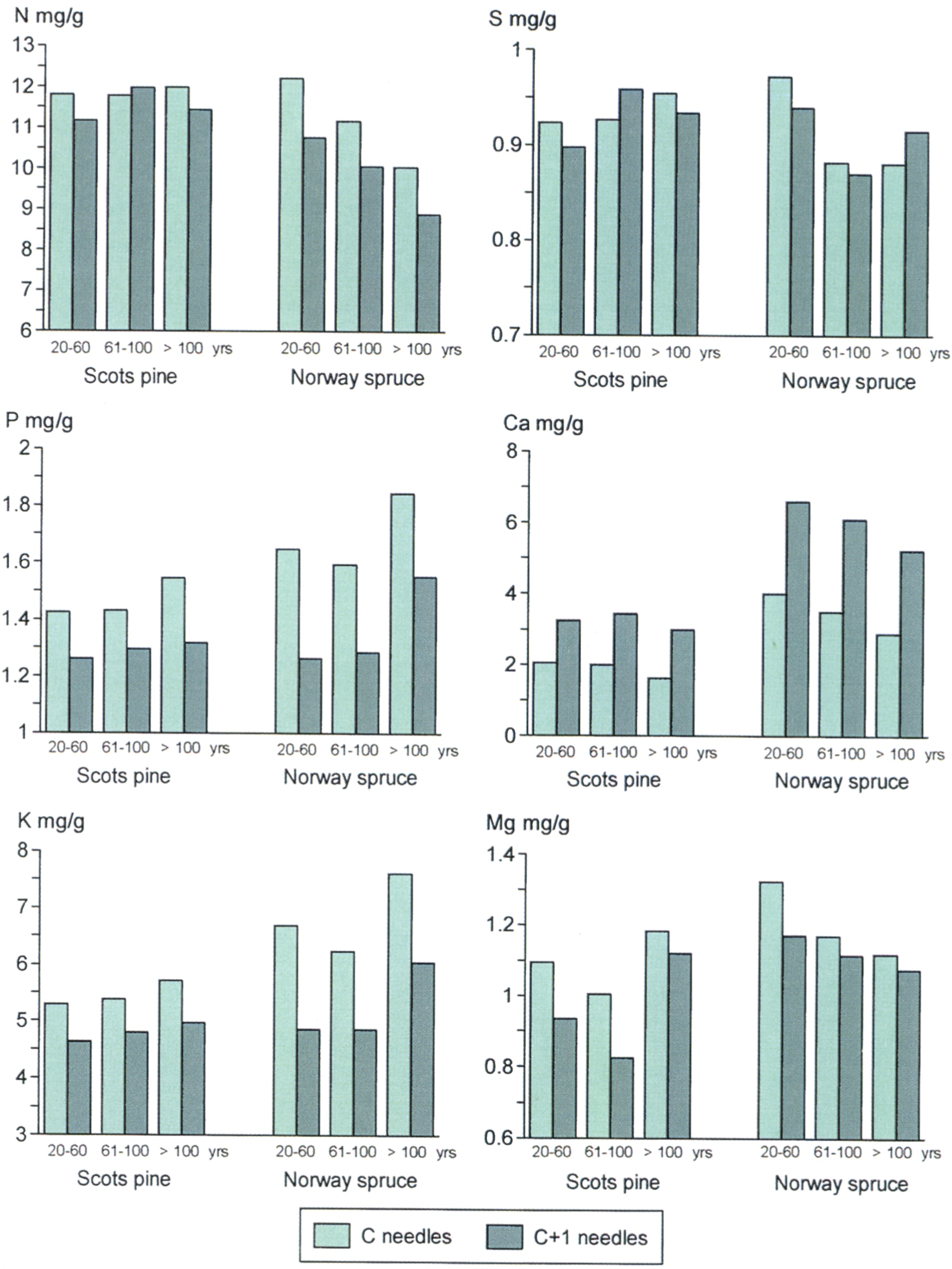

Figure 13. Average element concentrations of Scots pine and Norway spruce needles in three stand age classes.

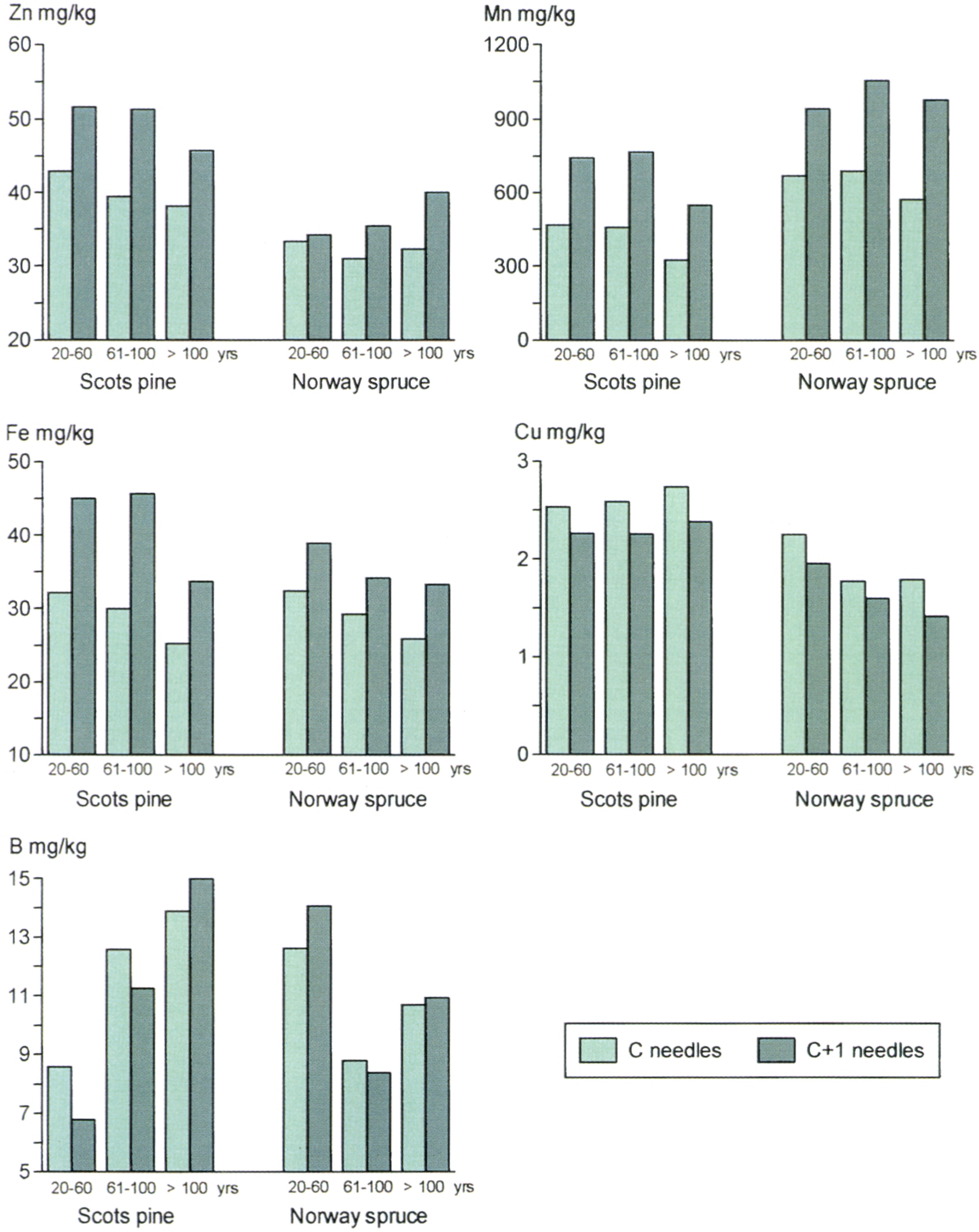

Figure 13. Continues.

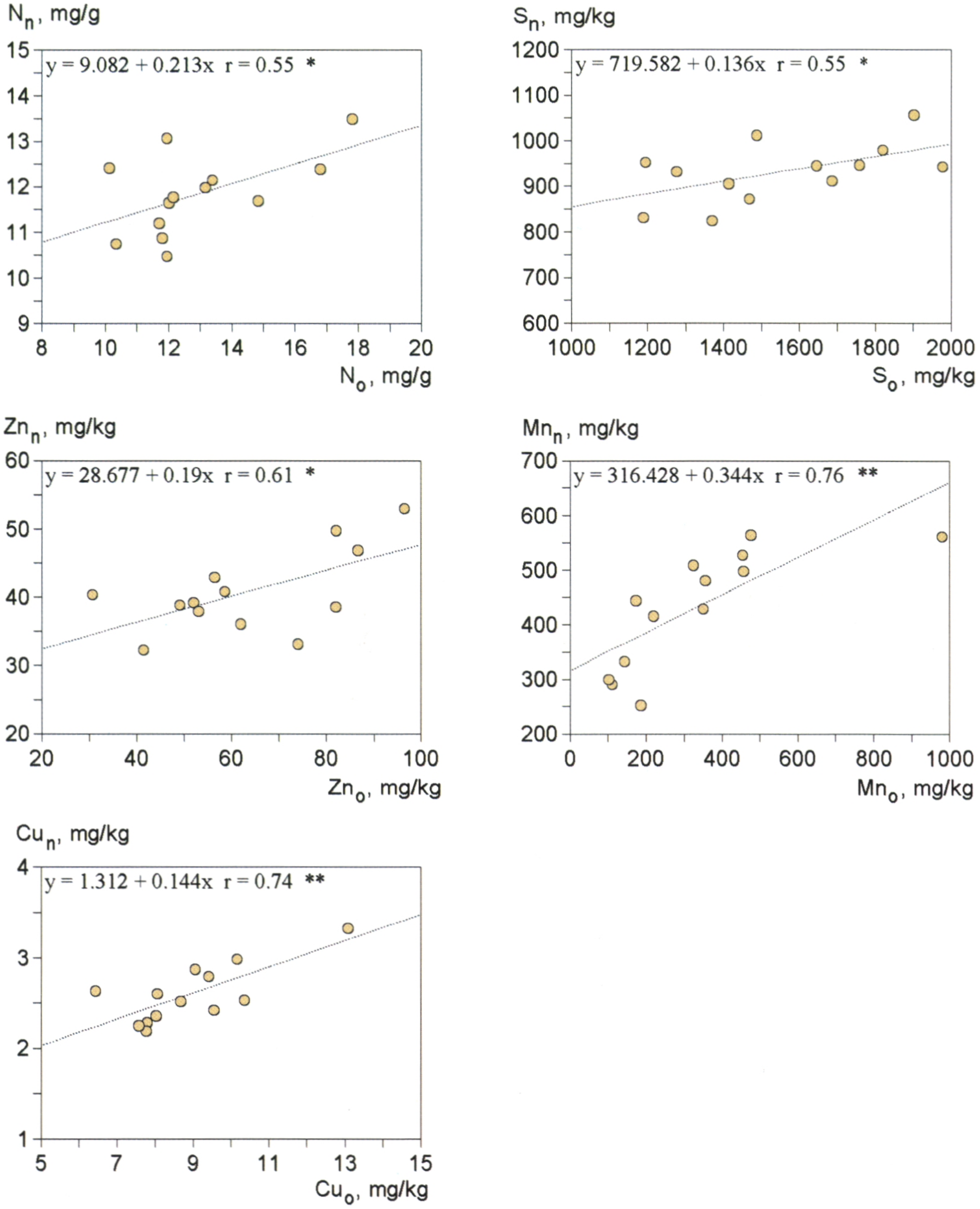

Figure 14. The dependence of the nutrient concentrations in current needles (n) of Scots pine on the nutrient content of organic matter (o) in the humus layer.

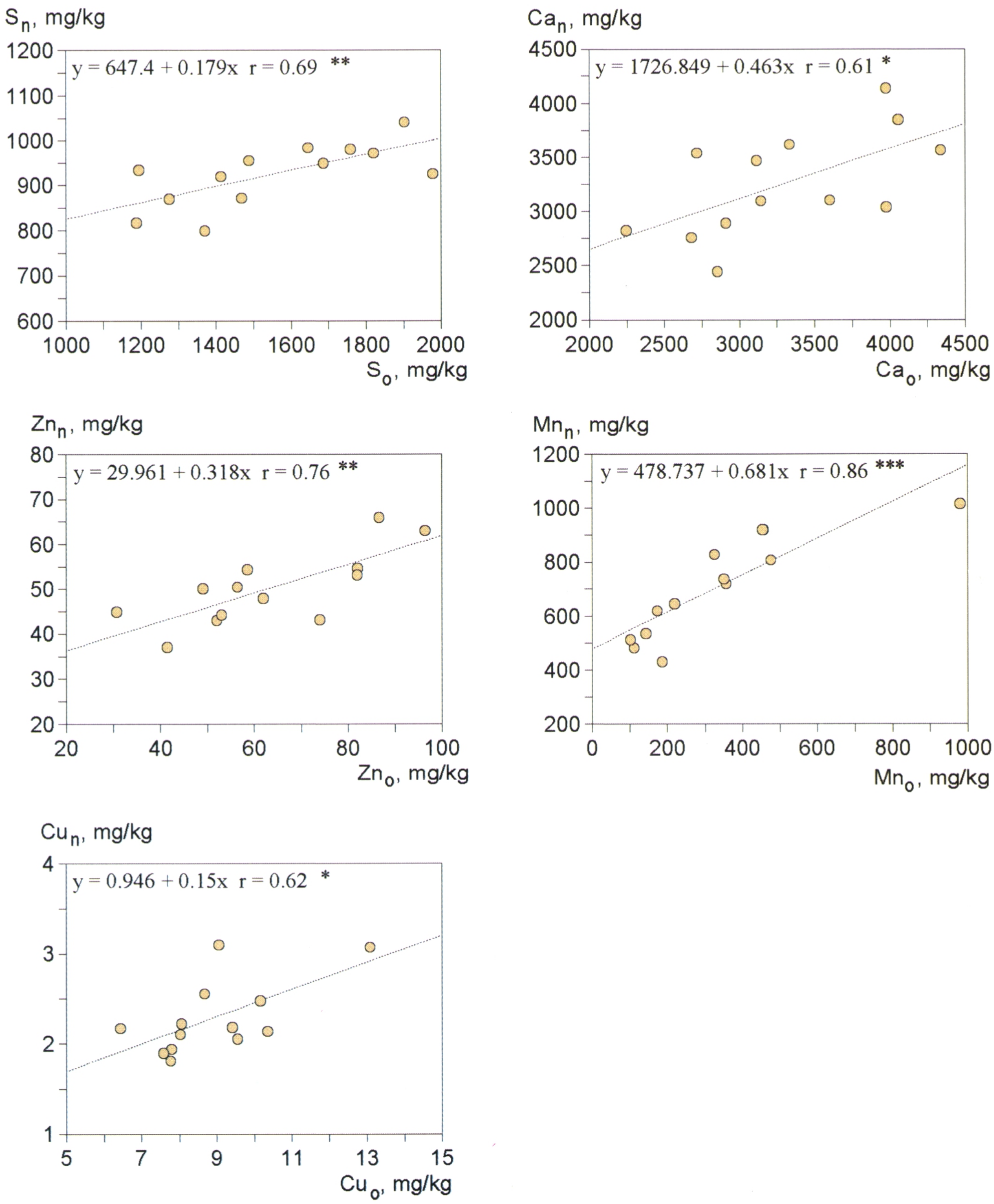

Figure 15. The dependence of the nutrient concentrations in previous-year needles (n) of Scots pine on the nutrient content of organic matter (o) in the humus layer.

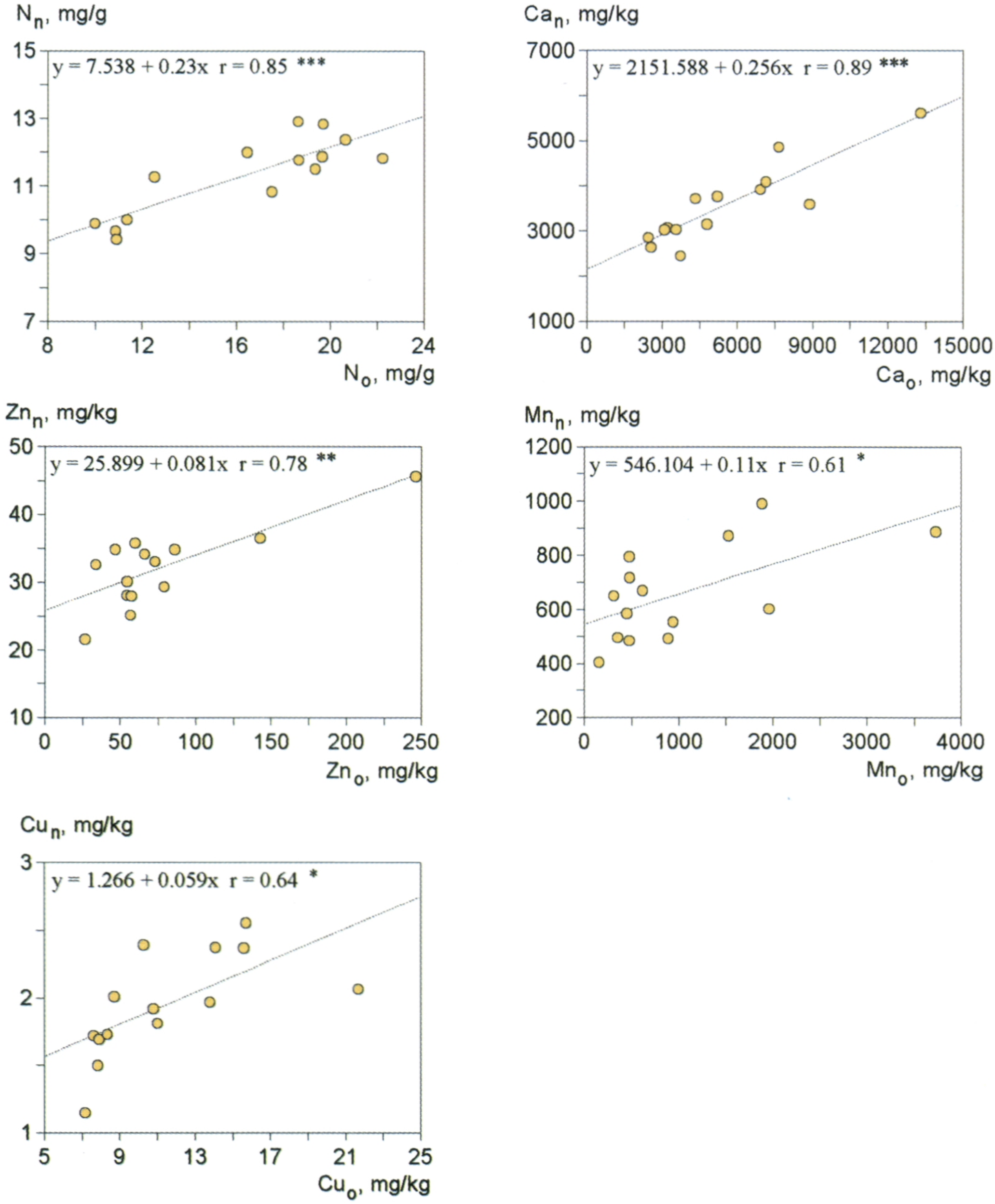

Figure 16. The dependence of the nutrient concentrations in current needles (n) of Norway spruce on the nutrient content of organic matter (o) in the humus layer.

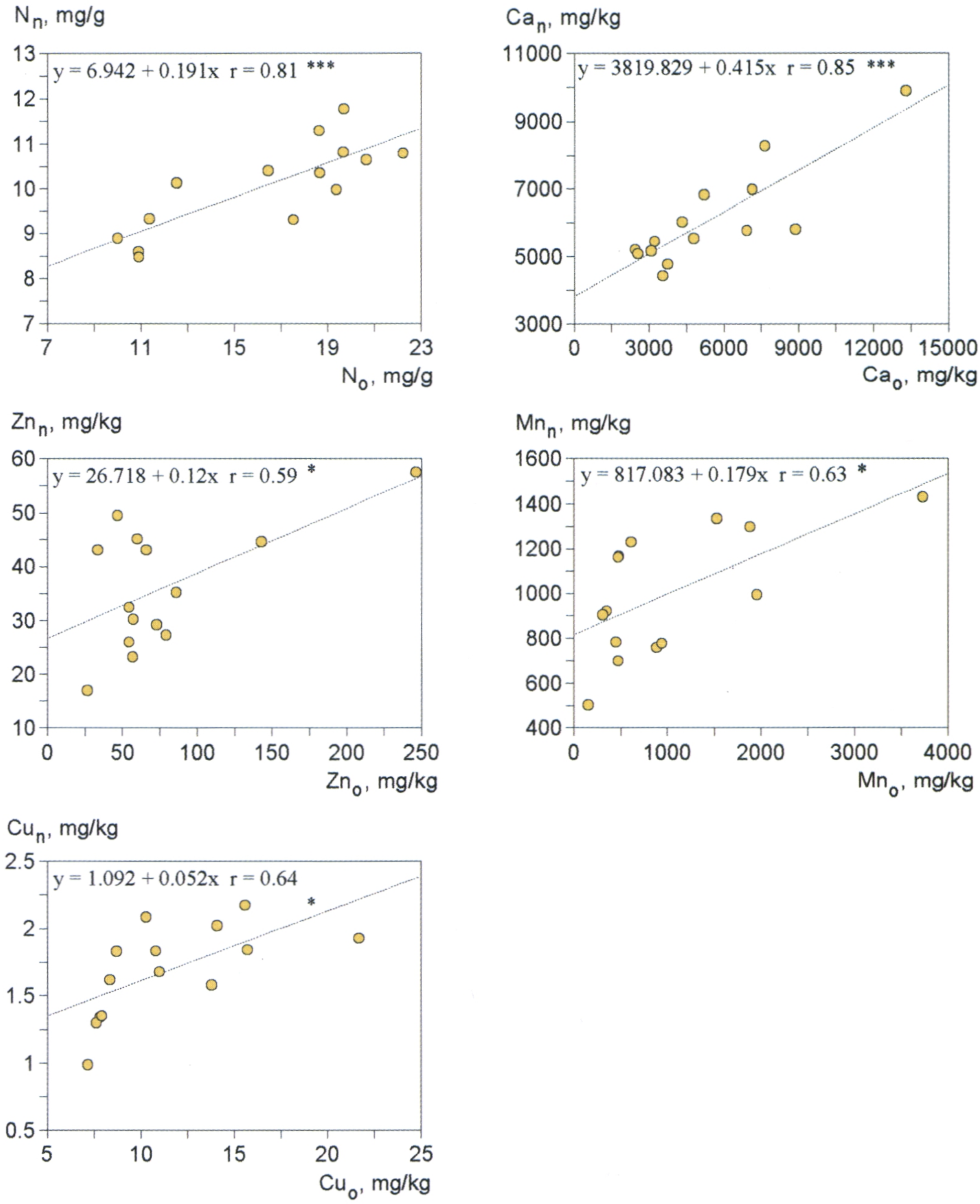

Figure 17. The dependence of the nutrient concentrations in previous-year needles (n) of Norway spruce on the nutrient content of organic matter (o) in the humus layer.

Soil condition

Observation plots on peatlands

Markku Saarinen and Seppo Kaunisto

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Introduction

The area of peatlands in Finland is about 9 million hectares, covering almost one third of the total land area. During the last 70 years large areas of Finnish mires have been drained for forestry, especially during the 1960's and 1970's. The total area of drained peatlands is currently about 4.7 million hectares.

According to the 8th National Forest Inventory, the total annual forest growth on peatlands is nearly 18 million m^3. This is almost one fourth of the total annual volume increment of Finnish forests. Out of this, only about 2 million m^3 are produced on pristine peatlands. Peatland drainage has increased the annual volume growth of the growing stock by 10.5 million m^3. Consequently, drained mires are of major importance for the forest industries in Finland.

The four intensive monitoring plots on peatlands have been established in pairs, the unfertilised and fertilised plots in each pair being located close to each other. One of the plot pairs (Nos. 26 and 27) is located at Ikaalinen, in southern Finland, and the other (Nos. 29 and 30) is at Pyhäntä, in the northern part of Central Finland.

Peat properties

The peatland plots are locatedd on thick-peat mires (0.7–1.2 m on plots 29 and 30, and over 3 m on plots 26 and 27). The original site types were oligotrophic or "oligo-ombrotrophic" pine mires and open fens. There are differences in the peat density (bulk density), especially in the 20–60 cm peat layer, between the two locations (Fig. 18). Peat density is considerably higher on plots 29/30 than on plots 26/27.

With peat soils it is preferable to express nutrient concentrations on a volumetric basis (mg/l *in situ*), because the bulk density of the peat has a strong effect on the total nutrient concentrations in different peat layers. This is also the main reason for the higher N and P concentrations, especially in the 20–40 and 40–60 cm peat layers, in plots 29/30 (Fig. 18) than in plots 26/27.

The peat nitrogen concentration varies considerably in drained pine mires in Finland. In the surface peat layer (0–20 cm) it varies from 700 to 2900 mg/l on oligo-ombrotrophic, and from 1600 to 3300 mg/l on meso-oligotrophic sites *in situ* (Kaunisto & Moilanen 1998, Kaunisto & Paavilainen 1988, Laiho & Laine 1994). The corresponding P concentrations are 40–140 mg/l and 80–160 mg/l, and for K 20–35 mg/l and 25–40 mg/l, respectively. According to these figures, plots 26/27 and 29/30 have relatively normal K concentrations but, according to their low N and P concentrations, they should be considered mire sites (Fig 18). The Fe concentrations are also relatively low. This indicates that the peat has a low phosphorus adsorption capacity, with the result that fertiliser P may be readily leached. The other elements in Figure 18 show, as for K, a relatively average nutrient status.

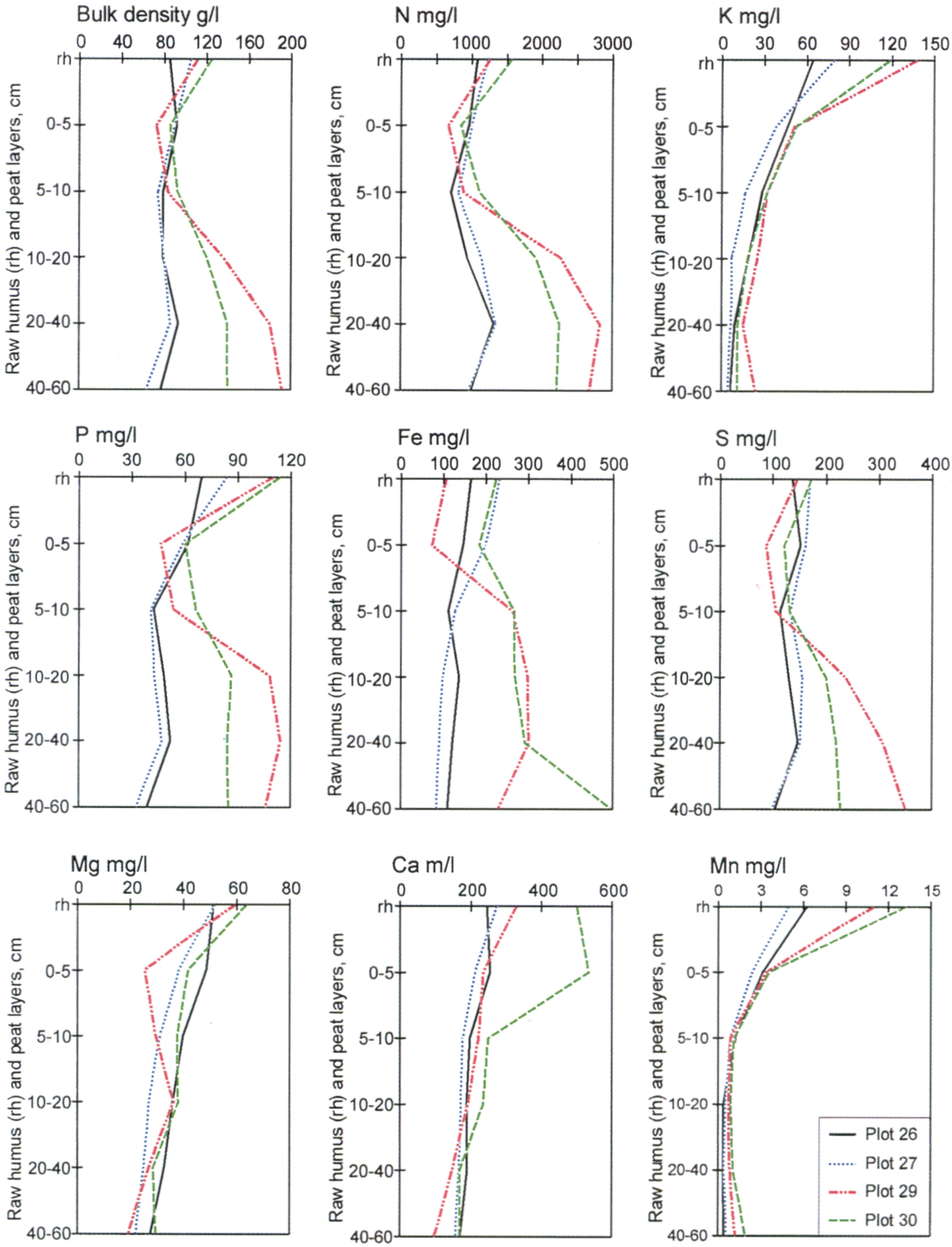

Figure 18. Bulk density of peat and volymetric concentrations (in situ) of nutrients in raw humus (rh), 0–5 cm, 5–10 cm, 10–20 cm, 20–40 cm and 40–60 cm peat layers on the observation plots no 26, 27, 29 and 30.

Deposition

Antti-Jussi Lindroos[1], John Derome[2], Kirsti Derome[2] and Kaarina Niska[2]

[1)] Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

[2)] Finnish Forest Reasearch Institute
Rovaniemi Research Station
P.O. Box 16, FIN-96301 Rovaniemi, Finland

Introduction

Deposition samples were collected throughout 1997 from 17 forest stands (9 Scots pine and 8 Norway spruce) and adjacent open areas. The stand throughfall samples were collected at 4-week intervals using 20 systematically located precipitation collectors during the snowfree period (diam. 20 cm, height 0.4 m) and 6 snow collectors during wintertime (diam. 36 cm, height 1.8 m). The corresponding number of collectors for the adjacent open area were 3 and 2, respectively.

The open area and throughfall values for 13 of the sample plots were compared to the corresponding values measured in 1996. In addition, open-area deposition was compared to the long-term median values (1971–1988) recorded by the National Board of Waters and the Environment (Järvinen & Vänni 1990). This long-term series was chosen for comparison since sulphur deposition in Finland was at its highest during the 1970s and 1980s.

Precipitation and deposition acidity

Annual precipitation in the open varied between 382–704 mm in southern and central Finland and between 295–565 mm in northern Finland during 1997. The variation in the precipitation values between the plots was somewhat greater in 1997 than in 1996 (Tables 4 and 5). The long-term (1971–1988) median precipitation in southern and central Finland was 600–650 mm and in northern Finland about 450 mm.

The interception of precipitation by the tree canopies was generally higher in the spruce stands than in the pine stands. The tree canopies intercepted 7–31 % of the bulk precipitation in the pine stands in 1996 and 1997 (Table 4), and between 16–46 % in the spruce stands, apart from plots 5 and 21 where no or only slight interception was recorded (Table 5). The higher interception in the spruce canopies is generally related to the structural differences between these two tree species (e.g. Hyvärinen 1990).

The mean pH of bulk deposition in the open area was, in general, higher in 1997 than in 1996 on the plots located in southern and central Finland, while in northern Finland no corresponding increase in pH was detected. The mean pH of stand throughfall also increased clearly from 1996 to 1997 on the plots in southern and central Finland. Overall, the mean pH of stand throughfall was lower than that in the open area in both the pine and spruce stands. The highest pH values (mean >5.3) of open-area deposition and stand throughfall were measured on the plot (No. 23) located near the Finnish west coast (Tables 4 and 5).

Sulphur and nitrogen deposition

SO_4-S deposition in the open area in the intensive monitoring plot network in 1996 and 1997 was clearly lower than the long-term

Table 4. Annual deposition in open area (BD) and in stand throughfall (TF) in pine stands during 1996 and 1997. Plots 1, 22, 6, 9 and 20 are located in northern Finland. The other plots are located in central and southern Finland.

Sample plot tree species	Year	Sample type	Precipitation mm	pH mean	SO4-S mg/m²	N-total mg/m²	NH4-N mg/m²	NO3-N mg/m²	Ca mg/m²	Mg mg/m²	K mg/m²	Na mg/m²	Cl mg/m²	DOC mg/m²
1	1996	BD	427	4.89	135	107	30	39	31	31	45	317	486	919
Sevettijärvi		TF	395	4.74	196	133	39	37	78	69	101	574	964	2299
Scots pine	1997	BD	295	4.89	100	91	20	36	47	38	33	324	579	703
		TF	262	4.64	134	74	15	30	58	64	90	432	737	1507
22	1997	BD	299	4.77	106	88	24	36	29	25	24	196	374	973
Kevo		TF	276	4.69	167	76	10	27	82	94	126	667	1097	4009
Scots pine														
6	1996	BD	462	4.93	144	222	65	78	39	9	46	77	89	832
Kivalo		TF	390	4.55	205	174	44	74	74	26	127	123	140	3146
Scots pine	1997	BD	513	4.85	152	187	58	79	46	9	35	77	98	1143
		TF	401	4.67	159	116	19	52	76	27	179	133	156	3626
9	1996	BD	430	4.87	182	226	70	94	35	8	46	58	87	890
Ylikiiminki		TF	344	4.56	202	182	46	76	77	25	138	84	131	2644
Scots pine	1997	BD	565	4.86	133	184	67	86	30	9	25	65	75	1000
		TF	490	4.62	171	163	36	73	83	33	191	122	170	3791
20	1997	BD	563	4.81	139	190	68	90	33	9	45	65	106	1701
Lieksa		TF	526	4.56	244	219	47	91	162	50	190	142	224	6515
Scots pine														
10	1996	BD	616	4.54	300	329	114	160	63	14	199	106	142	1050
Juupajoki		TF	524	4.48	322	225	81	108	119	33	369	167	225	5429
Scots pine	1997	BD	603	4.65	233	287	111	155	54	13	31	93	121	1102
		TF	536	4.6	289	266	67	131	125	47	277	191	248	4473
13	1996	BD	494	4.61	382	432	172	209	72	20	70	128	214	1011
Tammela		TF	417	4.25	601	478	126	226	299	79	494	200	375	5772
Scots pine	1997	BD	704	4.69	315	422	152	207	103	31	90	154	214	1706
		TF	521	4.56	342	328	68	165	223	74	511	236	337	5883
16	1996	BD	499	4.63	264	284	101	134	93	14	206	151	105	930
Punkaharju		TF	361	4.32	413	259	78	97	223	53	271	109	182	3652
Scots pine	1997	BD	399	4.82	145	192	66	100	58	14	50	80	102	842
		TF	276	4.65	199	158	33	66	136	41	281	115	167	3350
18	1996	BD	642	4.51	519	540	229	234	219	31	96	152	247	1387
Miehikkälä		TF	507	4.31	664	493	172	257	388	79	334	214	368	3989
Scots pine	1997	BD	512	4.66	295	370	155	190	117	20	37	117	163	1156
		TF	419	4.54	365	322	94	176	244	53	257	187	257	3698

Table 5. Annual deposition in open area (BD) and in stand throughfall (TF) in spruce stands during 1996 and 1997. Plots 3, 5 and 21 are located in northern Finland. The other plots are located in central and southern Finland.

Sample plot tree species	Year	Sample type	Precipitation mm	pH mean	SO4-S mg/m²	N-total mg/m²	NH4-N mg/m²	NO3-N mg/m²	Ca mg/m²	Mg mg/m²	K mg/m²	Na mg/m²	Cl mg/m²	DOC mg/m²
3	1996	BD	541	4.94	114	144	31	60	28	9	147	83	110	1161
Pallasjärvi		TF	408	4.91	151	89	17	29	77	34	268	103	197	2216
Norway spruce	1997	BD	526	4.93	106	110	29	66	30	10	43	84	125	899
		TF	403	4.84	139	102	18	42	68	36	424	157	278	2942
5	1996	BD	443	4.95	165	195	48	71	39	9	78	133	191	1009
Kivalo		TF	460	4.85	268	164	24	56	110	40	381	146	216	3407
Norway spruce	1997	BD	547	4.91	170	145	17	81	53	13	49	90	121	1227
		TF	521	4.89	243	204	67	58	106	42	568	175	248	4351
21	1997	BD	440	4.8	177	154	48	54	29	9	35	49	83	1773
Oulanka		TF	508	4.85	247	119	14	45	139	80	427	136	269	6149
Norway spruce														
23	1997	BD	382	5.35	111	231	109	69	80	25	135	75	102	975
Uusikaarlepyy		TF	208	5.34	310	473	193	87	140	89	1472	237	701	7001
Norway spruce														
11	1996	BD	616	4.54	300	329	114	160	63	14	199	106	142	1050
Juupajoki		TF	452	4.49	615	224	34	62	274	96	1083	178	384	6926
Norway spruce	1997	BD	603	4.65	233	287	111	155	54	13	31	93	121	1102
		TF	467	4.65	421	246	41	74	221	92	1214	216	397	7673
12	1996	BD	494	4.61	382	432	172	209	72	20	70	128	214	1011
Tammela		TF	416	4.37	956	388	86	127	476	165	1230	300	645	15433
Norway spruce	1997	BD	523	4.69	263	362	128	177	83	28	69	143	203	1376
		TF	406	4.62	562	327	51	91	357	142	1148	340	584	9695
17	1996	BD	499	4.63	264	284	101	134	93	14	206	151	105	930
Punkaharju		TF	313	4.52	720	260	36	67	368	111	1067	180	392	7954
Norway spruce	1997	BD	396	4.86	156	190	66	96	62	19	94	83	111	1025
		TF	256	4.66	376	171	30	53	206	81	724	128	301	5426
19	1996	BD	608	4.59	302	356	169	161	58	12	64	68	123	805
Evo		TF	440	4.48	673	333	75	113	377	118	1068	143	328	5132
Norway spruce	1997	BD	517	4.88	201	259	110	117	58	14	49	72	135	1800
		TF	380	4.72	442	304	40	91	327	132	873	173	399	7270

(1971–1988) median values (Fig. 19, Tables 4 and 5). This is undoubtedly due to the reduction in S emissions during the past decade. Although the sulphate load has decreased strongly during the past decade throughout the whole country, a decreasing sulphate gradient running from south to north was detectable in the open-area deposition and stand throughfall in 1997 (Fig. 19). SO_4-S deposition also decreased in the open area and in stand throughfall from 1996 to 1997 in the sample plot network. The decrease was the strongest on the plots located in southern and central Finland (Tables 4 and 5).

The SO_4-S load reaching the forest floor (stand throughfall) in both the pine and spruce stands was higher than that in the open area, reflecting the effect of canopy interaction. The relative increase in the sulphate load as the rainwater passed through the canopies was the greatest in the spruce stands located in southern and central Finland (Fig 19, Tables 4 and 5). Most of the sulphate load reaching the forest floor in stand throughfall is derived from atmospheric wet and dry deposition, but the contribution from sulphur cycling can also be important.

There was a clear decreasing gradient in total N deposition running from south to north in the open area and stand throughfall in 1996 and 1997. The total N deposition values in the open area were lower than the long-term (1971–1988) median values (Fig. 20, Tables 4 and 5). The throughfall N load (total N, NH_4-N, NO_3-N) was generally lower than the corresponding value in the open, indicating uptake processes in the tree canopies (Tables 4 and 5). The clearest exception to this, which is a typical phenomenon in the Nordic countries, was the situation on the plot (No. 23) located on the Finnish west coast. Total N, ammonium and nitrate deposition values were strongly elevated in stand throughfall compared to deposition in the open area. This was especially true for ammonium deposition, indicating relatively high NH_3 emissions from agriculture in the area. The neutralizing effect of the NH_3 emissions can be seen as elevated pH values on this plot compared to the other plots (see above).

Base cations, chloride and dissolved organic carbon

The base cation, chloride and dissolved organic carbon (DOC) loads were generally higher in stand throughfall than in bulk deposition (Tables 4 and 5). The increase in these components was much stronger in the spruce than in the pine stands; the input of these components from the atmosphere in the spruce and pine stands located relatively close to each other (plots 5/6, 10/11, 12/13 and 16/17) were similar.

Conclusions

Sulphur and nitrogen deposition in the open area were clearly lower in 1996 and 1997 on the Level II sample plot network than the long-term values in the 1970s and 1980s. Thus, the reduction in S emissions is reflected in deposition, and has strongly decreased the potential stress to the forest ecosystems. The reasons for the low nitrogen deposition may be partly meteorological, because the reduction in N emissions from anthropogenic sources has not been as strong as that for sulphur. Although the sulphur and nitrogen depositions were relatively low in 1996–97 compared to the situation earlier, the deposition loads reaching the forest floor within the stand, as well as in the open area, were higher in southern Finland and decreased on moving to the north.

The loads of base cations and DOC were higher in stand throughfall than in the open area and the increase in the loads of these components was higher in the spruce than in the pine stands.

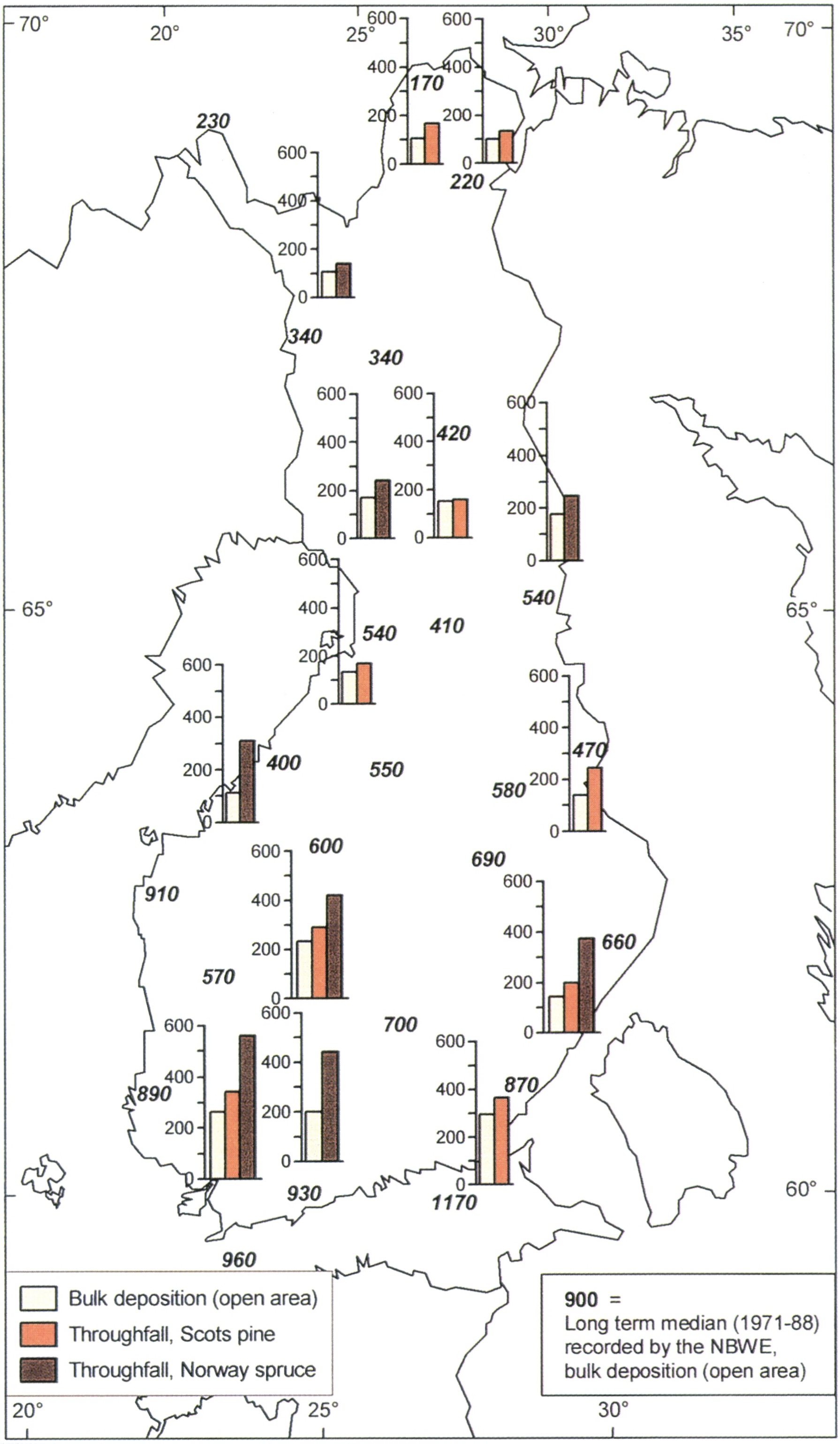

Figure 19. SO_4-S deposition (mg/m²/a) in 1997. Long-term median values (open area) are recorded by National Board of Waters and the Environment (NBWE).

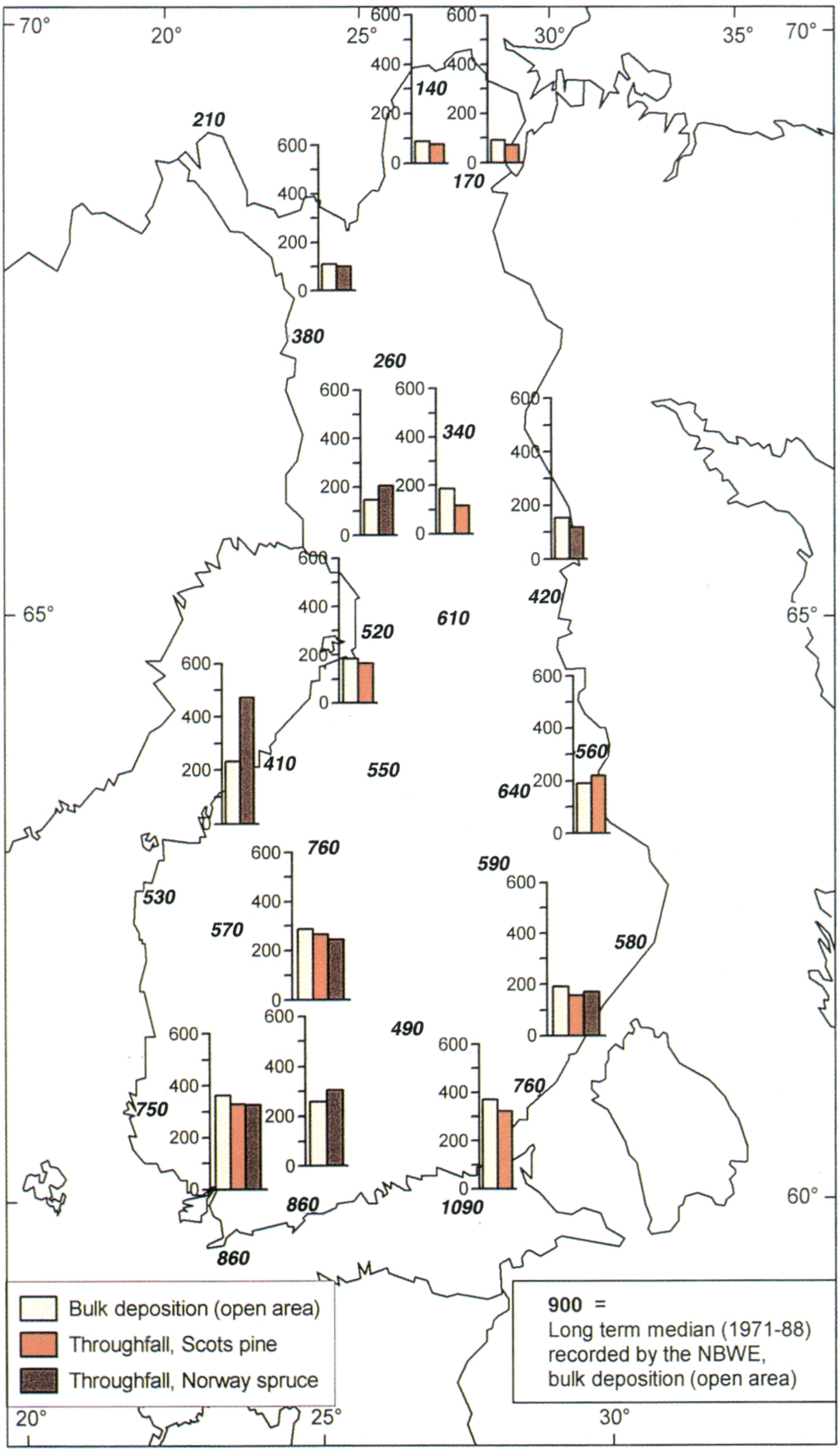

Figure 20. N-total deposition (mg/m²/a) in 1997. Long-term median values (open area) are recorded by National Board of Waters and the Environment (NBWE).

5.2.2 Optional monitoring

Meteorological measurements

Päivi Merilä

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Introduction

During 1997 meteorological measurements were carried out throughout the year on 7 of the Level II monitoring plots: Pallasjärvi (plot No. 3), Kivalo (No. 5), Juupajoki (No. 11), Tammela (No. 12), Punkaharju (No. 17), Uusikaarlepyy (No. 23) and Närpiö (No. 24) (Fig. 7, p. 51). In addition, three new weather stations were established in autumn 1997 and data from those stations are also being submitted: Ylikiiminki (plot No. 9), Miehikkälä (No. 18) and Vilppula (No. 25) (Fig. 7, p. 51).

The following meteorological variables have been monitored within or above the tree stand:

Card 1 of the datalogger:
1. Air temperature above the tree canopy
2. Air temperature within the crown canopy
3. Relative humidity within the crown canopy
4. Wind speed above the tree canopy
5. Wind direction above the tree canopy
6. Photosynthetically active radiation (PAR) above the tree canopy
7. Solar radiation above the tree canopy *new*
8. Precipitation under the canopy

Card 2 of the datalogger:
8. Soil temperature
9. Soil frost
10. Soil moisture *new*

The meteorological data submitted consist of observations of air temperature, relative humidity, wind speed, wind direction and soil temperature on all the ten, above-mentioned Level II plots with some exceptions including lacking measurements of soil temperature in Kivalo (No. 5) in 1997 and those of soil temperature and wind monitoring in Juupajoki (No. 11) before the end of September 1997. As new observations, measurements of soil moisture and total solar radiation were started in the three stations established in 1997. The older stations will be supplemented with these sensors in 1998.

Daily sums of precipitation have not been monitored. However, monthly sums of precipitation and throughfall are included in the datafile with deposition measurements.

Technical remarks

There were several technical problems which resulted in some gaps in the data set. The most severe problems were associated with power supply in Tammela. In addition, in this same station insufficient damp proofing of the wind sensor caused problems in wind monitoring, and because of electric interference caused by wind sensor, air temperature and humidity observations saved in the same data-logger card were also affected. Similar problems with wind monitor sensors occurred in Kivalo (No. 8), Uusikaarlepyy (No. 23) and Närpiö (No. 24). The manufacturer of wind sensor was contacted in order to find an appropriate course of action and sensors were repaired during summer 1998. The most serious problems at the norhernmost plots – Pallasjärvi (No. 3) and Kivalo (No. 5) – were associated with the lap-top computer, which did not function at temperatures of down to -30 °C. Because temperature data from

Pallasjärvi was needed in a pilot study the gaps (13.–29.1. and 6.–27.2.) were supplemented with the data from the nearest weather station of Finnish Meteorological Institute. There were also some other problems in downloading the data from the data-logger to the lap-top computer in these two northernmost stations. It is evident that by learning from experience most of the problems can be avoided or at least be repaired more rapidly. The construction of the on-line system for the transfer of meteorological data from the weather stations to the Parkano Research Station will also make it possible to check the sensors more frequently.

During the last few years a great effort has been made in construction of the weather stations. In the future more attention will be needed in maintenance (calibration and validation) of the sensors.

Weather conditions in 1997

The most remarkable fact in the weather conditions in 1997 was that all the summer months in Finland (June–August; Fig. 21) were warmer than the long-term averages (Finnish Meteorological Institute 1998). The same also applies to the first three months of the year (January–March). On the contrary, April, May and October were exceptionally cool. As a result, growing season of the year was warm but rather short (Table 6). Mean temperatures of the year were about 1 °C warmer than long-term averages (Finnish Meteorological Institute 1998).

The yearly courses of air and soil temperatures in the northest (Pallasjärvi No. 3), the easternmost (Punkaharju No. 17) and the westernmost (Närpiö No. 24) Level II plots are presented in Figs. 22 a–c. Western Finland differs from the eastern inland with more maritime climate: in Närpiö autumn and winter are milder and spring and early summer are cooler than in Punkaharju. The coastal region of the western Finland is characterized by low snowfall (Solantie 1987). Consequently, the soil freeze to considerable depth annually and in the beginning of the growing season the soil temperature remains lower in the western coast (Uusikaarlepyy and Närpiö) than in the eastern Finland (Punkaharju) in spite of the fact that winter index is higher in the eastern Finland (Fig. 23, Table 6).

Table 6. Winter index, late frost, growing season and its length, average temperature sum above 5 °C (1961–90) (Ojansuu & Henttonen 1983) and temperature sums of 1997 in some Level II plots.

Plot No.	Name	Winter index (d.d.)		Late frost		Growing season		Summer index (°Cd.)	
		1.10.–1.4.	total	max 15 d before g. s.	during g. s.	period	d	1961–90	1997
3	Pallasjärvi	1252	1401	-3.1 (20.5.)	-0.2 (4.6.)	26.5. –18.9.	116	684	914
5	Kivalo	–	–	-8.2 (26.4.)	-2.1 (20.5.)	7.5.–18.9.	135	826	966
11	Juupajoki	650	672	-5.5 (21.4.)	-1.5 (6.5.)	6.5.–2.10.	150	1140	1396
17	Punkaharju	793	821	-4.9 (21.4.)	-0.6 (20.5.)	6.5.–2.10.	150	1289	1425
23	Uusikaarlepyy	567	605	-4.5 (26.4.)	-3.1 (6.5.)	6.5.–10.10.	158	1131	1294
24	Närpiö	554	579	-7.8 (25.4.)	-2.5 (24.5.)	6.5.–3.10.	151	1187	1320

The key parameters presented in Table 1 are:

Winter index equals the sum of daily mean temperatures below 0 °C in the period from 1 October to 1 April (degree days below 0 °C). The sum was calculated also for the whole period having daily mean temperatures below 0 °C.

Late frost: This index is defined as the lowest minimum temperature (below 0 °C) in a period starting 15 days before the beginning of the growing season and ending at June 30. In addition, the lowest minimum temperature of the period from the beginning of the growing season till the end of June is presented.

Summer index is calculated as an effective temperature sum, which equals the sum of differences between daily mean temperatures during the growing season and a threshold of 5 °C.

Growing season is the period during which summer index accumulates.

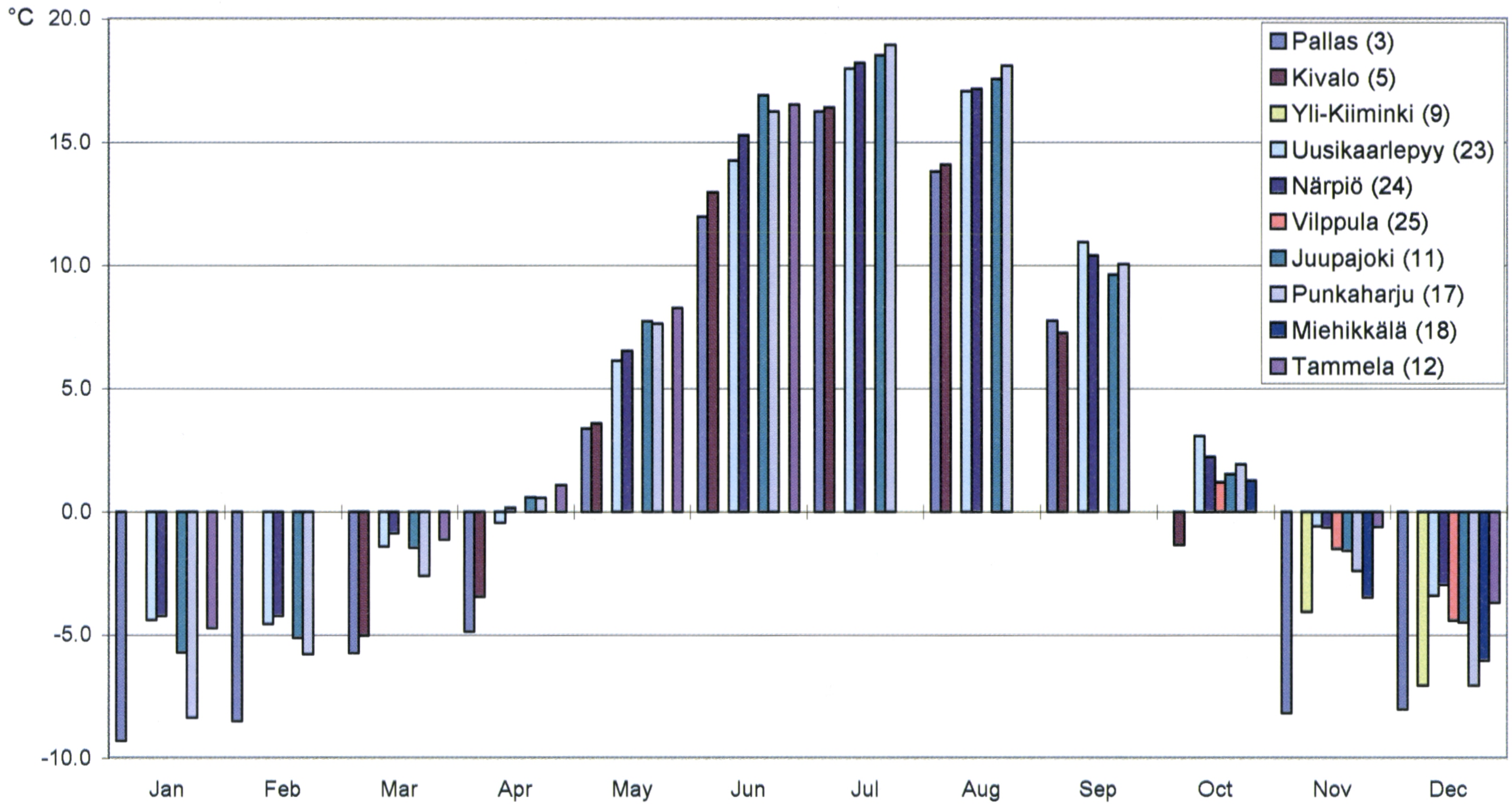

Figure 21. Mean monthly temperatures on Level II plots (from north to south) with meteorological measurements in 1997.

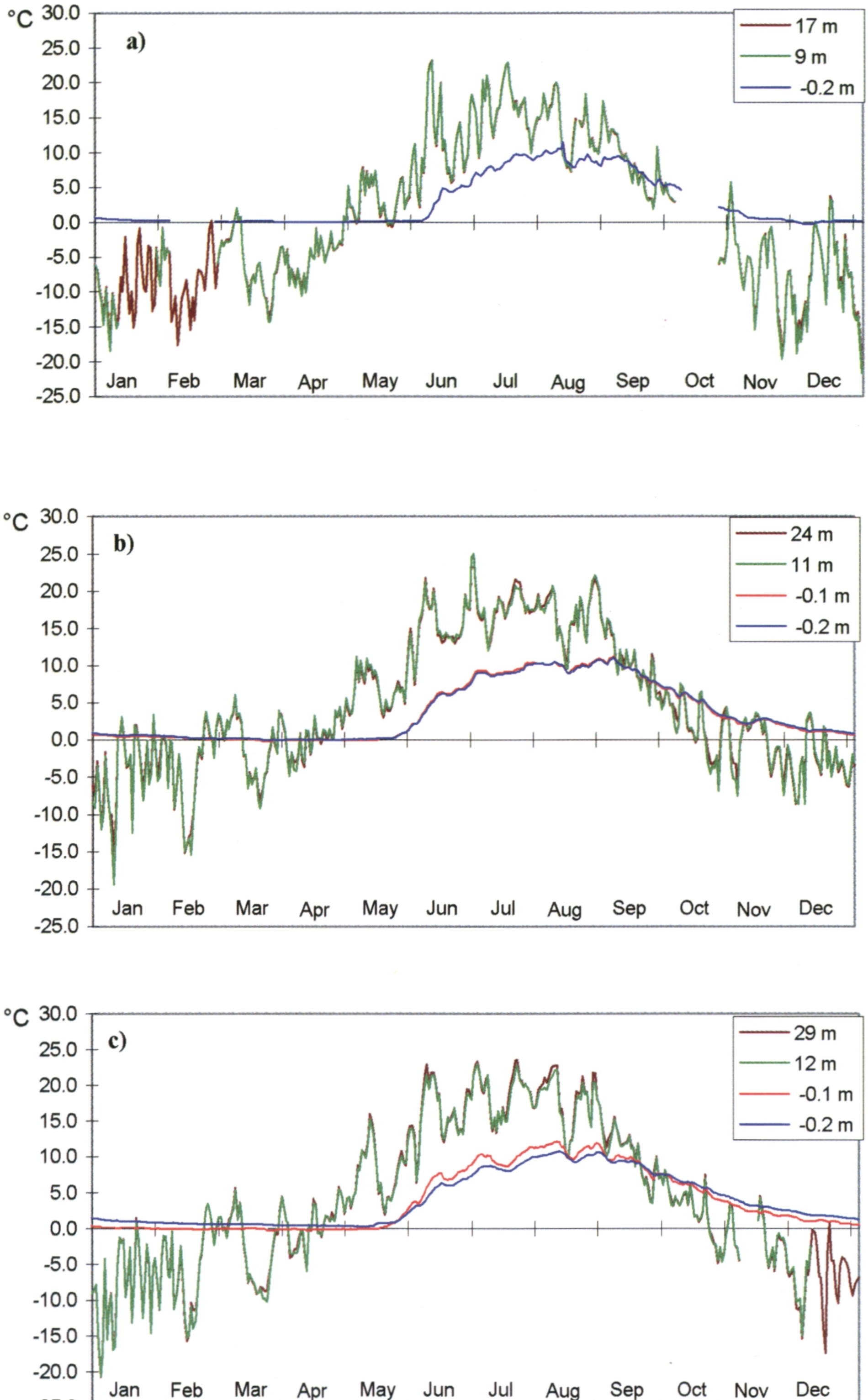

Figure 22 a-c. Yearly courses of air and soil temperatures in a) Pallasjärvi, b) Närpiö and c) Punkaharju in 1997.

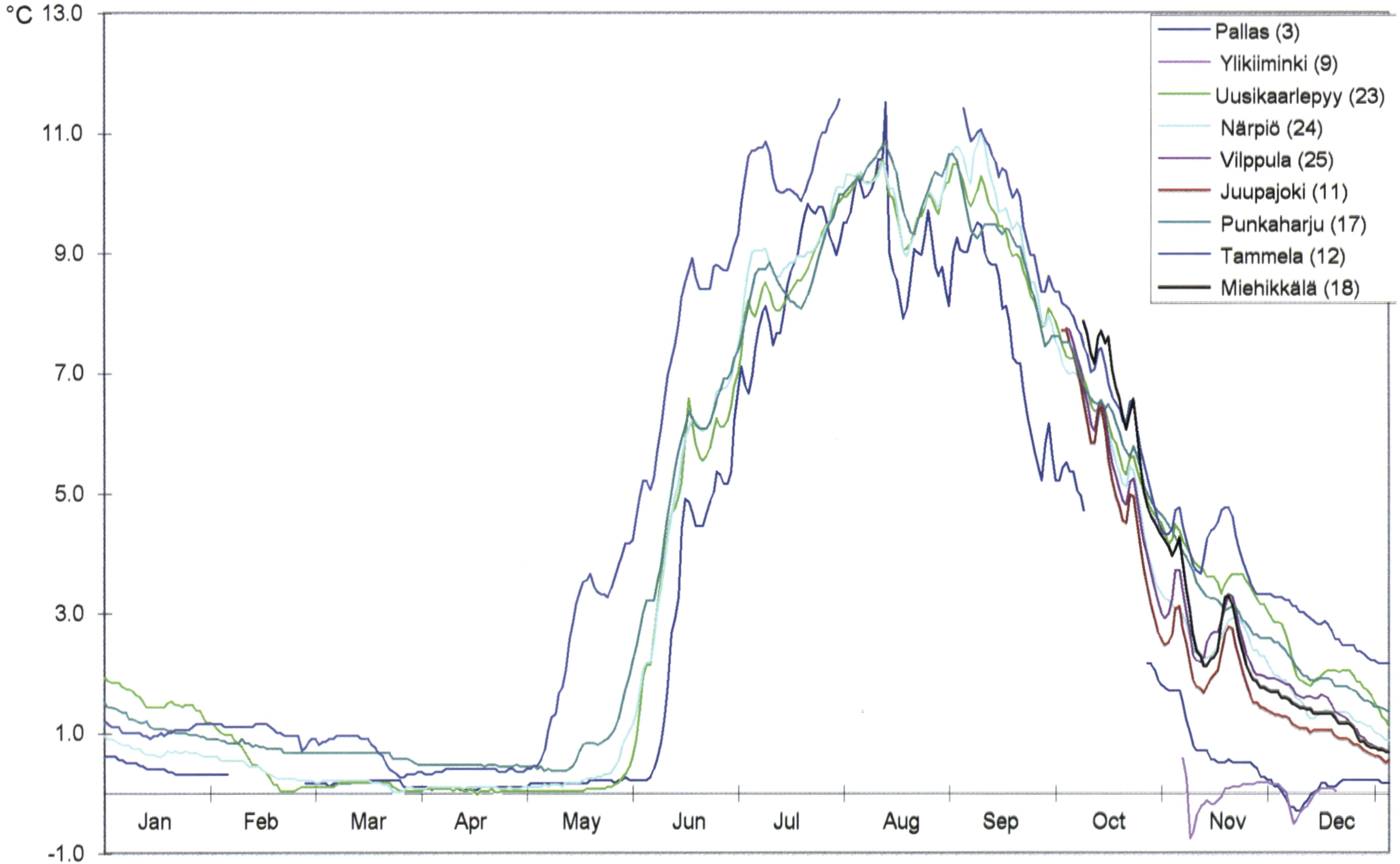

Figure 23. Yearly course of soil temperature (-20 cm) in Level II plots with meteorological measurements in 1997.

References

Bartels, U. 1996. ICP-Forests. 2nd Needle/leaf Interlaboratory Test 1997/98. 2nd report. Evaluation based on robust statistics. North Rhine-Westphalia State Environment Agency (LUA), D-45133 Essen. 74 p.

Bartels, U. 1998. ICP-Forests. 3rd Needle/leaf Interlaboratory Test 1997/98. Results. North Rhine-Westphalia State Environment Agency (LUA), D-45133 Essen. 81 p.

Finnish meteorological institute. 1998. Climate report No. 12/97. ISSN: 1239–0291. (In Finnish).

Hyvärinen, A. 1990. Deposition on forest soils – effect of tree canopy on throughfall. In: Kauppi, P., Anttila, P. & Kenttämies, K. (Eds). Acidification in Finland. Springer-Verlag Berlin Heidelberg. pp. 199–213.

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

Kaunisto, S. 1992. Effects of potassium fertilization on the growth and nutrition of Scots pine. Lyhennelmä: Kalilannoituksen vaikutus männyn kasvuun ja ravinnetilaan. Suo 43.2: 45–62.

Kaunisto, S. & Paavilainen, E. 1988. Nutrient stores in old drainage areas and growth of stands. Seloste: Turpeen ravinnevarat vanhoilla ojitusalueilla ja puuston kasvu. Communicationes Instituti Forestalis Fenniae 145: 1–39.

Kaunisto, S. & Moilanen, M. 1998. Kasvualustan, puuston ja harvennuspoistuman sisältämät ravinnemäärät neljällä vanhalla ojitusalueella. Metsätieteen aikakauskirja – Folia Forestalia 3/1998: 393–410. (In Finnish).

Kolari, K. (Ed.). 1983. Growth disturbances of forest trees. Metsäpuiden kasvuhäiriöt. Communicationes Instituti Forestalia Fennica 116: 1–208.

Kubin, E., Lippo, H. & Poikolainen, J. 1998. Raskasmetallikuormitus. In: Mälkönen, E. (Ed.). Ympäristömuutos ja metsien kunto. Metsien terveydentilan tutkimusohjelman loppuraportti. Finnish Forest Research Institute. Research Papers 691: 55–61. (In Finnish).

Kukkola, M. & Saramäki, J. 1983. Growth response in repeatedly fertilized pine and spruce stands on mineral soil. Seloste: Toistuvalla lannoituksella saatava kasvunlisäys kivennäismaiden männiköissä ja kuusikoissa. Communicationes Instituti Forestalis Fenniae 114: 1–55.

Laiho, R. & Laine, J. 1994. Nitrogen and Phosphorus Stores in Peatlands Drained for Forestry in Finland. Scandinavian Journal of Forest Research 9: 251–260.

Lumme, I., Arkhipov, V., Fedorets, N. & Mälkönen, E. (Eds.) 1994. Männiköiden kunto Karjalan kannaksen – Kaakkois-Suomen ja Kostamuksen – Kainuun alueilla. Suomalais-venäläisen tutkimushankkeen loppuraportti. Finnish Forest Research Institute. Research Papers 665. 75 p. (In Finnish).

Merilä, P., Raitio, H. & Wahlheim, M. 1996. Kuusikoiden ravinnetila. Granskogarnas näringstillstånd. In: Raitio, H. (Ed.). Kuusikoiden kunto merenkurkun alueella. Granskogarnas hälsotillstånd i Kvarkenregionen. Merenkurkun Neuvosto. Gummerus Kirjapaino Oy, Jyväskylä. 145 p. (In Finnish).

Ojansuu, R. & Henttonen, H. 1983. Kuukauden keskilämpötilan, lämpösumman ja sademäärän paikallisten arvojen johtaminen Ilmatieteen laitoksen mittaustiedoista. Summary: Estimation of local values of monthly mean temperature, effective temperature sum and precipitation sum from the measurements made by the Finnish Meteorological Office. Silva Fennica 17(2): 142–160. (In Finnish).

Raitio, H. 1992. The foliar chemical composition of Scots pines in Finnish Lapland and on the Kola Peninsula. Arctic Centre Publication 4: 226–231.

Raitio, H. 1994. Kangasmetsien ravinnetila neulasanalyysien valossa. In: Mälkönen, E & Sivula, H. (Eds.). Suomen metsien kunto. Metsien terveydentilan tutkimusohjelman väliraportti. Finnish Forest Research Institute. Research Papers 527: 25–34. (In Finnish).

Raitio, H. 1995. Neulasten alkuainekoostumus. In: Tikkanen, E. (Ed.). 1995. Kuolan saastepäästöt Lapin metsien rasitteena. Gummerus Kirjapaino Oy, Jyväskylä. p. 133–134. (In Finnish).

Raitio, H. 1998. Neulasanalyysi puiden ravinnetilan kuvaajana. In: Mälkönen, E. (Ed.). 1998. Ympäristönmuutos ja metsien kunto. Metsien terveydentilan tutkimusohjelman loppuraportti. Finnish Forest Research Institute. Research Papers 691: 86–89. (In Finnish).

Raitio, H., Derome, J., Lindgren, M. & Nöjd, P. 1996. European programme for the intensive monitoring of forest ecosystems. National report 1995, Finland. The Finnish Forest Research Institute, Parkano Research Station. 19 p.

Solantie, R. 1987. Precipitation and snow cover. In Alalammi, P. (ed.) Climate. National Board of Survey, Geographical Society of Finland. Helsinki, Atlas of Finland, Folio 131: 18–22.

Stefan, K., Fürst, A., Hacker, R. & Bartels, U. 1997. Forest foliar condition in Europe. Results of large–scale foliar chemistry surveys. UN/ECE and EC, Brussels, Geneva, Vienna. 206 p.

Tamm, C. O. 1991. Nitrogen in terrestrial ecosystems – Questions of productivity, vegetational changes, and ecosystem stability. Ecological Studies 81: 1–115.

5.3 Integrated studies

5.3.1 Preliminary evaluation of the effects of acidifying nitrogen and sulphur deposition on soil condition on the monitoring plots

John Derome[1], Antti-Jussi Lindroos[2] and Kaarina Niska[1]

[1)] Finnish Forest Research Institute
Rovaniemi Research Station
P.O. Box 16, FIN-96301 Rovaniemi, Finland

[2)] Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

The atmospheric pollutants carried into the forest ecosystem in the form of both wet and dry deposition can have either direct effects on the tree stand via the foliage, or indirect effects via changes in the nutrient balance of the soil. Acidic deposition, resulting from the emissions of sulphur and nitrogen compounds, is a potential stress factor for the forest ecosystem by accelerating soil acidification. The acidity of podsolic soils is a natural phenomenon in the cool and moist climate prevailing in the coniferous forests of the boreal zone, and accelerated acidification caused by the deposition of strong mineral acids may lead to a decrease in the soil pH, the leaching of base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) from the cation exchange sites on the soil particles, and aluminium mobilisation (Abrahamsen 1983, Matzner & Murach 1995).

The capacity of podsolic forest soils to neutralise and buffer the inputs of hydrogen ions derived from deposition is dependent on a number of processes, e.g. cation exchange, silicate mineral weathering and Fe, Al and Mn buffering systems (Schwertmann et al. 1987). As a result of the buffering and neutralisation reactions, the chemical composition of the water changes as it passes down through the soil profile. For instance, the pH of soil percolation water increases with increasing depth in forest soil (e.g. Lindroos et al. 1995, Helmisaari & Mälkönen 1989, Soveri & Ahlberg 1990). The chemical composition of the soil solution is therefore a key indicator in estimating soil acidification and the buffering capacity of the forest soil.

The base saturation (BS) of the soil is widely used for estimating soil acidity and buffering capacity, a decrease in BS being considered as an indicator of acidification and decreased buffering capacity (de Vries et al. 1989). The C/N ratio of the organic layer can also be used to assess soil fertility, as well as the risk of nitrogen saturation and subsequent nitrate leaching in coniferous stands (Gundersen et al. 1998).

The aim of this study was to determine whether there is any relationship between the deposition of acidifying N and S compounds and soil parameters such as pH, total N and S concentrations, base saturation and the C/N ratio on the 27 plots in the ICP Forests intensive (level II) monitoring network in Finland. The effects of the deposition of acidifying N and S compounds on percolation water quality on 6 of the monitoring plots are also presented.

Material and methods

Site type distribution

The site-type distribution (Fig. 1) of the 27 monitoring plots on mineral soil corresponds rather well to the site-type distribution of forest land in the whole country (Tamminen 1998). Herb-rich, moist and dryish sites are the most important sites for growing spruce and pine in commercial forestry. The spruce stands in the monitoring network are restricted to till soils on the more fertile site types, and pine primarily to the dryish site type. Dry and barren sites usually occur on sorted, sandy soils, and are hence considered to be the most susceptible to acidifying deposition (Tamminen & Mälkönen 1986). The most infertile site is located in the NE corner of Lapland close to the Norwegian border.

Location of the monitoring plots

The distribution of pine and spruce monitoring plots throughout the country is rather similar, apart from the predominance of pine plots in the northernmost part of the country which are located to the north of the spruce treeline (Fig. 2). The distribution is also somewhat weighted towards the southern half of the country, i.e. there are more plots in that part of the country where timber production is the highest, and consequently commercial forestry the most important.

Soil and soil water samples

Organic layer samples were taken systematically from 20 points on the plot, bulked, and milled to pass through a 1 mm sieve. pH was determined from a water/soil slurry, total N on a CHN analyser, total S by wet digestion (HNO_3+H_2O_2) followed by analysis by inductively coupled plasma atomic emission spectrometry (ICP/AES), and base saturation by extraction with $BaCl_2$ followed by titration and analysis of Ca, Mg and K by ICP/AES.

Zero-tension lysimeters were inserted at depths of 5, 20 and 40 cm measured from the ground surface. The lysimeters were located systematically on the plots, with 5 replications per depth. The water samples were collected at approximately 1-month intervals at the same

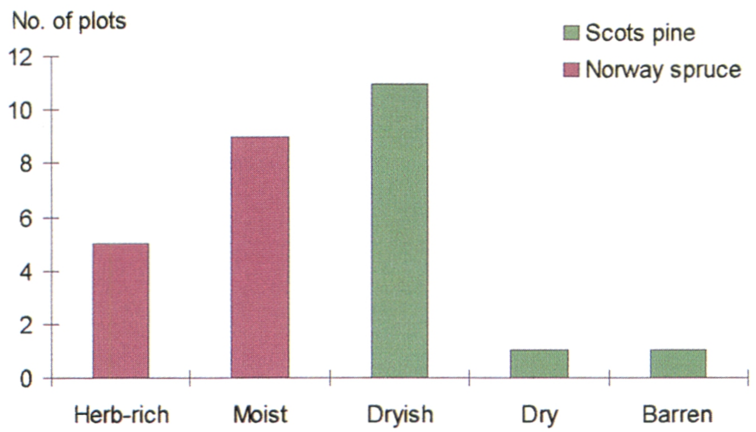

Figure 1. Distribution of the monitoring plots according to the site-type distribution. Sites with Scots pine and Norway spruce are grouped separately. The site type on the left is the most fertile, and on the right the least fertile.

time as deposition samples. The samples were filtered through membrane filters (0.45 µm). The filtrate was conserved with suprapure concentrated HNO_3 for the determination of Ca, Mg, K, Na, Al, Fe, Mn and total S and P by (ICP/AES), as well as DOC on a TOC analyser. NH_4-N, Ca, Mg, Na, K, NO_3-N, Cl, SO_4-S, PO_4-P were determined on unconserved samples by ion chromatography (IC), and total-N by flow injection analysis (FIA).

Results and discussion

pH and base saturation of the organic layer

The pH(H_2O) of the organic layer in the whole material varies from 3.2 to 4.4, with a median of 3.5 (Fig. 3). These values are somewhat lower than the averages for the whole country

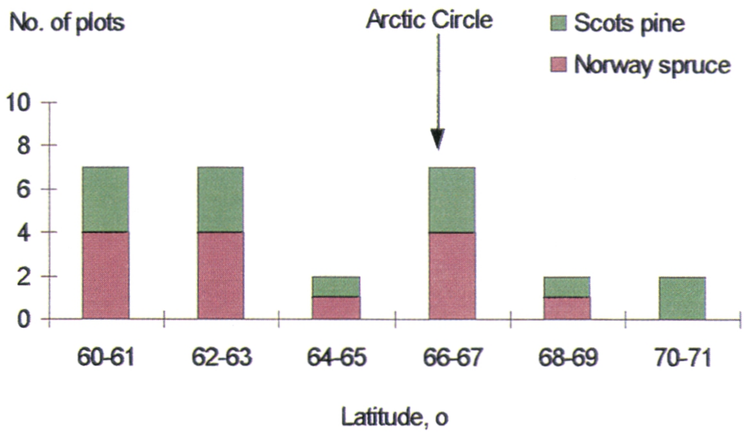

Figure 2. Distribution of the monitoring plots according to latitude.

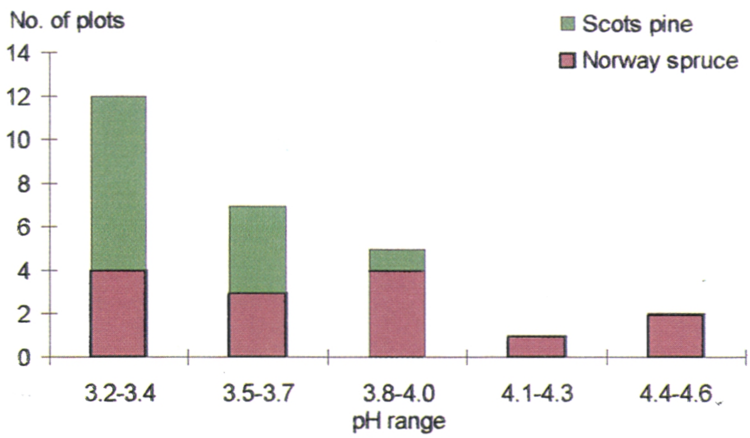

Figure 3. Distribution of the monitoring plots according to the pH(H_2O) of the organic layer.

(Tamminen 1998): 3.4 to 5.5, and median 4.1. Pine is restricted to the sites with a relatively low pH, while spruce shows a rather even distribution over the whole pH range.

Most of the plots have a base saturation in the organic layer of over 50 % (Fig. 4). The average value for the whole material is 59 %, which is somewhat lower than the average of 70 % for the whole country (Tamminen 1998). The pine plots have clearly lower base saturation values than the spruce plots; in general, the lower the site fertility, the lower is the base saturation.

Total sulphur concentrations in the organic layer

The average total sulphur concentration in the organic layer on the monitoring plots is 1.3 g/kg (Fig. 5), which is almost the same as the mean value of 1.4 g/kg for the whole country (Tamminen 1998). The average values for the spruce and pine plots are also very similar, 1.3 and 1.2 g/kg, respectively.

Total nitrogen concentration and C/N ratio of the organic layer

A high proportion of the plots have relatively low total N concentrations in the organic layer (Fig. 6), the mean value for all the plots being 11.1 g/kg. The pine sites are characterised by the lowest total N concentrations (average 9.8 g/kg), while the spruce sites (average 11.8 g/kg) are more evenly distributed over the whole range . The mean value for the whole country is 11.6 g/kg (Tamminen 1998).

The range of C/N ratio values for the organic layer on the 27 plots is very broad, 24.3 to 53.0, and there are no clear trends with respect to tree species (Fig. 7). However, the average for the pine plots (42.4) is much higher than that for the spruce plots (32.6). The average value for all the plots, 37.9, is very similar to the value of 37.2 for the whole country (Tamminen 1998). The C/N ratio is widely used as a measure of nitrogen saturation of the soil; a C/N ratio of below 20–25 indicating nitrogen saturation and an increased risk of soil acidification and nitrate leaching into the groundwater.

Relationship between the properties of the organic layer and the geographical location of the plots

The terrain in Finland is relatively flat, with only small variations in altitude, and there is a strong N–S gradient in the temperature sum. The soil consists of till or sorted material, and

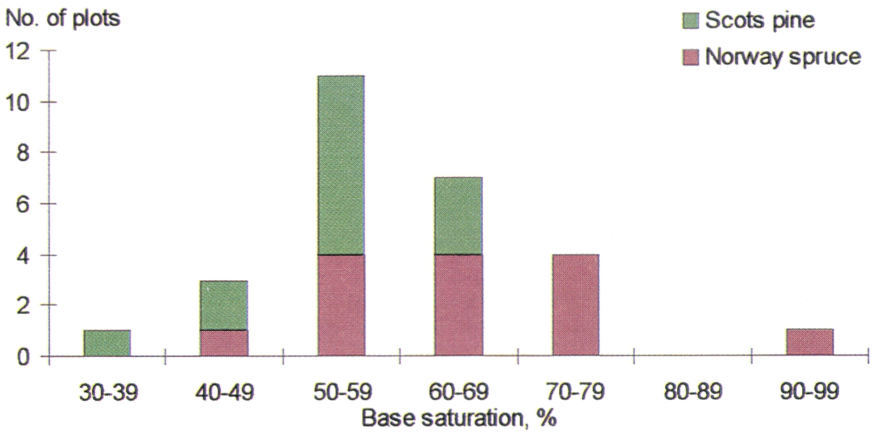

Figure 4. Distribution of the monitoring plots according to the base saturation of the organic layer.

the base cation weathering rates in the soil are relatively low due to the mineral composition of the bedrock. This has resulted in a rather uniform N–S gradient in tree growth and biomass production. Precipitation is greater than transpiration throughout most of the country. There is highly significant correlation between the C/N ratio and the geographical location (latitude) of the plots (Table 1), primarily due to the N–S climatic gradient. The C/N ratio is a widely used indicator of the mineralisation rate of the organic matter in the soil, which is dependent on the microbiological activity and the soil temperature and moisture conditions. The soil moisture content increases and soil temperature decreases on moving to the north.

Relationship between sulphur and nitrogen deposition and the acidity and nitrogen and sulphur status of the organic layer

There was highly significant correlation between the geographical location (latitude) of

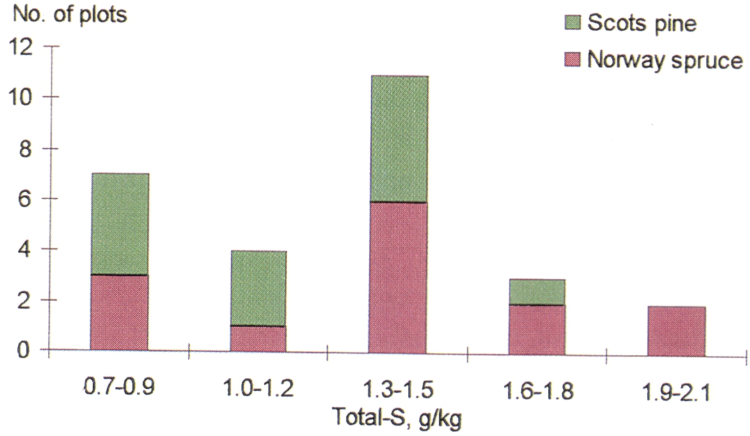

Figure. 5. Distribution of the monitoring plots according to the total sulphur concentration in the organic layer.

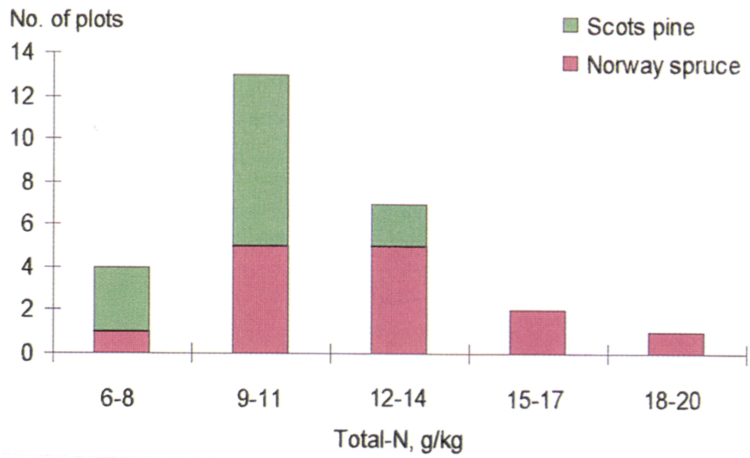

Figure 6. Distribution of the monitoring plots according to the total nitrogen concentration of the organic layer.

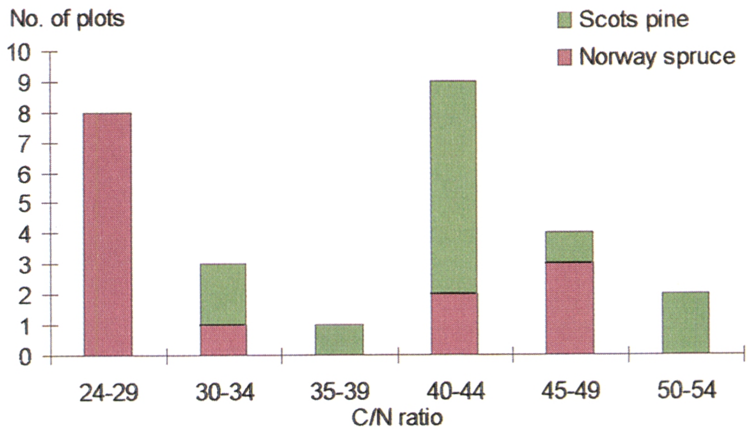

Figure 7. Distribution of the monitoring plots according to the C/N ratio of the organic layer.

the plots and the annual deposition of S and N and mean precipitation pH in 1997 (Table 2). This indicates a clear N–S decreasing gradient in Finland in the annual deposition of nitrogen and sulphur compounds, as has been reported earlier. Total N and S in the organic layer also correlated significantly with annual deposition of N and S. However, it is not possible, on the basis of these results, to separate the possible effects of acidifying nitrogen and sulphur deposition on the acidity, nitrogen and sulphur status of the organic layer of forest soils from the effects of the S–N climatic gradient on the accumulation of N and S in the soil.

The capacity of the soil to withstand acidifying nitrogen and sulphur deposition on six of the monitoring plots

The six plots are three pairs of spruce and pine stands located in south, central and northern Finland (Fig. 8). The spruce stands are growing on relatively fertile sites (moist and herb-rich types), and the pine stands on sites of the less-fertile, dryish type. At all the sites, the input of protons in stand throughfall has been effectively buffered or neutralised by the time the percolation water has reached a depth of 40 cm (Fig. 8). The pH of percolation water at this depth depends on the neutralising and buffering properties of the subsoil. There is considerable variation in the pH increase in percolation water at depths of 5 and 20 cm, because the rate of buffering or neutralisation depends on a number of soil properties, e.g. thickness of the organic layer and E and B horizons, the soil texture, which determines the percolation rate of the water and the degree of interaction between the percolation water and the soil, and the base saturation of the organic layer and uppermost mineral soil layers.

There is a clear increase in sulphate concentrations in percolation water with increasing soil depth (Fig. 9). The main reason for this is that sulphate is a relatively mobile ion in the soil; the sulphate-adsorption capacity of the organic layer and underlying E horizon is relatively low, and most of the sulphate is adsorbed by the Al and Fe sesquioxides precipitated lower down the soil profile in the B horizon (Prietzel et al. 1995). The amount of water percolating down the soil decreases with increasing soil depth as a result of evaporation from the soil surface and evapo-transpiration by the tree stand. This results in an increase in the sulphate concentration with increasing soil depth.

The nitrate concentrations in percolation water were extremely low (Fig. 10). Nitrogen in a plant-available form is the primary factor limiting tree growth on forest soils in Finland, and it is clear that a nitrogen input (e.g. as

Table 1. Correlation between latitude and the pH, base saturation (BS), total nitrogen and sulphur concentrations and C/N ratio of the organic layer on the 27 monitoring plots. n = 27.

	Latitude	pH	BS	Total-S	Total-N
pH	-0.314*				
BS	-0.378*	0.806***			
Total-S	-0.455**	0.186	0.373*		
Total-N	-0.507**	0.349*	0.458**	0.893***	
C/N	0.716***	-0.506**	-0.552**	-0.713***	-0.841***

Table 2. Correlation between latitude and the annual deposition of sulphur and nitrogen and mean precipitation pH on the 18 monitoring plots in 1997, and the total nitrogen and sulphur concentrations, pH and C/N ratio of the organic layer. Dep = deposition in the open. n = 18.

	Latitude	Dep pH	Soil pH	Dep S	Soil S	Dep N	Soil N
Dep pH	0.866***						
Soil pH	-0.352	-0.206					
Dep S	-0.899***	-0.765***	0.336				
Soil S	-0.631**	-0.515*	0.377	0.640**			
Dep N	-0.899***	-0.714***	0.364	0.986***	0.592**		
Soil N	-0.578**	-0.468*	0.332	0.586**	0.928***	0.554*	
Soil C/N	0.808***	0.717***	-0.557*	-0.720***	-0.792***	-0.716***	-0.790***

nitrate) will be rapidly taken up by the roots of the trees and ground vegetation. These results also support the conclusion that the nitrogen status in the soil on these plots has not reached so-called nitrogen saturation. Furthermore, the C/N ratio in the organic layer on all these plots is well above 25, and there is not likely to be a risk of nitrification and nitrate leaching into the ground water.

Conclusions

The strong S–N climatic gradient in Finland appears to be the main reason for the S–N gradients in the total N and S concentrations and C/N ratio in the organic layer. There is also a strong decreasing S–N gradient in the deposition of nitrogen and sulphur compounds, and an increasing gradient in the average pH of bulk precipitation. It is very difficult to separate, with any degree of certainty, the effects of deposition on the soil chemical status from those attributable to climatic conditions. However, the strong correlations between the geographical location of the plots and the deposition and soil parameters indicate that both the climatic conditions and deposition should be taken into account when estimating the chemical properties of forest soil.

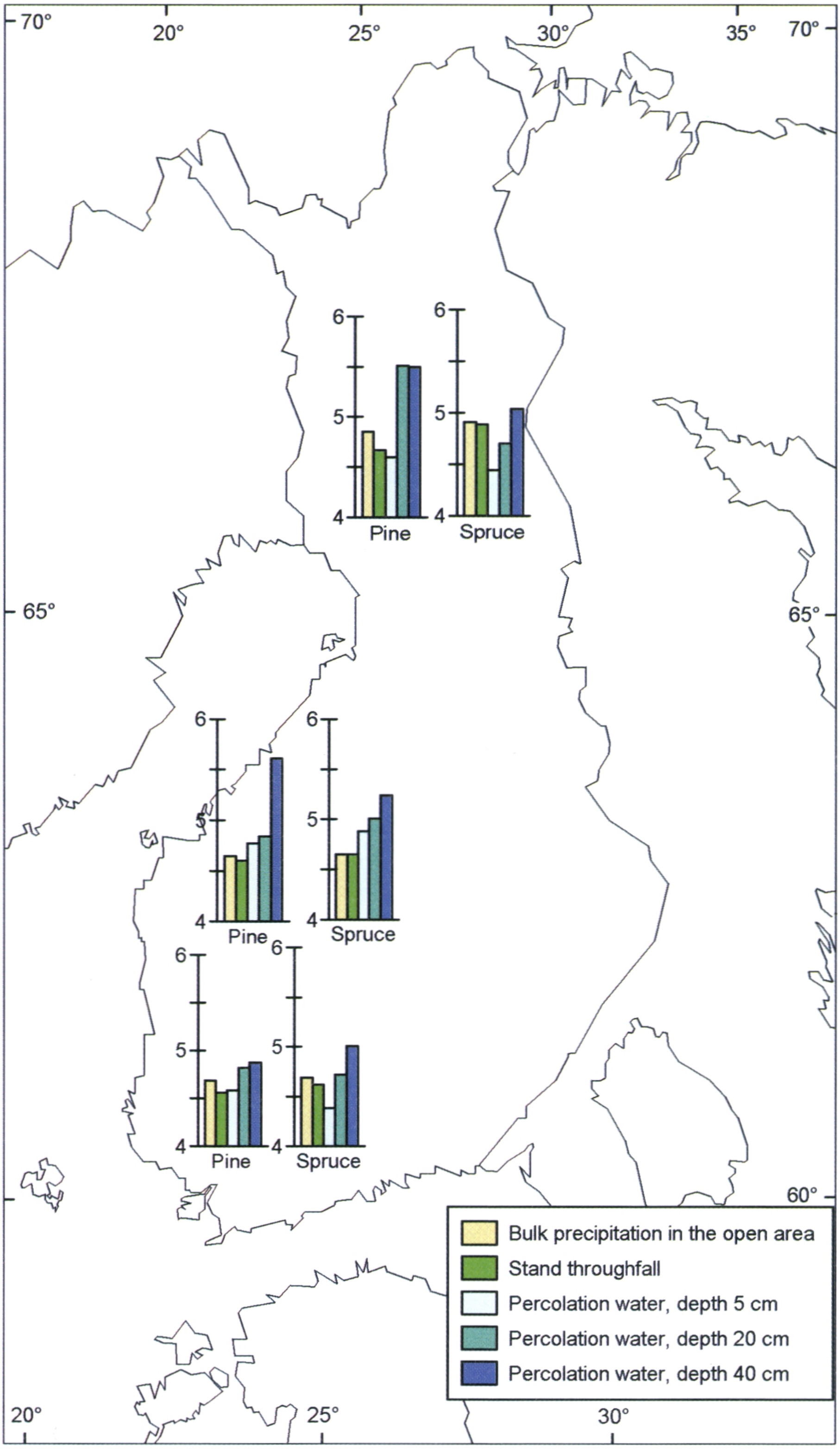

Figure 8. Mean pH of bulk precipitation in the open area, stand throughfall and percolation water (depths 5, 20 and 40 cm) on three pairs of monitoring plots in 1997.

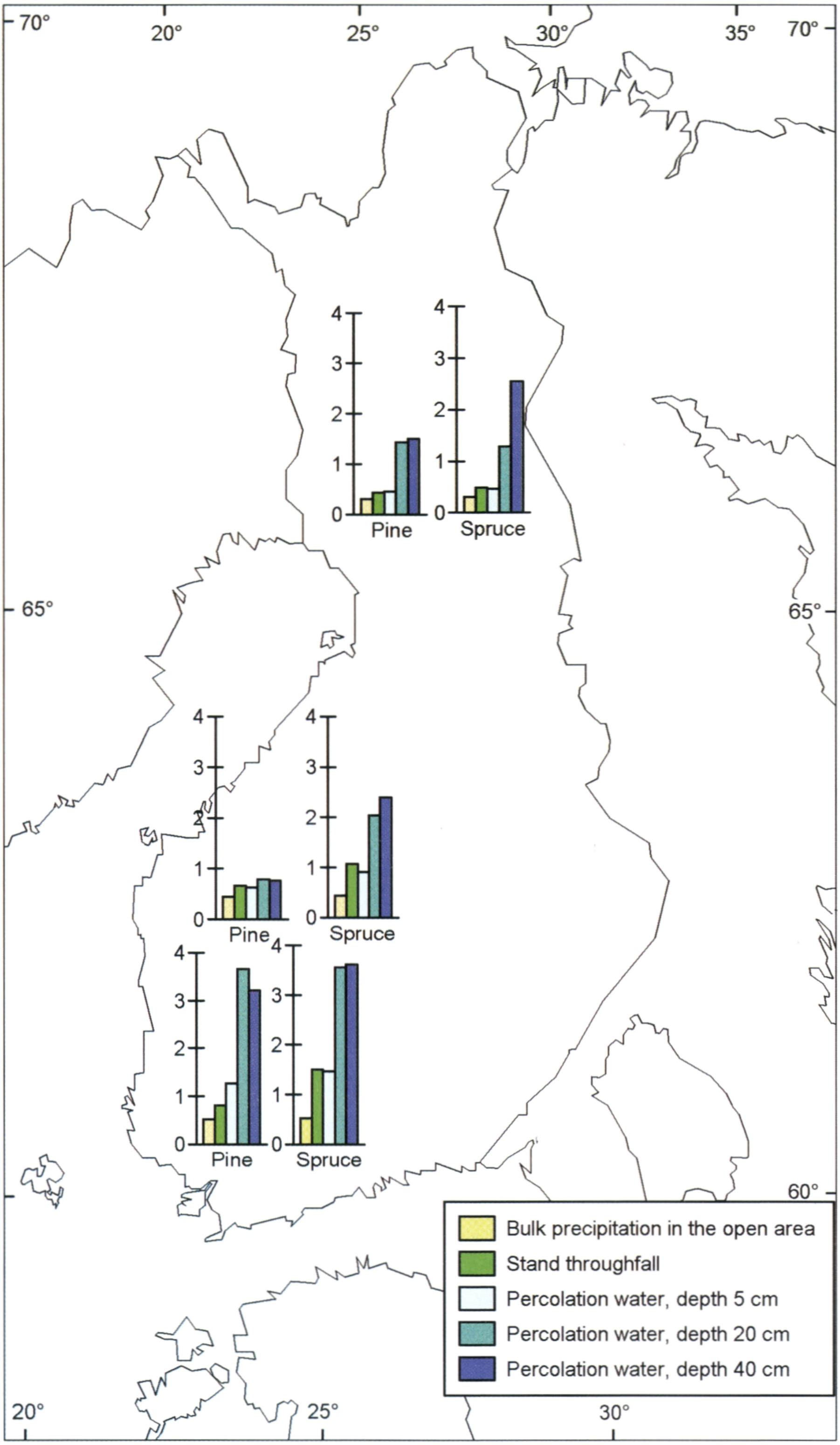

Figure 9. Mean SO4-S concentration (mg/l) in bulk precipitation in the open area, stand throughfall and percolation water (depths 5, 20 and 40 cm) on three pairs of monitoring plots in 1997.

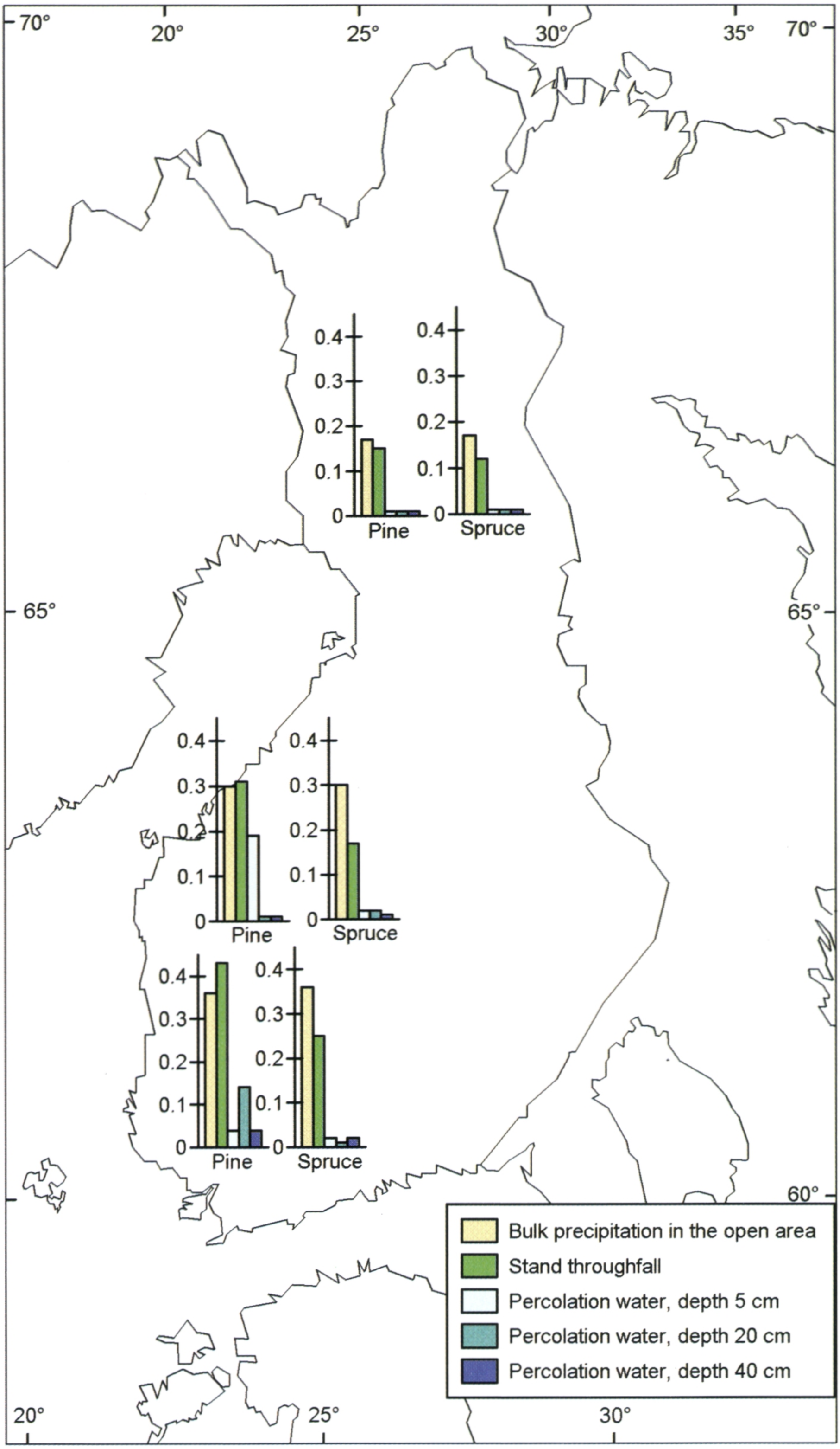

Figure 10. Mean NO3-N concentration (mg/l) in bulk precipitation in the open area, stand throughfall and percolation water (depths 5, 20 and 40 cm) on three pairs of monitoring plots in 1997.

According to the change in soil water acidity as it passes down through the soil profile, the buffering capacity of the soil on six of the ICP Forests (level II) monitoring plots is relatively high. The sulphur concentrations in bulk deposition, stand throughfall and percolation water were the highest on the plots located in southern Finland. The nitrate concentrations in percolation water on all the plots were extremely low as a result of efficient nitrogen uptake, and the risk of nitrate leaching into the groundwater appears to be negligible.

References

Abrahamsen, G. 1983. Sulphur pollution: Ca, Mg and Al in soil and soil water and possible effects on trees. In: Ulrich, B. & Pankrath, J. (Eds.). Effect of accumulation of air pollutants in forest ecosystems. Reihel Publishing Company. pp. 207–218.

Gundersen, P., Callesen, I. & de Vries, W. 1998. Nitrate leaching in forest ecosystems is related to forest floor C/N ratios. Environmental Pollution 102, S1: 403–407.

Helmisaari, H-S. & Mälkönen, E. 1989. Acidity and nutrient content of throughfall and soil leachate in three *Pinus sylvestris* stands. Scandinavian Journal of Forest Research 4: 13–28.

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

Lindroos, A.-J., Derome, J. & Niska, K. 1995. The relationship between dissolved organic matter and percolation water chemistry in Northern Finland. Water, Air and Soil Pollution 79: 191–200.

Matzner, E. & Murach, D. 1995. Soil changes induced by air pollutant deposition and their implication for forests in Central Europe. Water, Air and Soil Pollution 85: 63–76.

Schwertman, U., Susser, P. & Nätscher, L. 1987. Protonpuffersubstanzen in Böden. Zeitschrift für Pflanzenernährung und Bodenkunde 150: 174–178.

Prietzel, J., Mayer, B., Krouse, H.R., Rehfuess, K.E. & Fritz, P. 1995. Transformation of simulated wet sulfate deposition in forest soils assessed by a core experiment using stable sulfur isotopes. Water, Air and Soil Pollution, 79: 243–260.

Soveri, J. & Ahlberg, T. 1990. Effects of air pollutants on chemical characteristics of soil water and groundwater. In: Kauppi, P., Anttila, P. & Kenttämies, K. (Eds.). Acidification in Finland. Springer-Verlag, Berlin. pp. 865–881.

Tamminen, P. & Mälkönen, E., 1986. Kangasmaiden herkkyys happamoitumiselle (Sensitivity of forested mineral soils to acidification). Finnish Forest Research Institute. Research Papers 210: 1–25. (In Finnish).

Tamminen, P. 1998. Ympäristömuutos ja metsien kunto. Metsien terveydentilan tutkimusohjelman loppuraportti. In: Mälkönen, E. (Ed.). Ympäristömuutos ja metsien kunto. Metsien terveydentilan tutkimusohjelman loppuraportti. Finnish Forest Research Institute. Research Papers 691: 64–82. (In Finnish).

de Vries, W., Posch, M. & Kämäri, J. 1989. Simulation of the long-term soil response to acid deposition in various buffer ranges. Water, Air and Soil Pollution 48: 349–390.

5.3.2 Water and element fluxes at the Hietajärvi monitoring site; an application of the ACIDIC model

Timo Kareinen[1], Hannu Ilvesniemi[1], Ari Nissinen[1], Michael Starr[2], Liisa Ukonmaanaho[2], Antti-Jussi Lindroos[2] and Risto Sievänen[2]

[1)] University of Helsinki
P.O. Box 24
FIN-00014 Helsingin yliopisto, Finland

[2)] Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

The European Programme for the Intensive Monitoring of Forest Ecosystems (Level II) is collecting data on the pools and fluxes in forest ecosystems throughout Europe (Haussmann 1995). The intention is to identify and characterise cause-effect relationships between the changing environment, primarily atmospheric deposition, and the biological response of the forest ecosystems. Although the spatial coverage of the measurements is pan-European, the time series is not yet long enough to determine the response of the ecosystem to changing environmental conditions and to make response predictions.

Dynamic process-oriented models provide a comprehensive approach for integrating data from ecosystem studies. Some of the more widely used dynamic soil models are MAGIC (Cosby et al. 1985), SAFE (Warfvinge et al. 1993) and SMART (De Vries et al. 1989, Posch et al. 1993). These models have been used to simulate the past and future time development of soils at a number of UN/ECE ICP Integrated Monitoring (IM) sites (Forsius et al. 1996), particularly in the context of Critical Loads (Posch et al. 1993). However, these models are based on a rather simple scheme of the soil, and use a lumped set of soil parameters for the whole soil profile. Models that use a more explicit description of the soil profile and processes offer a more realistic alternative. In the ACIDIC model, developed at the Department of Forest Ecology, University of Helsinki, all the soil processes are simulated separately for a defined number of soil horizons.

In this report we present the preliminary results of an application of ACIDIC to the Hietajärvi monitoring plot (No. 20). This site was established in 1988 as an ICP Integrated Monitoring site, and there are thus a considerable amount of data already available (Bergström et al. 1995). The main objective of the study was to determine how well the ACIDIC model could be calibrated to an intensive monitoring site.

Overview of ACIDIC

Model structure

The ACIDIC model has been developed as a tool for modelling water and ion fluxes in soils. It is a process-oriented model, simulating the hydrological and chemical fluxes through the vegetation-soil system. The model is two dimensional, allowing both the fluxes between different layers within a soil profile, and those between adjacent soil profiles along a slope, to be modelled. The water and ion fluxes and the processes included in the model are presented in Fig. 1.

Parameterisation and simulation of the processes are carried out separately for each soil layer. The soil pore system is divided into two size classes, macro- and micro-pores, both classes having mobile water, but with different flow velocities. The model description includes water flows between the two pore classes in each soil layer. Ions move in the profile only with flowing water, except in the case of nutrient uptake, which is described as an independent process. The chemical processes are formulated assuming that equilibrium conditions prevail all the time. Weathering is an exception, being described as a steady-state process driven by a rate parameter. Water flows and chemical processes are simulated simultaneously, and the calculations are carried out at intervals of between one minute to one hour, depending on the water fluxes.

The model has been described in detail and its behaviour tested against data from intensively monitored sites by Kareinen et al. (1998) and Ilvesniemi et al. (1999).

Model application to the Hietajärvi monitoring plot

The Hietajärvi site (63˘ 10' N, 30˘ 43' E; plot no. 20) is located in the community of Lieksa, in eastern Finland. Measured soil chemistry and hydrology properties were used to parameterise the model, and the model was run using measured deposition chemistry as the driving force.

The stand on the plot is dominated by Scots pine (*Pinus sylvestris*) (90 %) with some birches (*Betula pendula*). The stem volume in 1988 was 224 m^3 ha^{-1} and the mean annual stem volume increment 2 m^3 ha^{-1} a^{-1} (unpublished data). The

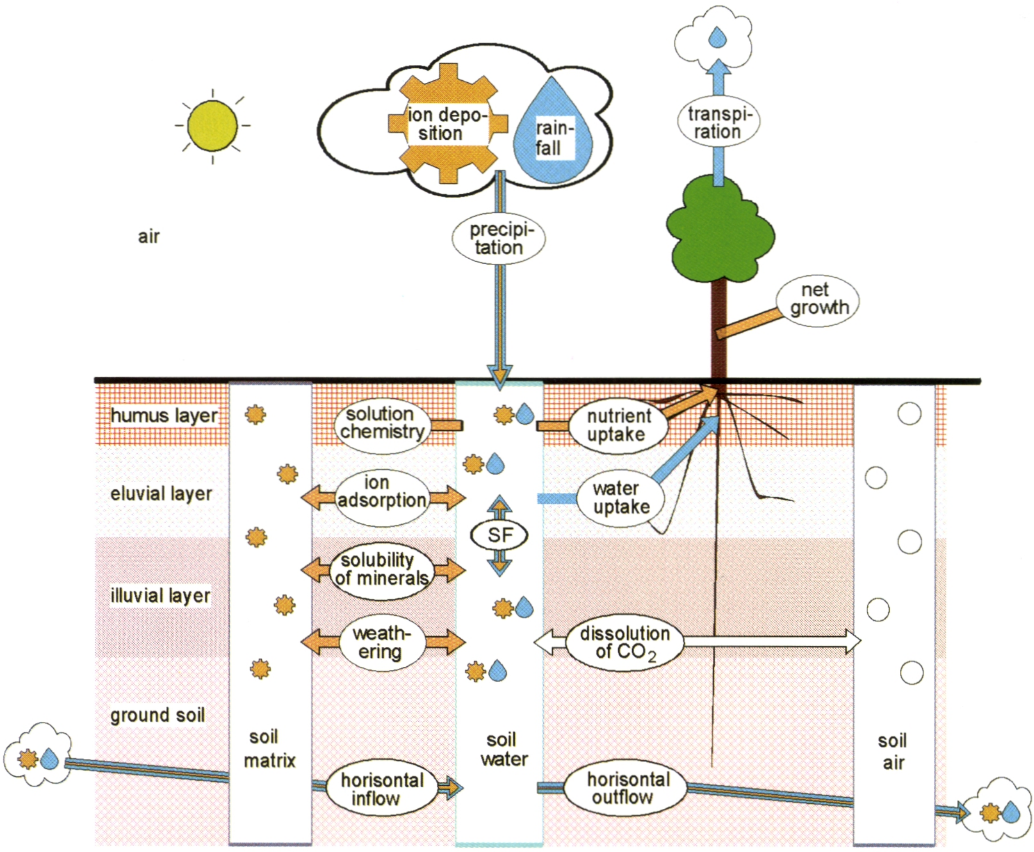

Figure 1. Water and ion fluxes and the processes included in ACIDIC. Horizontal inflow and outflow also include the water flow in the soil surface (SF = water flow in the soil profile).

nutrient demand for stem growth was based on published concentrations of stemwood nutrient concentrations (Mälkönen 1974, Helmisaari 1990).

The soil at the site is podzolic, and has developed in a thin (c. 1–1.5 m) glacifluvial sand deposit overlying till (Starr 1995, Starr et al. 1998). The soil exchange chemistry data are from samples taken at plot establishment, and the soil water-retention properties from samples taken in 1996. Empirical relationships between soil texture and the amount of organic carbon and exchangeable aluminium were used to estimate the hydraulic conductivity.

Weekly soil solution samples have been collected at depths of 15 and 35 cm since 1989 using suction-cup lysimeters (60 kPa tension) (Ukonmaanaho & Starr 1995b). Soil water content has been measured continuously from August 1996 using TDR probes installed at the same depths as the lysimeters.

Deposition in an open area and under the canopy (throughfall) have been monitored since plot establishment (Ruoho-Airola 1995, Ukonmaanaho & Starr 1995a). The transformation of monthly values into daily values, as required by ACIDIC, was based on the daily precipitation observations from a nearby weather station of the Finnish Meteorological Institute at Ilomantsi. In the model runs it was assumed that 20 % of the water released at snowmelt leaches down through the soil profile, and that the rest is either evaporated or lost as surface runoff.

In ACIDIC, the cation exchange properties of the soil are described using semi-empirical equations parameterised with the data measured from the site. Sulphate adsorption has not been measured yet, and the model was therefore calibrated to produce average sulphate concentrations based on approaches described by Cosby et al. (1985, 1986) and Karltun (1995). Weathering rate values for the site were taken from Starr et al. (1998).

The modelled soil solution output from ACIDIC was compared to the measured soil solution chemistry data in order to assess how well the measured results were estimated by the model.

Results

Soil water content

Soil water is one of the most important factors controlling plant biomass production. In addition, the soil water content is an important factor in calculating soil water movement and nutrient leaching losses.

The soil water retention characteristics used to parameterise the model were not measured from the same spot as the soil water content measurements were done, and thus they do not precisely represent the properties of the soil at the point of the soil water content measurements. There was also a considerable spatial variation between the TDR measurements at the same soil depth, complicating the comparison of measured and modelled soil water contents.

In early spring and late autumn both the level and the dynamics of the modelled and measured soil water contents are similar. In contrast, during the growing season the simulated water contents in the upper soil horizons are lower than the observed values, but the dynamics are still equal (Fig. 2). In ACIDIC, water uptake from the soil is based on the root distribution within the soil profile. Data on the biomass distribution of the roots at the site are not yet available, and it was therefore assumed to be the same as that for a site in south Finland. However there may be more roots deeper in the soil at the Hietajärvi site than we have assumed, because the observed ground water table is relatively close to the soil surface (c. 1.5 m). We intend to investigate this question in the near future when root biomass distribution data for the site become available.

The role of the snow cover is crucial for the annual water balance and outflow estimates of the site. In the model run, where the amount of evaporation and surface flow was assumed to be 80 % of the water stored in snow, the amount of simulated evapo-transpiration was nearly two thirds the amount of water reaching the soil surface during the study period (Fig. 3). However, if all water in snow was allowed

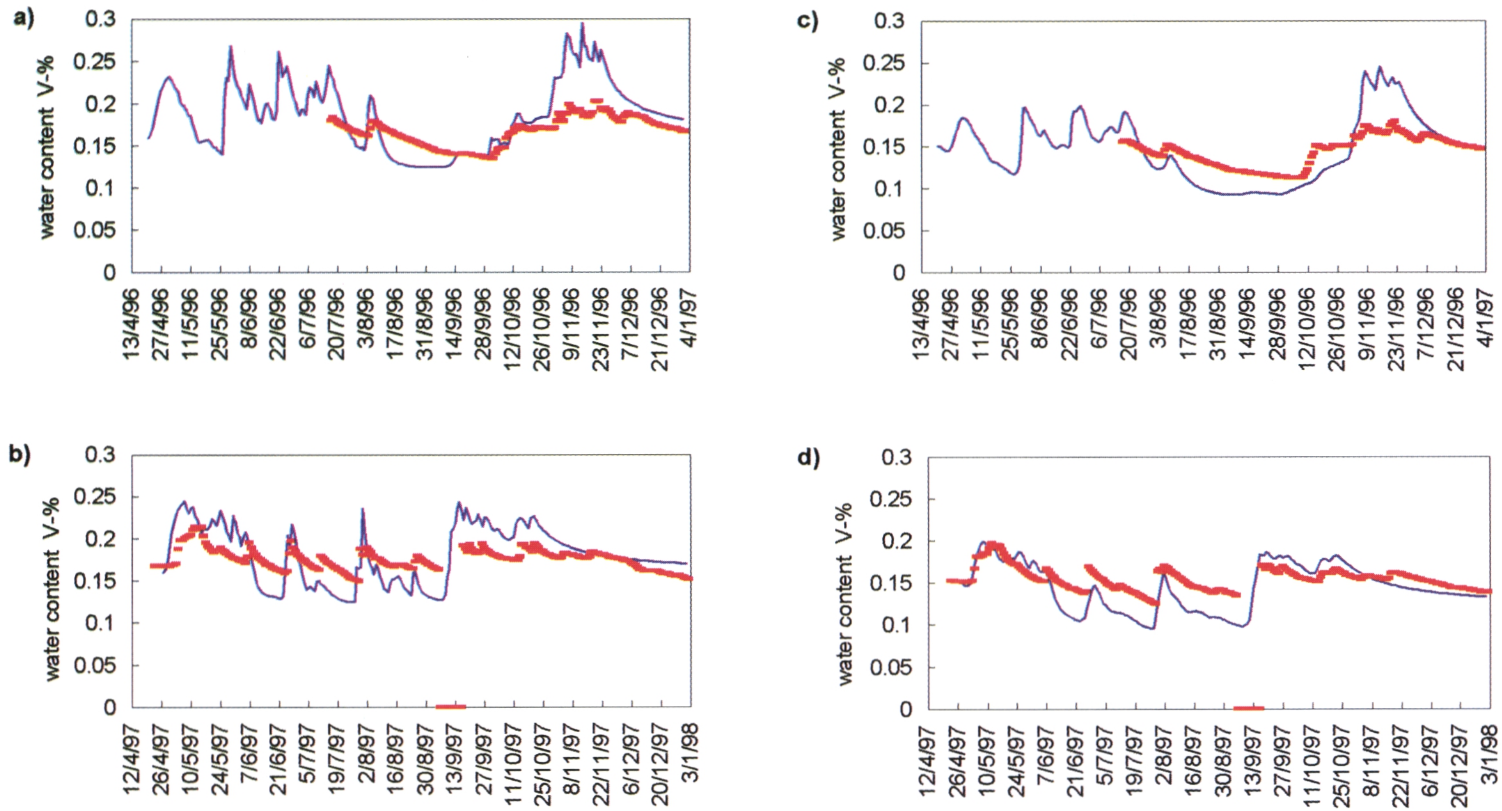

Figure 2. Simulated water contents (—) and the observed water contents (– –) in depth 15 cm (a and b) and in depth 35 cm (c and d) during the years 96–97.

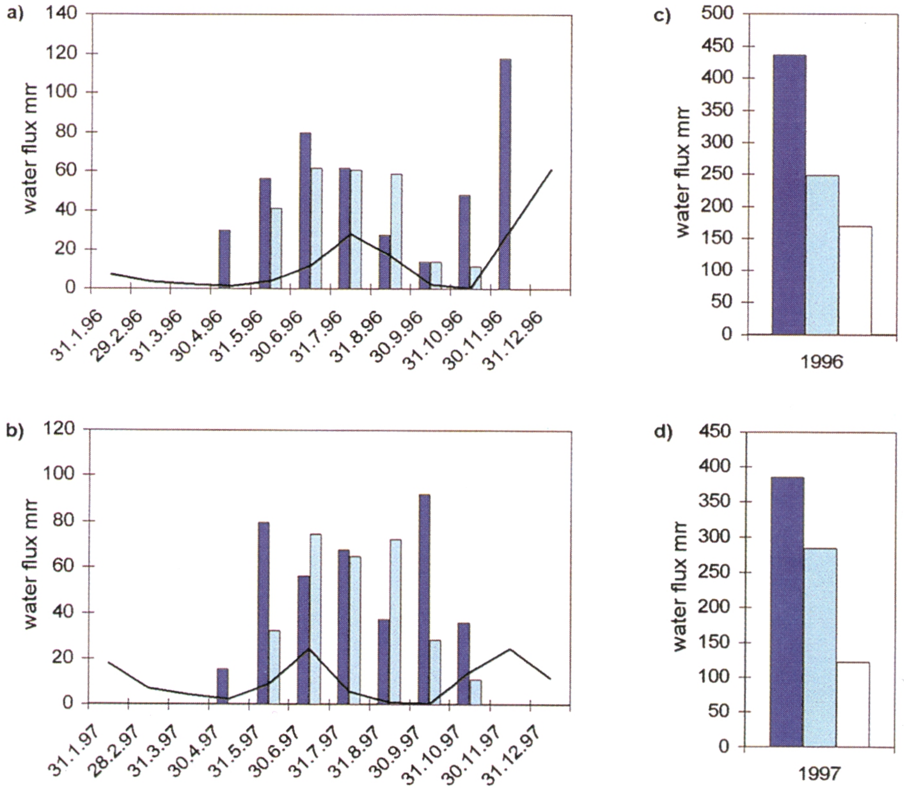

Figure 3. Simulated precipitation (■), evapotranspiration (□) and outflux (□ and —) during the years 96–97. The fluxes are added up to month (a and b) and year (c and d) totals.

to run through the profile, the proportion of evapo-transpiration was one half. Water in the soil that is not removed by evapo-transpiration passes down through the soil profile.

Soil solution chemistry

Soil solution was collected with suction lysimeters at depths of 15 and 35 cm, three replicates per layer. The variation in ion concentrations between the replicate lysimeters was large; the maximum concentrations being 2- to 5-fold compared to the minimum values. At the depth of 15 cm, soil solution pH varied between 4.5 and 6.5, indicating that the solution was not in chemical equilibrium with the solid phase of the soil (Fig. 4). The variation between replicate lysimeters at 35 cm depth was not as great as that at 15 cm. The temporal pattern in ion concentrations was also partly hidden by the large variation in ion concentrations between replicate lysimeters.

The modelled ion concentrations for 1997 are not directly comparable with the observed data, since each observation is a monthly aggregation of weekly samples. The weekly sample volumes weight the bulk sample to moist seasons, and thus they do not represent the average concentration of the month.

Chloride is often used as a tracer since it does not react with the soil matrix and the uptake of chloride by vegetation is negligible. Thus, changes in the chloride concentration of the soil solution can be used as an indicator of the distribution of water uptake down the soil profile. When the simulated chloride concentration at 15 cm depth are compared with the observed values, the temporal patterns are

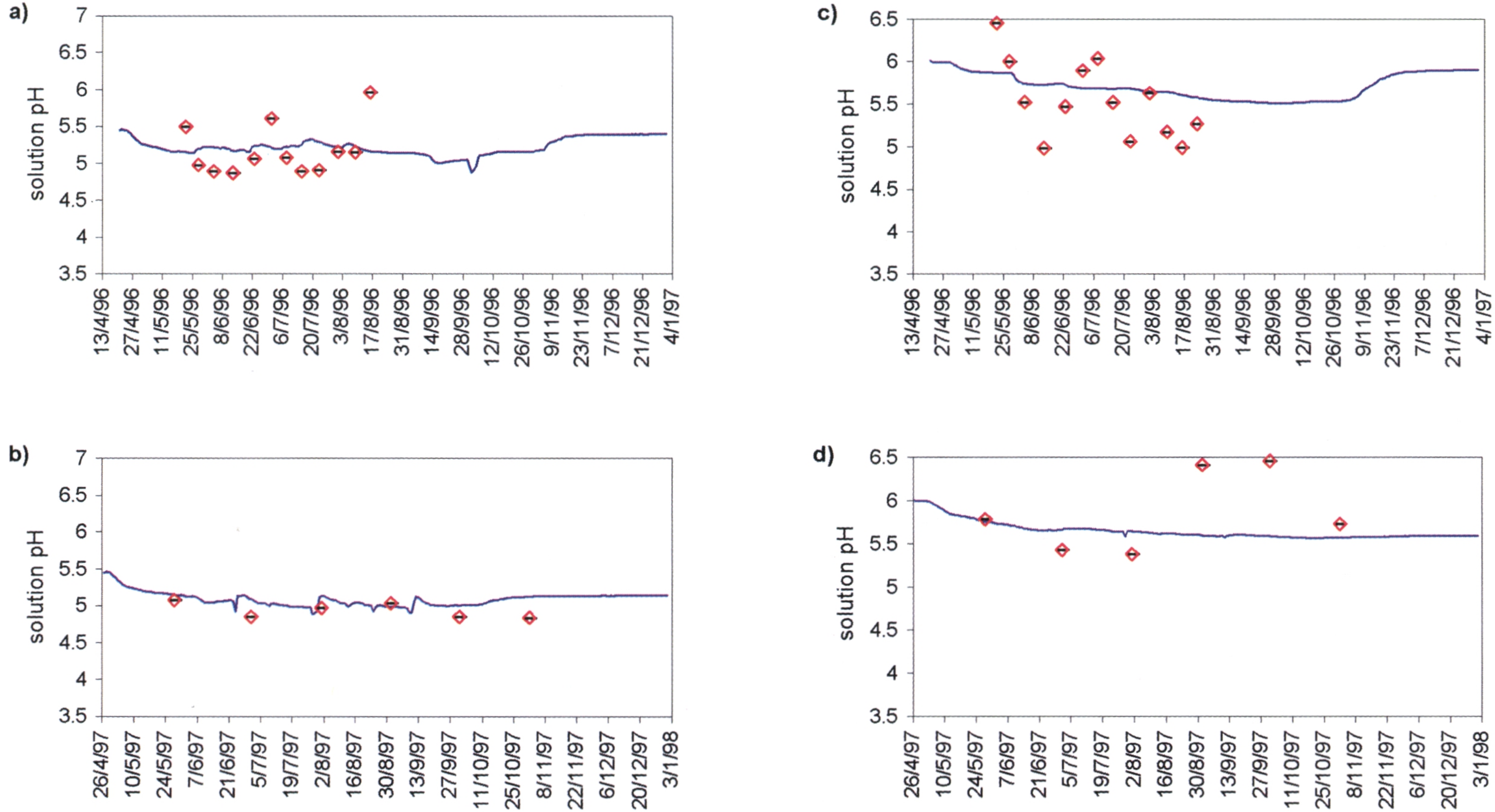

Figure 4. Simulated pH of soil solutions (—) in depth 15 cm (a and b) and in depth 35 cm (c and d) during the years 96–97. The averages (◇) and the minimum and maximum (I) of the observed pH values are shown.

generally similar, but the simulated chloride concentration is somewhat higher than observed values (Fig. 5). At 35 cm depth, the difference between the simulated and measured values is larger than that at 15 cm. This may also be connected to the use of vertical root distribution measured from another site.

The simulated calcium concentrations show the same temporal pattern as the observed concentrations, but the levels in the simulation are again higher than the observed values (Fig. 6). In 1994, the measured chloride concentrations increase in early summer, indicating strong evapo-transpiration. However, the measured calcium concentrations decrease at this time. We cannot explain this discrepancy at present.

The simulated annual calcium fluxes indicate that more calcium is leaving the soil profile in outflow than is entering as deposition (Fig. 7). Despite this, the total amount of calcium in the soil profile is not decreasing because the release of calcium through weathering is larger than the nutrient uptake plus the leaching loss (= outflow - deposition).

Changes in exchangeable cation and adsorbed sulphate pools

Only the exchangeable cation data from the first round of soil sampling, carried out in 1989, were available at the time of this study. Thus the simulated changes in exchangeable cations and adsorbed sulphate cannot be compared with the observed values.

During the period simulated, the amount of exchangeable Ca increased (1 % of the initial value), and that of exchangeable H^+ decreased (3 %). The sinks of H^+ from soil solution were sulphate adsorption and weathering (Fig. 8). The simulated amount of adsorbed sulphate increased in the uppermost layers during the first half of the simulation period, but then started to decrease due to the reduction in sulphate deposition. In the deeper layers, sulphate was adsorbed during the whole period (total increase of adsorbed sulphate = 13 %). It thus appears that the sulphate lost from the upper layer has accumulated deeper in the soil.

The sulphate adsorption properties of the soil have not yet been determined experimentally, and the modelled estimate will be more reliable when measurements become available. Sulphate adsorption is often not included in leaching studies, although this is one of the main sinks of hydrogen ions in podzolic soils (Kareinen et al. 1998), and strongly affects the dynamics of exchangeable cation leaching.

Conclusions

The ACIDIC simulations of water content and soil solution ion concentrations were generally comparable to the measured values. However, comparison with measured values was sometimes difficult due to the large variation in the observations.

The results of this preliminary study indicate that ACIDIC is an effective tool that can be used to integrate and analyse intensive monitoring plot data. The model output could also be used to produce estimated values for episodes and layers for which no actual measurements are available.

The application of ACIDIC is most effective when large data sets, such as those for the Hietajärvi site, are available. The application of the model showed that detailed investigations of the regional variation in the chemical and physical properties of the soil are an essential basis for regional analyses.

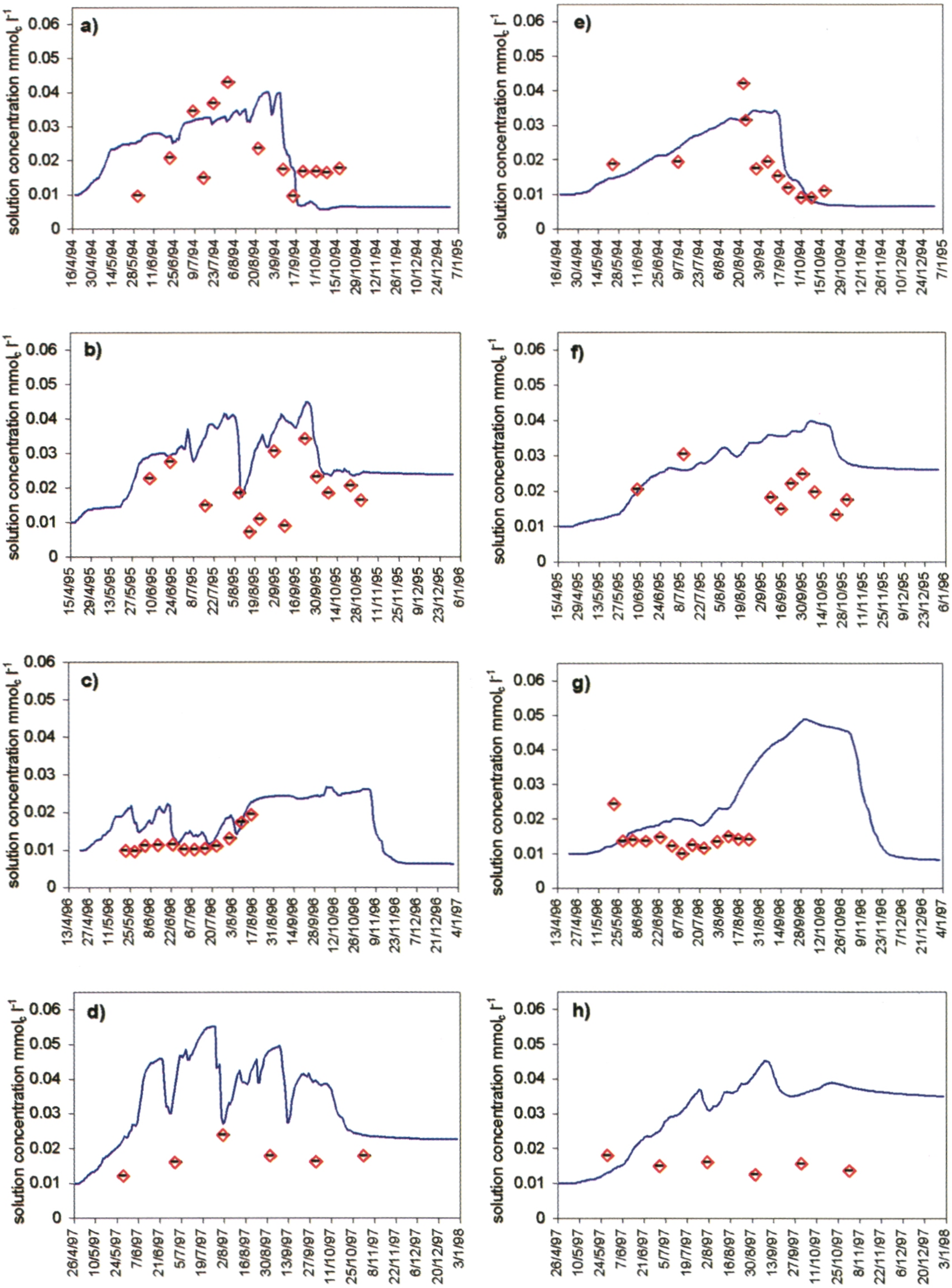

Figure 5. Simulated chloride concentrations in soil solution (▬) in depth 15 cm (a, b, c and d) and in depth 35 cm (e, f, g and h) during the years 94–97. The averages (◇) and the minimum and maximum (I) of the observed chloride concentrations are shown.

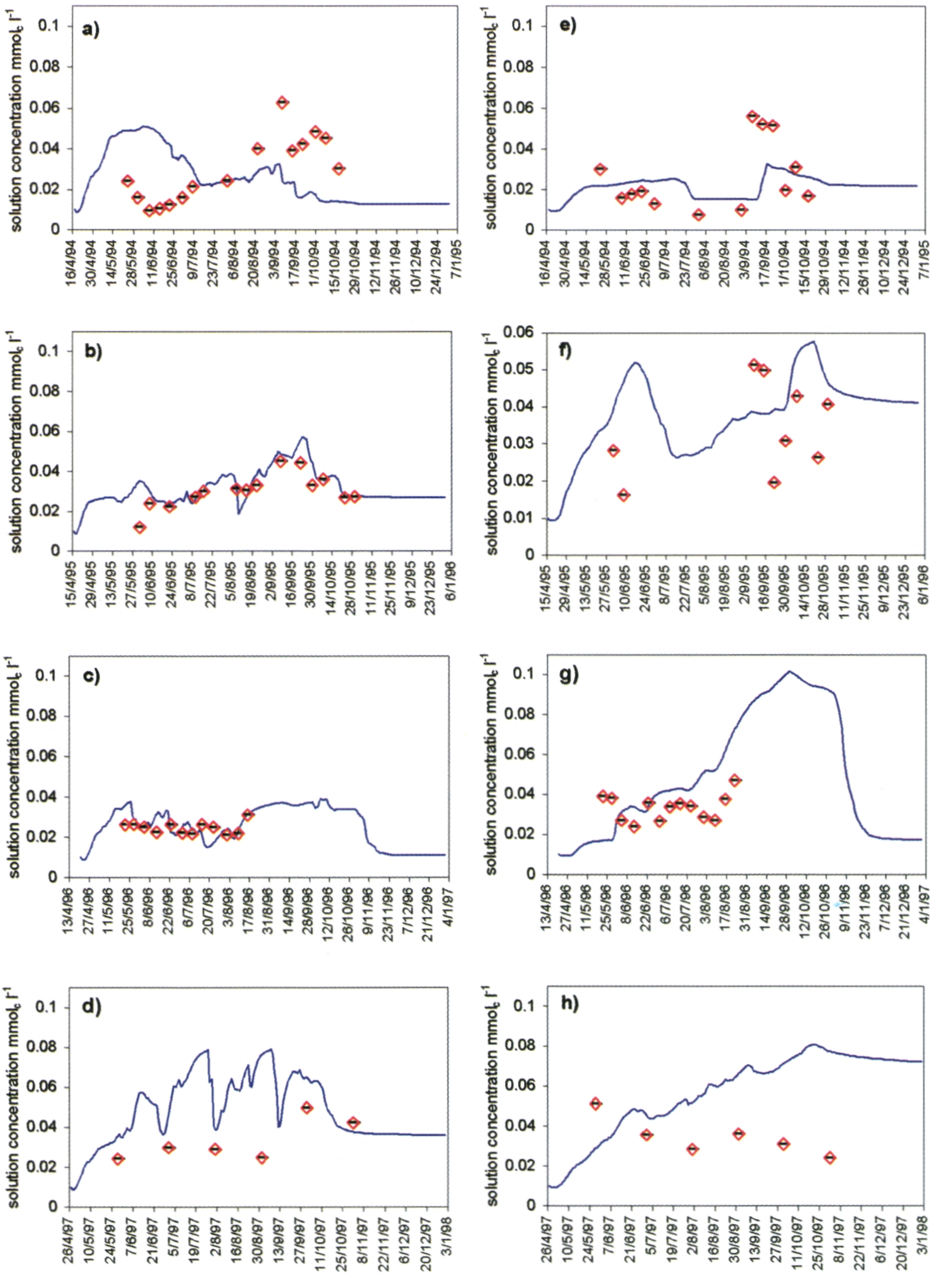

Figure 6. Simulated calsium concentrations in soil solution (—) in depth 15 cm (a, b, c and d) and in depth 35 cm (e, f, g and h) during the years 94–97. The averages (◇) and the minimum and maximum (I) of the observed chloride concentrations are shown.

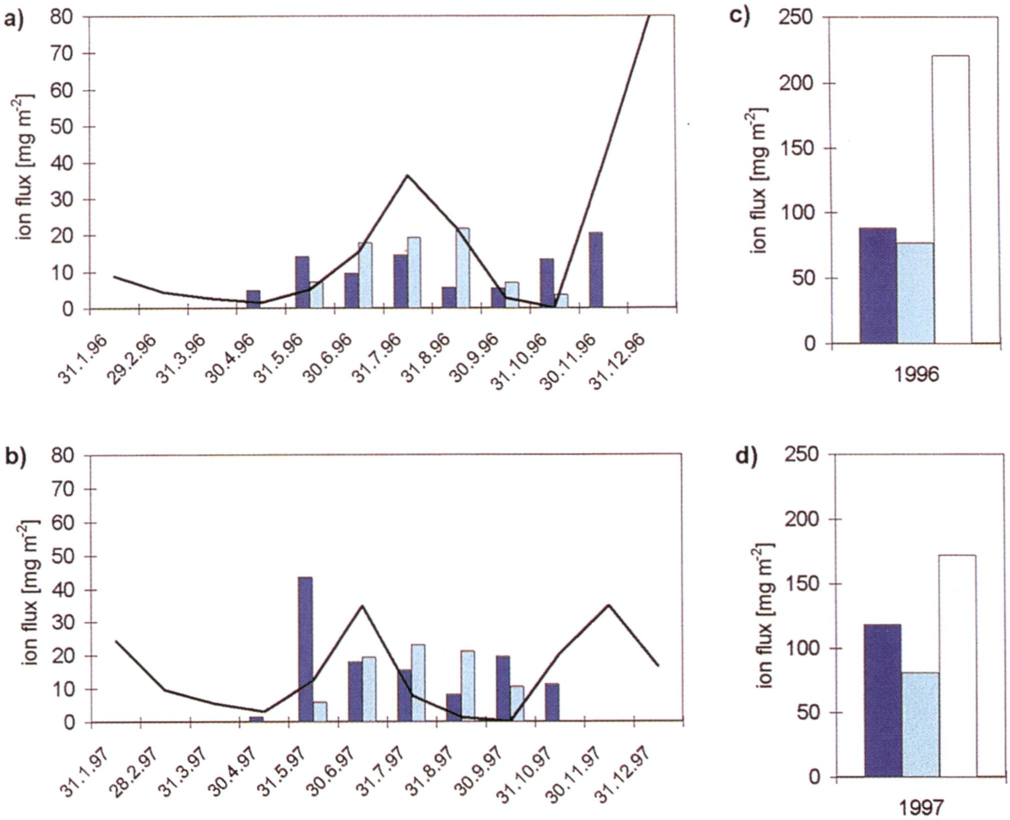

Figure 7. Simulated deposition ( ), nutrient uptake ( ) and outflux (and) of calsium during the years 96–97. The fluxes are added up to month (a and b) and year (c and d) totals.

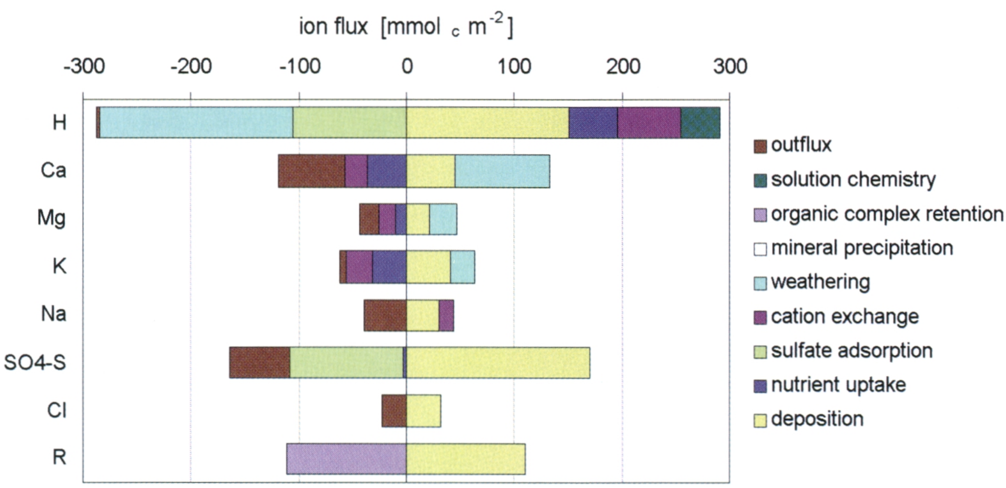

Figure 8. Simulated changes in solution ion amounts in the soil profile, when all ion fluxes in each soil layer are added up. For example deposition, nutrient uptake, cation exchange and solution chemistry (mainly hydrolysis of aluminium) increased the H^+ amount in soil solution, and sulfate adsorption, weathering and outflux decreased it. The decrease of H^+ on exchange sites was about 60 mmol m^{-2}.

References

Bergström, I., Mäkelä, K. & Starr, M. (Eds). 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department Report 1/1995. 138 p. + 7 appendices.

Cosby, B.J., Hornberger, G.M., Galloway J.N. & Wright, R.F. 1985. Modelling the effects of acid deposition: Assessment of a lumped parameter model of soil water and streamwater chemistry. Water Resources Research 21: 51–63

Cosby, B.J., Hornberger, G.M., Wright, R.F. & Galloway, J.N. 1986. Modeling the effects of acid deposition: Control of long-term sulfate dynamics by soil sulfate adsorbtion. Water Resources Research 22: 1283–1291.

De Vries, W., Posch M. & Kämäri J. 1989. Simulation of the long-term soil response to acid deposition in various buffer ranges. Water, Air and Soil Pollution 48: 349–390.

Forsius M., Alveteg M., Jenkins A., Johansson M., Kleemola S., Lükewille A., Posch M., Sverdrup H., Syri S. & Walse C. 1996. Dynamic model applications at selected ICP IM sites. In: Kleemola, S. & Forsius, M. (Eds). 5th Annual Report 1996. UN ECE ICP Integrated Monitoring. Finnish Environment Institute, Helsinki. The Finnish Environment 27: 10–24.

Haussmann T. (Ed). Protection of Forests Against Atmospheric Pollution (Regulation (EC) No. 3528/86 and its amendements), Basic Documents for the Implementation of the European Programme of the Intensive Monitoring of Forest Ecosystems. EC, DG VI F.II.2. 97 p.

Helmisaari, H.-S. 1990. Nutrient retranslocation within Pinus sylvestris. D.Sc. Thesis, University of Joensuu. 13 p. + appendices.

Ilvesniemi, H., Kareinen, T., Nissinen, A. & van Hees, P. 1999. Water balance in a Scots pine stand, an application of a model ACIDIC. Submitted to: Agricultural and Forest Meteorology.

Kareinen, T., Nissinen, A. & Ilvesniemi, H. 1998. Analysis of forest soil chemistry and hydrology with a dynamic model ACIDIC. Acta Forestalia Fennica 262: 1–42.

Karltun, E. 1995. Sulphate adsorption on Variable-Charge Minerals in Podzolozed Soils in relation to Sulphur deposition and Soil Acidity. Swedish University of Agricultural Sciences., Department of Soil Sciences, Reports and Dissertations 26. Uppsala.

Mälkönen, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Communicationes Instituti Forestalis Fenniae 84(5): 1–87.

Posch, M., Reinds, G.J. & De Vries, W. 1993. SMART – A Simulation Model For Acidification's Regional Trends: Model Description and User Manual. Mimeograph Series of the National Board of Waters and the Environment 477, Helsinki, Finland, 43 p.

Ruoho-Airola, T. 1995. Air quality and deposition. In: Bergström, I., Mäkelä, K. & Starr, M. (Eds). 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department Report 1/1995. 138 p. + 7 appendices.

Starr, M. 1995. Soil chemistry. In: Bergström, I., Mäkelä, K. & Starr, M. (Eds). 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department Report 1/1995. 138 p. + 7 appendices.

Starr, M. , Lindroos, A.J., Tarvainen, T. & Tanskanen, H. 1998. Weathering rates in the Hietajärvi Integrated Monitoring catchment. Boreal Environment Research 3(3): 275–284.

Ukonmaanaho, L. & Starr, M. 1995a. Throughfall and stemflow. In: Bergström, I., Mäkelä, K. & Starr, M. (Eds). 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy

Department Report 1/1995. 138 p. + 7 appendices.

Ukonmaanaho, L. & Starr, M. 1995b. Soil water chemistry. In: Bergström, I., Mäkelä, K. and Starr, M. (Eds).1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department Report 1/1995. 138 p. + 7 appendices.

Warfvinge, P., Falkengren-Gerup, U., Sverdrup, H. & Andersen, B. 1993. Modelling long-term cation supply in acidified forest stands. Environment Pollution 80: 209–221.

6 Co-operation between the integrated monitoring programme (ICP IM) and the intensive and continuous monitoring of forest ecosystems (ICP Forests/Level II) in Finland

Michael Starr and Liisa Ukonmaanaho

Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Introduction

As with the Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems (Level II), the UN-ECE Integrated Monitoring Programme (ICP IM) is a long-term forest ecosystem monitoring programme. The ICP IM programme permanent monitoring plots are located within headwater catchments. The fluxes and pools of substances and the effects of environmental change (e.g. air pollution, climate change) in the terrestrial (forested) environment can therefore be linked to the aquatic environment (lakes and streams) in a well defined hydrological unit.

Within the ICP IM programme, considerable emphasis is given to linking the abiotic environment to biological effects and to the development of bioindicators. Because of the complexity of ecosystem functioning and responses to environmental stress and change, and the need for predicting the future response of ecosystems, modelling is also a central theme in the ICP IM programme. In practice, the monitoring is divided into a number of compartmental subprogrammes which are linked by the use of the same parameters (cross-media flux approach) and of the same/close stations (cause-effect approach). The ICP IM programme is guided by a manual, the latest version of which is strongly harmonised with other European monitoring programmes (EMEP, ICP waters, ICP Forests manuals, in particular) and a strong multi-disciplinary approach has been adopted. Annual reports on ICP IM activities and evaluations and assessments of ICP IM data have been produced since 1992. The ICP IM programme formed the basis of a recent EU/LIFE project (LIFE/95/FIN/A11/EPT/387), which was co-ordinated from Finland (Forsius et al. 1998b).

Integrated monitoring in Finland

There are four ICP IM catchments in Finland and one of the stations (pairs of plots) in each catchment now also functions as a Level II plot (Fig. 1, Table 1). The catchments are located in large forested areas in national parks or reserves and protected from disturbance. The forests represent natural to semi-natural, old-growth stands in the later stages of succession with growth at or approaching steady-state. The effects of forest management, agriculture and traffic are therefore negligible and the only source of air pollution is from long-range transported emissions. The sites therefore represent background levels of pollution in Finland.

All the main Finnish government research institutes and universities are involved in the execution of the Finnish ICP IM programme and the Finnish Environment Institute (FEI) acts as the national focal centre (Bergström 1998). Funding for the programme has primarily come

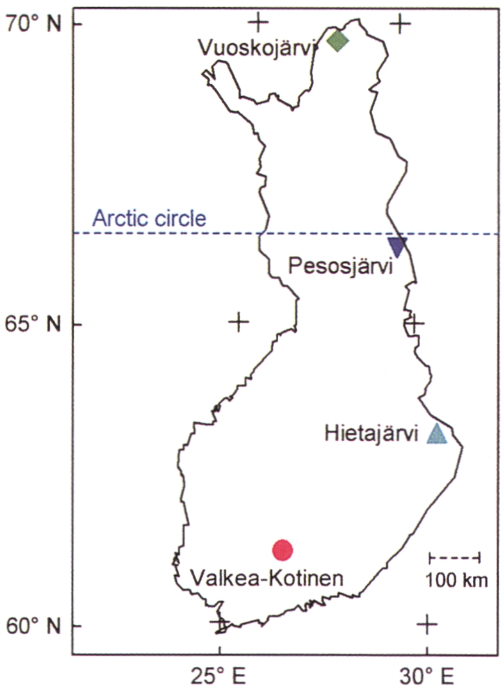

Figure 1. Location of ICP IM catchments.

from the Ministry of the Environment and from the research institutes and agencies involved. Partial funding for the Forest Research Institute's (Metla) ICP IM activities in 1998 has also come from the Ministry of Agriculture and Forestry.

Metla is responsible for the execution (sample collection, analyses, and data reporting) of most of the ICP IM terrestrial subprogrammes, including: throughfall, stemflow, soil water, soil chemistry (+ related soil properties), soil microbiology, litterfall, foliage chemistry, tree/stand growth and condition. Since 1996, Metla has also been continually measuring soil moisture and temperature at one of the plots in both the Valkea-Kotinen and Hietajärvi catchments. The plots are the joint ICP IM and Level II plots. All the primary ICP IM data collected by Metla are kept in a relational database (Paradox) at the Vantaa Research Centre.

At present, Finland is the only EU country which has permanent monitoring plots common to both the Level II and ICP IM programmes. The plots, which were established in 1988/89, have been reporting data to the ICP IM Programme Centre (FEI, Helsinki) for nearly 10 years. Since 1997, data are now reported to both Level II and ICP IM programme centres. Because of the location of the ICP IM Programme Centre and the active role played in the programme, Finland has and continues to be a leading participant in the ICP IM programme.

The Finnish ICP IM programme has produced some 100 reports/publications over the last 10 years. In 1995, the first national report was published (Bergström et al. 1995) and in 1998, a special volume of Boreal Environment Research (BER 1998) was dedicated to the latest results from the Finnish ICP IM programme.

Results

Some of the main ICP IM results related to the forest ecosystem compartments are presented below. For results concerning the air quality and open deposition, aquatic compartments and integrated results from catchment modelling and budget calculations, see Bergström et al. (1995), BER (1998) and Forsius et al. (1995, 1998a).

Sulphur and nitrogen

We have shown that monthly sulphate concentrations in both open and throughfall precipitation (bulk) were the highest in southern Finland and the lowest in northern Finland and that there has been a significant ($p<0.05$) decline in concentrations during the 1990's (Ukonmaanaho et al. 1998b). Growing season monthly volume weighted sulphate concentrations (mg SO_4-S l^{-1}) in throughfall during 1989–1995 averaged 1.5, 0.9, 0.8 and 0.7 for Valkea-Kotinen, Hietajärvi, Pesosjärvi and Vuoskojärvi catchments, respectively. The estimated decline in throughfall sulphate concentrations calculated over the same period ranged from 0.2 mg SO_4-S l^{-1} yr^{-1} at Valkea-Kotinen (the most southerly ICP IM site) to zero

Table 1. General features of the Finnish ICP-IM catchments

	Valkea-Kotinen	Hietajärvi	Pesosjärvi	Vuoskojärvi
Location	61° 14′ N 25° 03′ E	63° 09′ N 30° 40′ E	66° 17′ N 29° 26′ E	69° 44′ N 26° 56′ E
Area, km^2	0.3	4.6	6.1	2.0
Phytogeographic zone *)	Southern boreal	Middle boreal	Northern boreal	Northern boreal
Climatic zone **)	Humid continental	Continental subarctic	Continental subarctic	Continental subarctic
Annual mean temperature, °C	3.1	2.0	-0.5	-1.9
Annual mean precipitation, mm	618	592	571	395
Vegetation period (>5 °C), d	112	102	82	57

*) Ahti *et al.* 1968

**) Köppen-Geiger classification

at Vuoskojärvi (the most northerly ICP IM site) (Fig. 2). Further reductions in sulphate concentrations in deposition on this scale are unlikely.

Monthly mean concentrations of total inorganic N (TIN) in open and throughfall bulk deposition collected during 1989–1995 were <1.0 mg N l^{-1} and concentrations decreased northwards (Fig. 3). The amount of bulk deposition of TIN collected in the open decreased from c. 440 mg N m^{-2} yr^{-1} at Valkea-Kotinen in the south to about 50 mg N m^{-2} yr^{-1} at Vuoskojärvi in the north (1989–1991) (Ruoho-Airola 1995).

The deposition collected in the open has seen a significant ($p<0.05$) decrease in NH_4^+ concentrations in the southern catchments, Valkea-Kotinen and Hietajärvi, and in NO_3^- concentrations at Hietajärvi over this period. Throughfall monthly mean NH_4^+ and NO_3^- concentrations during the growing season, however, showed no significant change over the 1989–1995 period (Starr & Ukonmaanaho 1997). Nitrogen is removed from precipitation as it passes through the stand canopies and both concentrations and loads of N are less under the canopy than in the open (Starr & Ukonmaanaho 1994, 1997, Starr et al. 1995).

Concentrations of both NH_4^+ and NO_3^- in soil water collected at 15- and 35-cm depths (<0.5 mg N l^{-1}) were less than concentrations in throughfall (Starr & Ukonmaanaho 1997). This indicates that the forest soils are below N saturation.

The return of total N to the forest floor as litterfall during the summer months (June–September, 1990 and 1991) varied from nearly 1000 (Valkea-Kotinen) to 290 mg N m^{-2} (Vuoskojärvi) (Starr & Ukonmaanaho 1994, Starr et al. 1995). Compared to the annual deposition of N collected in the open (described above), these values show that soil N is dominated by the recycling (uptake and litterfall) and not the deposition of N at these ICP IM sites.

Heavy metals

A comprehensive evaluation of heavy metal (Cd, Cu, Ni, Pb and Zn) concentrations in various types of water samples (open bulk precipitation, bulk throughfall, stemflow, soil

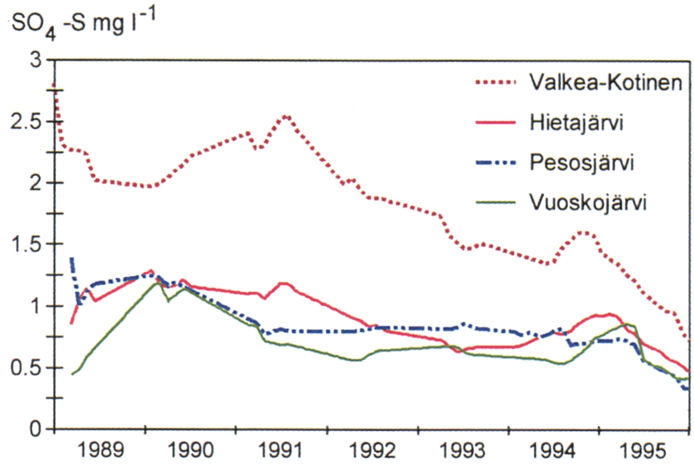

Figure 2. LOWESS trends (locally weighted) in throughfall sulphate concentrations for each ICP IM catchment 1989–1995 (average of two plot/catchments).

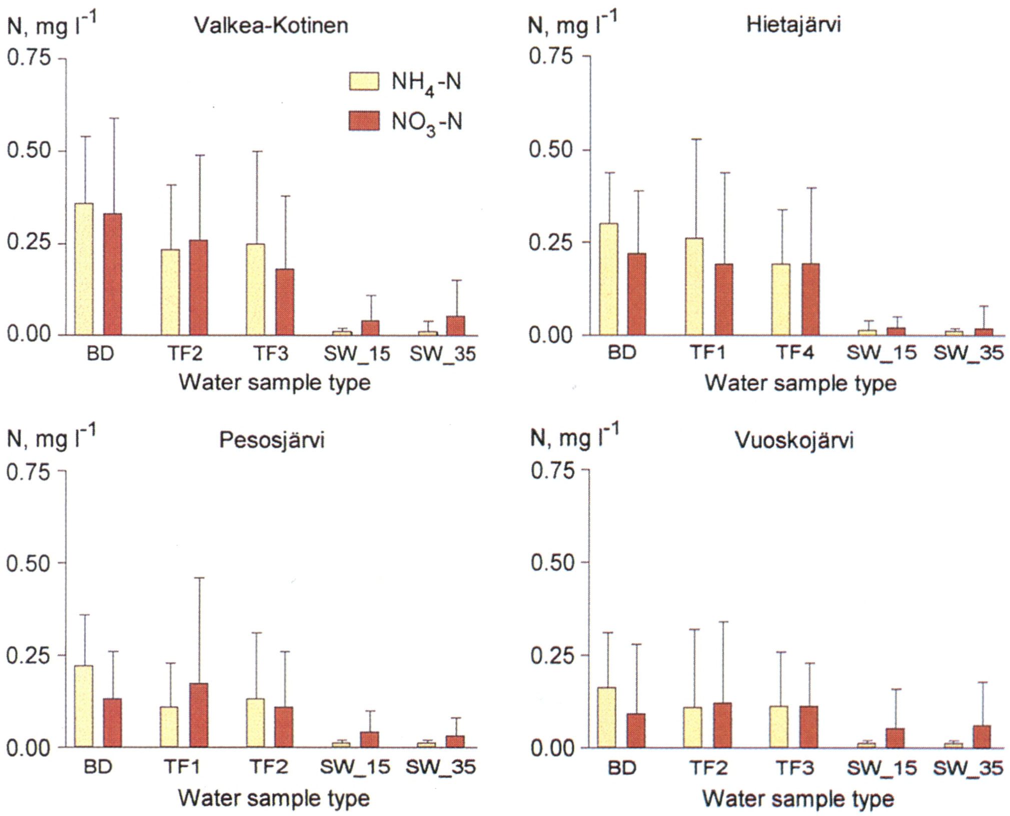

Figure 3. Monthly mean ammonium and nitrate and nitrate nitrogen concentration in open precipitation (BD), throughfall (TF) (two plots/catchments), and soil water (SW) (15 and 35 cm) at each catchments (error bars are standard deviations). (Starr & Ukonmaanaho 1997).

water, groundwater, lake and stream water) were low in comparison to European forest in the temperate zone (Ukonmaanaho et al. 1998a).

Concentrations of Pb in the deposition to the monitored forest stands have significantly declined during 1989–96 (Fig. 4). This decline is clearly in response to the replacement of leaded petrol with non-leaded petrol over this time period. However, the Pb (as with other heavy metals) has accumulated in the humus layer (Of+Oh) and from where it can continue to exert an effect on the ecosystem well into the future.

We found that concentrations of Cd, Cu, Pb and Zn in the humus layer were below lowest concentrations shown to have detrimental effects on humus layer (mor) microbiological activity (Ukonmaanaho et al. 1998a). Such lowest critical concentration values for Cd were not available. Concentrations in the lake water were also below corresponding critical concentrations for aquatic organisms. The importance of local geological sources of metals circulating in forest ecosystems was also shown.

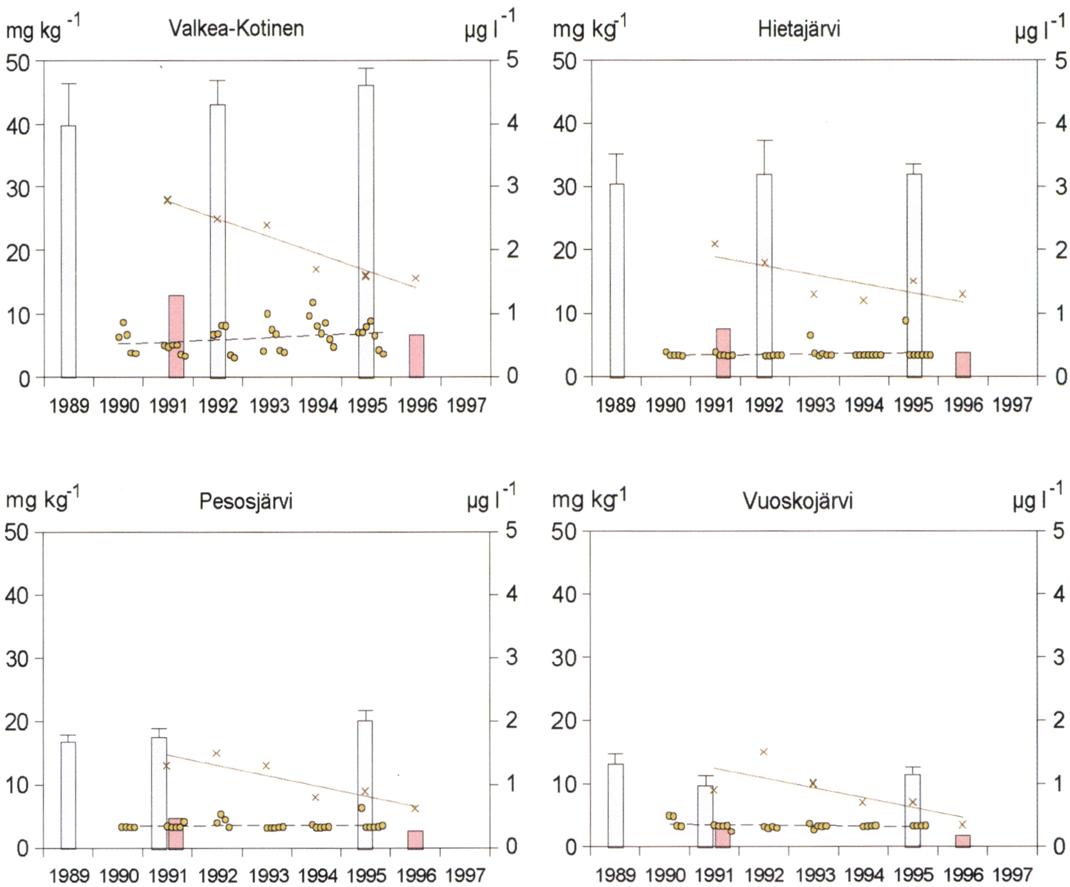

Figure 4. Pb concentrations in bulk precipitation (annual mean µg l^{-1},x), litterfall (monthly mg kg^{-1}, O), moss (Pleurozium schreberi) (mg kg^{-1}, solid bars) and humus layer (mg kg^{-1}, hatched bars). Lines are linear regression fits and error bars are standard deviations. (Ukonmaanaho et al. 1998).

We have applied SIMA, a dynamic model of forest growth and succession (Kellomäki et al. 1992), to the joint ICP IM/Level II plot at Hietajärvi (Starr et al. 1998a). The stand is dominated by Scots pine (90 % of stand stem volume) of >200 years age.

We wished to simulate the development of the stand biomass and the associated amounts of base cations taken up from the soil over the next 150 years. The amount of base cation uptake from the soil and bound in the biomass must be balanced by a reverse flux of protons (acidity) to the soil. We were then able to compare present levels of acidic deposition received by the stand (0.21 keq ha^{-1} a^{-1}) with the amounts of acidity released to the soil resulting from nutrient uptake and biomass accumulation.

The results indicated that the present annual net base cation uptake is about zero but that it will increase to a maximum of c. 0.18 keq ha^{-1} a^{-1} by the year 2050 and then slowly decline to zero again (Fig. 5). The increase in biomass and associated soil acidification is related to the increase in Norway spruce biomass. This can be explained in terms of vegetation succession. Norway spruce the climax species in northern boreal coniferous forests and stands left undisturbed will, in theory, become dominated by Norway spruce in time. The results also show that although the levels of acidic deposition are low in comparison to western and central Europe, deposition is the main source of net acidity in such old-growth forests at present.

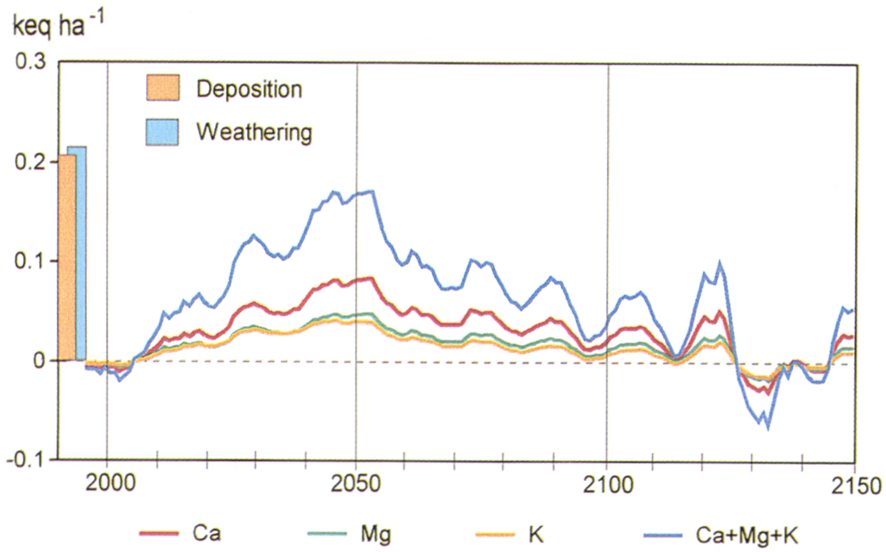

Figure 5. Simulated annual net base cation uptake (equivalent to amount of soil acidification) for Hietajärvi plot 4 (13 year smoothed average) (Starr et al. 1998a). H^+ deposition (1989–91) (Ruoho-Airola 1995) and weathering release of Ca+Mg (Starr et al. 1998b) values are also given.

Conclusions

Through the use of a long-term integrated monitoring approach, such as the ICP-IM and Level II programmes, we have been able to demonstrate that the reduction in the emission of long-range transported air pollutants related to UN-ECE agreements during the 1990s is resulting in quantifiable and significant improvements in the environment for Finnish forest ecosystems. Furthermore, the greatest improvements have taken place in the south of the country, where the pollution is the greatest. However, there is still a need to continue to monitor these changes, particularly in terms of interaction with the effects of climate change and global warming, and to determine whether these improvements in the environment are also resulting in clear biological/ecosystem responses.

References

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968. Vegetation zones and their sections in northwestern Europe. Annales Botanici Fennici 5: 378–386.

BER. 1998. Boreal Environment Research. Volume 3, Number 3. p. 201–303.

Bergström, I., Mäkelä, K. & Starr, M. (Eds.) 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department, Report 1/1995. 138 p. + 3 appendices.

Bergstöm, I. 1998. The Integrated Monitoring programme in Finland. Boreal Environment Research 3(3): 201–203.

Forsius, M., Kleemola, S., Starr, M. & Ruoho-Airola, T. 1995. Ion mass budgets for small forested catchments in Finland. Water, Air, and Soil Pollution 79: 19–38.

Forsius, M, Alveteg, M., Jenkins, A., Johansson, M., Kleemola, S., Lükewille, A., Posch, M., Sverdrup, H. & Walse, C. 1998a. MAGIC, SAFE and SMART model applications at Integrated Monitoring sites: effects of emission reduction scenarios. Water, Air and Soil Pollution 105: 21–30.

Forsius, M., Guardans, R., Jenkins, A., Lundin, L. & Nielsen, K.E. 1998b. Integrated Monitoring: Environmental assessment through model and empirical analysis. Final results from the EU/Life-project 'Development of assessment and monitoring techniques at integrated monitoring sites in Europe'. Suomen Ympäristö 218. 172 p. ISBN 952–11–0302–7.

Kellomäki, S., Väisänen, H., Hänninen, H., Kolström, T., Lauhanen, R., Mattila, U. & Pajuri, B. 1992. SIMA: A model for forest succession based on the carbon and nitrogen cycles with application to silviculture management of the forest ecosystem. Silva Carelica 22: 1–85.

Ruoho-Airola, T. 1995. Bulk deposition. In: Bergström, I., Mäkelä, K. & Starr, M. (Eds.) 1995. Integrated Monitoring Programme in Finland. First National Report. Ministry of the Environment, Environmental Policy Department, Report 1/1995: 54–58.

Starr, M. & Ukonmaanaho, L. 1994. The role of canopy leaching and litterfall in the return of nutrients to the soil in Finnish boreal forests. In: Helios Rybicka, E. & Sikora, W.S. (Eds.). 3rd International Symposium on Environmental Geochemistry, 12–15 September, 1994, Krakow, Poland. Abstracts. p. 387–388.

Starr, M., Ukonmaanaho, L., Ruoho-Airola, T. & Forsius, M. 1995. Some aspects of the nitrogen cycle in the Finnish Integrated Monitoring catchments. In: Forsius, M. & Kleemola, S. (Eds.). Effects of Nitrogen Deposition on Integrated Monitoring Sites. Proceedings from an International Workshop in Oslo, 6–7 March 1995. ICP IM Programme Centre, Finnish Environment Agency, Helsinki. p. 147–151.

Starr, M. & Ukonmaanaho, L. 1997. Nitrogen concentrations in bulk precipitation, throughfall, soil water, needles, litterfall and forest floor at Finnish Integrated

Monitoring areas. In: BIOGEOMON, 3rd International Symposium on Ecosystem Behaviour, June 21–25, 1997, Villanova, U.S.A. Journal of Conference Abstracts 2(2): 307.

Starr, M., Kinnunen, T. & Hartman, M. 1998a. Enhancement of forest growth and nutrient uptake estimates. In: Forsius, M., Guardans, R., Jenkins, A., Lundin, L. & Nielsen, K.E. (Eds.). Integrated Monitoring: Environmental assessment through model and empirical analysis. Final results from the EU/LIFE-project 'Development of assessment and monitoring techniques at Integrated Monitoring sites in Europe'. Suomen Ympäristö 218: 32–36.

Starr, M., Lindroos, A-J., Tarvainen, T. & Tanskanen, H. 1998b. Weathering rates in the Hietajärvi Integrated Monitoring catchment. Boreal Environment Research 3(3): 275–285.

Ukonmaanaho, L., Starr, M., Hirvi, J.-P., Kokko, A., Lahermo, P., Mannio, J., Paukola, T., Ruoho-Airola, T. & Tanskanen, H. 1998a. Heavy metal concentrations in various aqueous and biotic media in Finnish Integrated Monitoring catchments. Boreal Environment Research 3(3): 235–249.

Ukonmaanaho, L., Starr, M. & Ruoho-Airola, T. 1998b. Trends in sulfate, base cations and H^+ concentrations in bulk precipitation and throughfall at Integrated Monitoring sites in Finland 1989–1995. Water, Air, and Soil Pollution 105: 353–363.

7 Pilot studies

7.1 Sampling strategy for the assessment of temporal changes in ground vegetation in boreal forests

Maija Salemaa[1], Satu Monni[1], Felix Royo Peris[1] and Christian Uhlig[2]

[1)] Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

[2)] Department of Plant Physiology and Microbiology, IBG
University of Tromsø, Norway

Introduction

Changes in plant populations and communities are of great indicative value in monitoring forest ecosystems. Responses to anthropogenic impacts, e.g. air pollution or climatic change, may be detectable at an earlier state in understorey species than in long-lived trees. For instance, many moss and lichen species have proved to be rather sensitive to sulphur and nitrogen compounds and heavy metals (Folkeson 1984, Longton 1985, Mäkipää 1995). Although ground vegetation represents a relatively minor component of the whole biomass of boreal forests, it plays a crucial role in the annual biomass production and nutrient cycling of the ecosystem (Mälkönen 1974, Havas & Kubin 1983).

The temporal succession of boreal forest vegetation, which is relative poor in species, is mainly expressed through changes in the between-species abundance relationships. Species turnover is high in the early succession phases, e.g. after clear-cutting (Zobel 1989, Bråkenhielm & Liu 1998) or forest fire (Gorshkov & Bakkal 1996, Vanha-Majamaa 1999). The responses of plant species to air pollution or climatic change are usually small and gradual, and difficult to separate from natural succession. Alterations in the floristic composition of the community can only be expected after a long time period or severe environmental changes. In addition to determining total species composition, detailed quantitative data on species abundances are therefore essential for the long-term monitoring of boreal vegetation.

Schools of vegetation analysis

The methods used in analysing vegetation differ according to the objectives of the investigations. Biomass values are considered to give the most exact measure of plant abundances, but harvesting cannot be applied in large-scale surveys or when nondestructive sampling is obligatory, e.g. when monitoring permanent plots (Catchpole & Wheeler 1992). Visually estimated coverages of plant species have usually been used in vegetation monitoring. Different countries have developed their own individual approach to carrying out vegetation analyses. The Braun-Blanquet approach has traditionally been used in the classification of vegetation in the Central European countries (the Zürich - Montpellier school) (Braun-Blanquet 1932, Poore 1955, Økland 1990). The original form of the Braun-Blanquet method consists of the following steps: a) a botanist outlines homogeneous vegetation stands, on which the sample plots (the relevés) are then selected subjectively. The minimum area of a relevé is determined by studying the number of plant species first within a small area, and then duplicating the studied area until the species number no longer increases, b) the abundances of species are estimated using a simple class-scale, which links the information about the shoot frequency and the coverage of the species (Manual on methods... 1998) (Table 1), and c) the data are arranged in an ordered form in a vegetation table, which is the basis for hierarchical classification of the plant communities. The classification is based on the qualitative differences in the floristic composition, in which the character and differential species are essential indicators. The concept of association is the basic unit in the classification.

The Nordic tradition in vegetation analysis has been based on quantitative differences between the species abundances (Økland 1990). In the Uppsala school the data have usually been collected from a large number of small sample plots. In Finland, subjectively placed macroplots sized e.g. 100 m^2 (Hämet-Ahti 1963) or 4 m^2 (Haapasaari 1988) have also been used in studing forest and heathland vegetation. The abundances of the plants species have been estimated using different kinds of coverage scale (Pakarinen 1984). In the Finnish school, the aim of which was originally to classify the forest site types (Cajander 1926, Oksanen 1990), emphasis has been on ecological gradients rather than on vegetation hierarchies (Økland 1990). When forest and mire vegetation have been studied in connection with the national forest inventories, special attention has been paid to the statistical representativeness of the data (Kujala 1964, Reinikainen et al. 1998, Tomppo et al. 1998).

Aims

Different sampling methods used in vegetation analysis were compared in the pilot study carried out in 1996. The work came actual because European wide monitoring of forest vegetation was launched by the ICP Forest Programme (Manual on methods ... 1998). The objective was to select the most suitable method for the long-term monitoring of forest vegetation on Finnish ICP plots. The aims were to study 1) how similar are the data obtained with an application of the Braun-Blanquet method and the Nordic percentage cover method, and 2) how the size and number of the sample units (quadrats) affect the estimates of the parameters assessed on the plant communities.

Table 1. The transformation of the Braun-Blanquet rating to percentage coverages.

Scale	Cover range (%) & shoot frequency	Class midpoint
r	rare	0.01 %
+	few	0.5 %
1	numerous or <5 %	2.5 %
2	5–25 %	15.0 %
3	25–50 %	37.5 %
4	50–75 %	62.5 %
5	75–100 %	87.5 %

Material and methods

The data were collected from nine ICP observation plots representing different forest fertility classes in August, 1996 (Table 2). All the plots represented coniferous forest vegetation on mineral soil. Altogether 10–16 small sample quadrats were established on the sample areas (900 m^2, called sub-plots in the ICP Forest terminology), the 1 m^2 quadrats being located inside the 2 m^2 quadrats (Fig. 1). In addition, four 0.25 m^2 quadrats were established inside the 1 and 2 m^2 quadrats located at the corners of the sub-plot. Four large quadrats, 25 m^2 in size, were established with common corners with the smaller ones (Fig. 1). The whole sub-plot (900 m^2) was also analysed as one macroquadrat. On the small quadrats

(0.25, 1 and 2 m²) the coverages of the plant species were estimated using the scale 0.01, 0.1, 0.2, 0.5, 1, 2, ...99, 100 %. On the large quadrats (25 and 900 m²) the Braun-Blanquet scale was used. The percentage coverages calculated from the midpoint values of the Braun-Blanquet class ranges are presented in Table 1. It must be emphasised that no minimun-area determination was made when selecting the size of the large quadrats. The systematic placement of the quadrats also differs from that of the traditional Braun-Blanquet method.

Two resampling techniques were used in the data analysis. The expected number of species as a function of the quadrat number (depicted as species - area curves) was studied using an application of the rarefaction method. A description of the method and the formulae used are presented e.g. in Krebs (1989). A bootstrap method (Efron & Tibshirani 1993) was applied in determining when the within-site variance of the estimate of the species mean coverage stabilised to an adequately low level (Bruce 1993, Resampling stats program). Quadrats with the sizes of 1 m² and 2 m² were compared in both techniques. The assumption of complete randomness of the distribution of species or vegetation patches was not necessarily fulfilled because of the aggregated spatial pattern of many species. The number of species obtained by different methods were compared (when possible) using the paired t-test. The species coverages in the 2 m² quadrats (n = 16) and the 25 m² quadrats (n = 4) were compared by the 2-sample t-test (Analytic Software 1996, Statistix for Windows).

Table 2. Observation plots studied for vegetation sampling designs. Forest site types, dominant tree species and number of quadrats (0.25, 1, 2, 25, 900 m²) are given. Pine = Pinus sylvestris L. and spruce = Picea abies (L.) Karst.

Observation plot	Forest site type	Tree species	Stand age, yr.	Number of quadrats 0.25m²	1m²	2m²	25m²	900m²
1. Sevettijärvi	Ericaceae-Cladina Type, ErClT	pine	101	0	10	10	4	1
2. Pallasjärvi	Empetrum-Myrtillus Type, EMT	pine	45	4	16	16	4	1
4. Sodankylä	Empetrum-Myrtillus Type, EMT	pine	60	4	4	14	4	1
5. Kivalo	Hylocomium-Myrtillus Type, HMT	spruce	66	4	16	16	4	1
9. Yli-Kiiminki	Empetrum-Vaccinium Type, EVT	pine	59	4	4	4	4	1
12. Tammela	Myrtillus Type, MT	spruce	55	4	16	16	4	1
15. Lapinjärvi	Oxalis-Myrtillus Type, OMT	spruce	55	4	16	16	4	1
16. Punkaharju	Vaccinium Type, VT	pine	65	4	16	16	4	1
18. Miehikkälä	Calluna Type, CT	pine	90	4	16	16	4	1

Results and discussion

Here we present only the main results concerning the effect of the size and number of quadrats on the detected species number, as well as the comparison of the coverages given by the two coverage scales. Two common species, bilberry *Vaccinium myrtillus* L., and a feathermoss *Pleurozium schreberi* (Brid.) Mitt. are used as example species.

The number of species in relation to the quadrat size and number

The average number of species increased with quadrat size (0.25 m^2 < 1 m^2 < 2 m^2 < 25 m^2 < 900 m^2, nested quadrats) (Fig. 2). In northern Finland and on the less fertile sites in southern Finland, the species number did not increase essentially after 10 quadrats, sized 1 m^2 or 2 m^2 (Fig. 3). On the other hand, on the most fertile sites (Tammela and Lapinjärvi) the species number increased up to 16 quadrats. In most cases the rarefaction curve for 2 m^2 quadrats was above the curve for 1 m^2, i.e. the species number was higher in 2 m^2 quadrats.

The mean coverages of the species

The Braun-Blanquet scale (rating transformed to cover percentages, Table 1) gave somewhat different estimates for the mean coverages of the species compared to the direct percentage coverages. There were no systematic over- or underestimates in the mean values given by the Braun-Blanquet scale, but the results were site- and species-specific (Figs. 4 a,b). When the direct percentage value was close to either the upper or lower limit of the class range of the Braun-Blanquet estimate, it inevitably differed considerably from the midpoint value of the class range. It was concluded that the coverages given by the Braun-Blanquet scale were too inaccurate to be effective in detecting small-

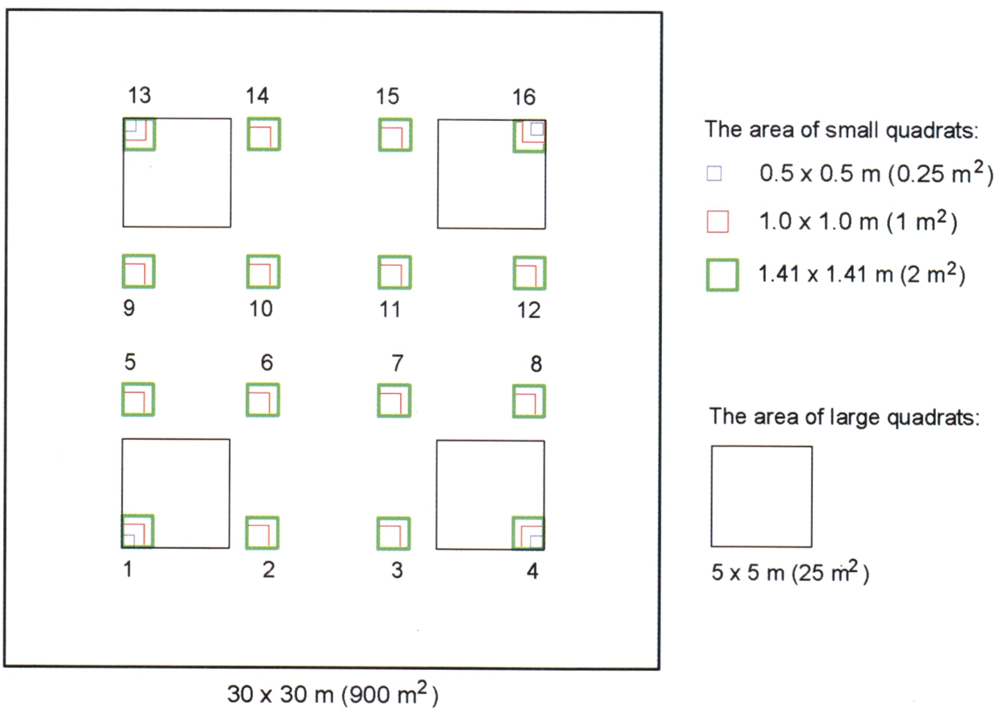

Figure 1. The location of the sample quadrats on the vegetation monitoring sub-plot (30 x 30 m).

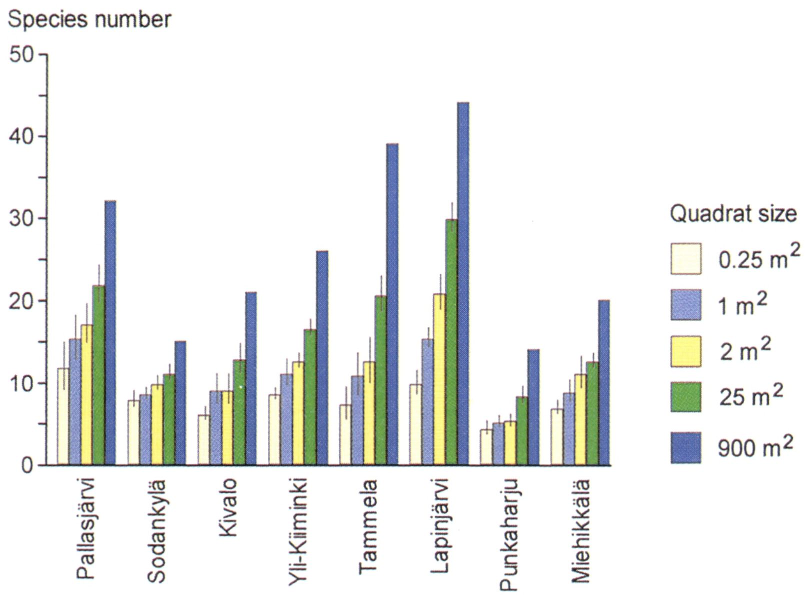

Figure 2. The average number of plant species (± sem) on the sample quadrat having different areas (the quadrats were located within each other, n = 4). The black column depicts the species number on the whole sub-plot (900 m², n = 1) All pairwise comparisons between the different quadrat sizes were statistically significant (p < 0.000, df = 31 paired t-test) in the combined data.

scale temporal changes in plant communities. However, the total area of the studied vegetation quadrats differed (e.g. 16 x 2 m^2 vs. 4 x 25 m^2), which may have affected the results to some extent.

The variances of the mean coverages

The variance of the estimate of the mean coverage decreased the most when quadrat number increased from 1 to 5, and was lower in the 2 m^2 than in the 1 m^2 quadrats (Figs. 5 and 6). The difference between the variances of the two quadrat sizes was at its greatest when the quadrat number was low, but the difference became insignificant when the number was over 10. The variances were dependent on the spatial pattern and the coverage of the species.

Selection of the most appropriate method

The results were relatively consistent with those presented by Jalonen et al. (1998) concerning the effect of quadrat number and size on the parameters estimated from the vegetation in Myrtillus-type forests. Kenkel & Podani (1991) have shown that the quadrat size should be larger than the mean patch size of the plant species, and that the estimation efficiency increases (i.e. variances decreases) with increasing quadrat size. For pattern recognition, however, a quadrat size which is the same as the mean plant patch size is appropriate for maximising between-plot variability (Kenkel et al. 1989).

A quadrat size of 2 m^2 (1.41 x 1.41 m) was selected on the basis of the results of the pilot study because it gave lower within-plot variance of the estimate of mean coverage than 1 m^2 quadrats. Although the number of species on the 2 m^2 quadrats was lower than that on the larger ones, it is possible to make a complete species list on the plot level. A total of sixteen 2 m^2 quadrats was thus established on the sub-plots (30 x 30 m) in 1998. Species coverages were assessed using the direct percentage values.

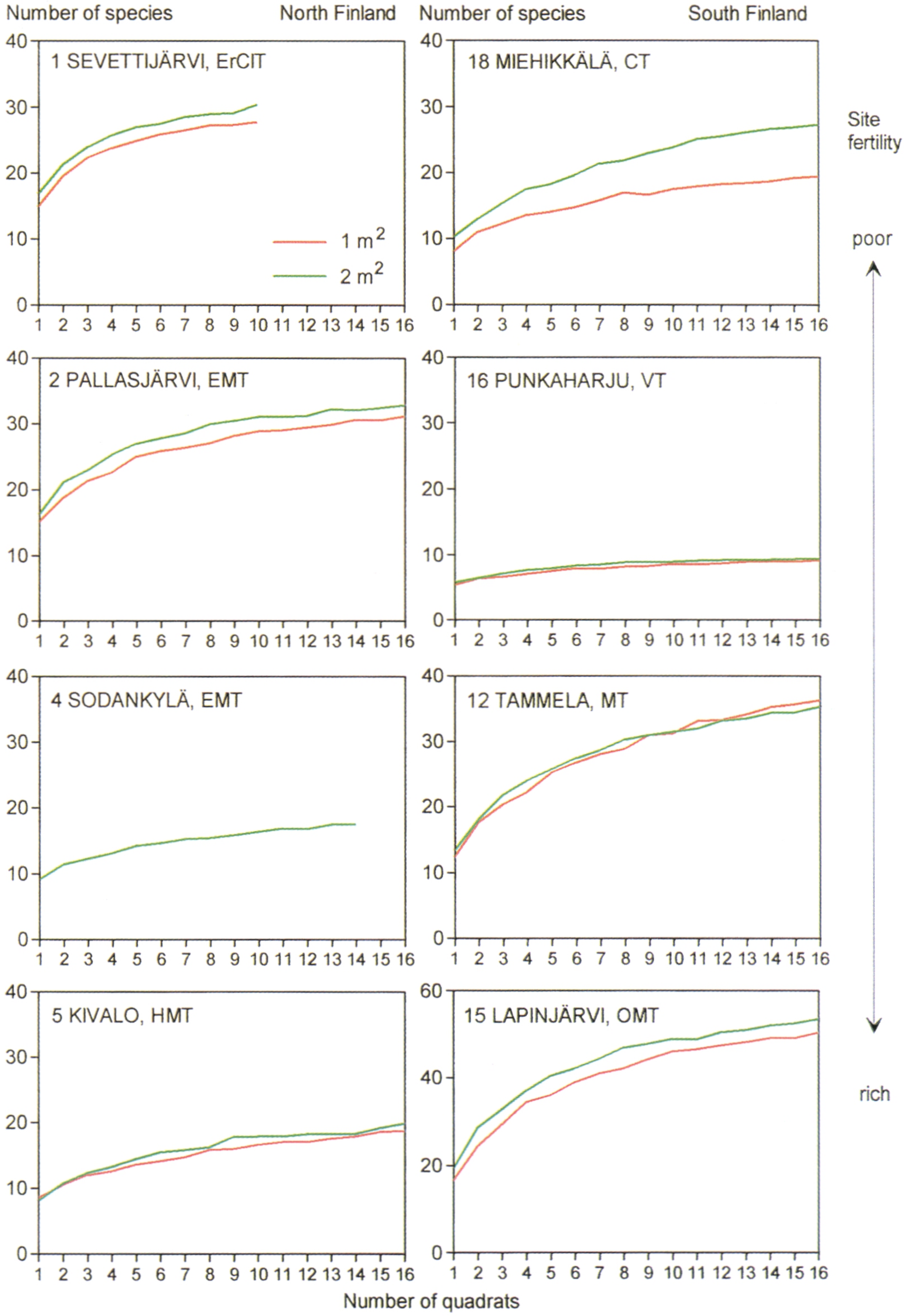

Figure 3. The expected number of plant species as a function of the number of studied quadrats (1 m² and 2 m² separately) on the observation plots in northern and southern Finland. The functions have been estimated by a rarefaction method.

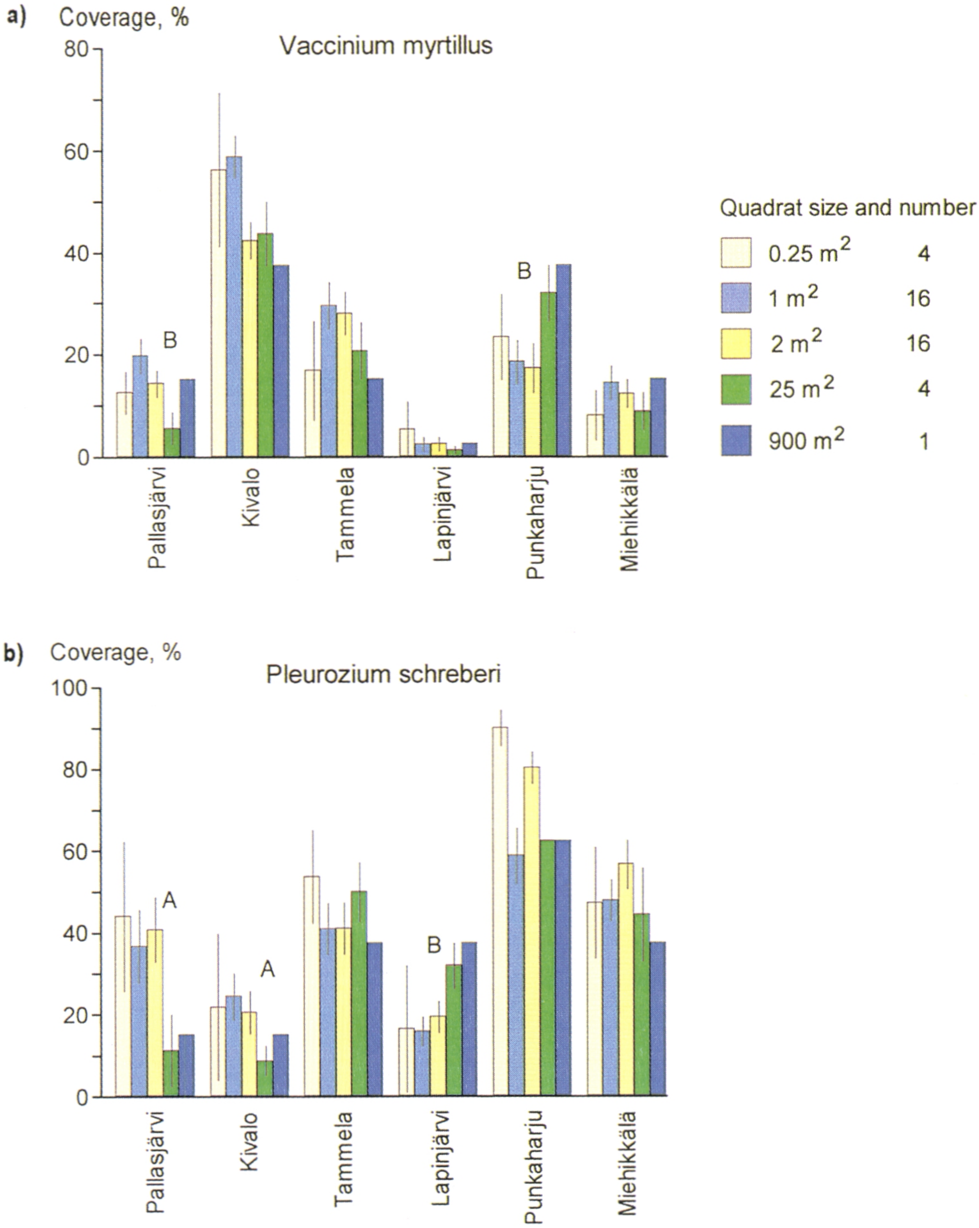

Figure 4. The estimates of the mean coverage (± sem) of a) bilberry (Vitalies myrtillus) and b) a feathermoss (P. schreberi) given by different methods on six observation plots. The mean coverages of the 2 m² quadrats and the 25 m² quadrats were compared by t-tests. Risk levels $p < 0.08$ are marked with A and $p < 0.17$ with B in the figure.

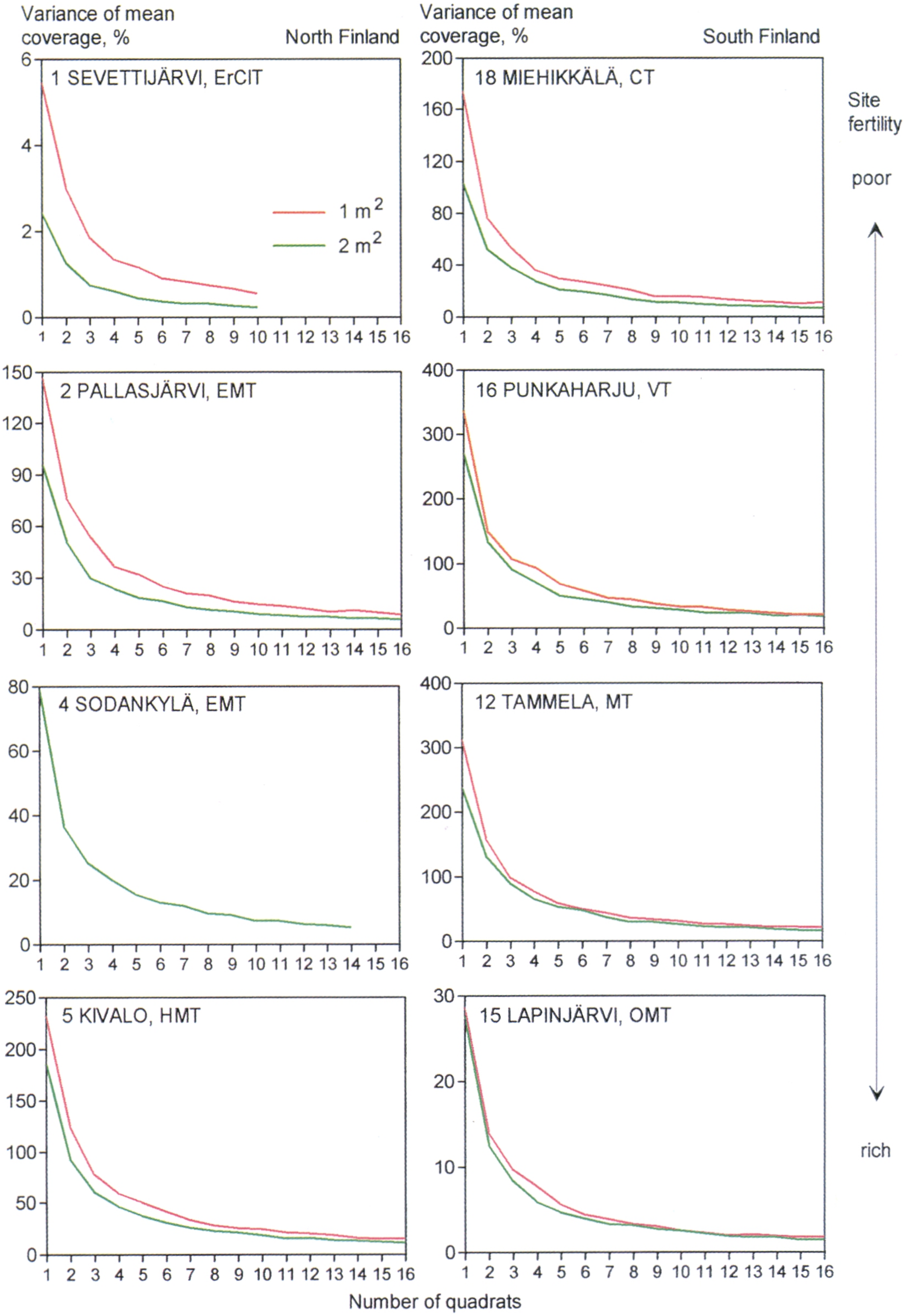

Figure 5. The variance of the estimate of the mean coverage of Vaccinium myrtillus as a function of the number of studied quadrats (1 m² and 2 m² separately) on the observation plots in northern and southern Finland. The functions have been estimated by a bootstrapping method.

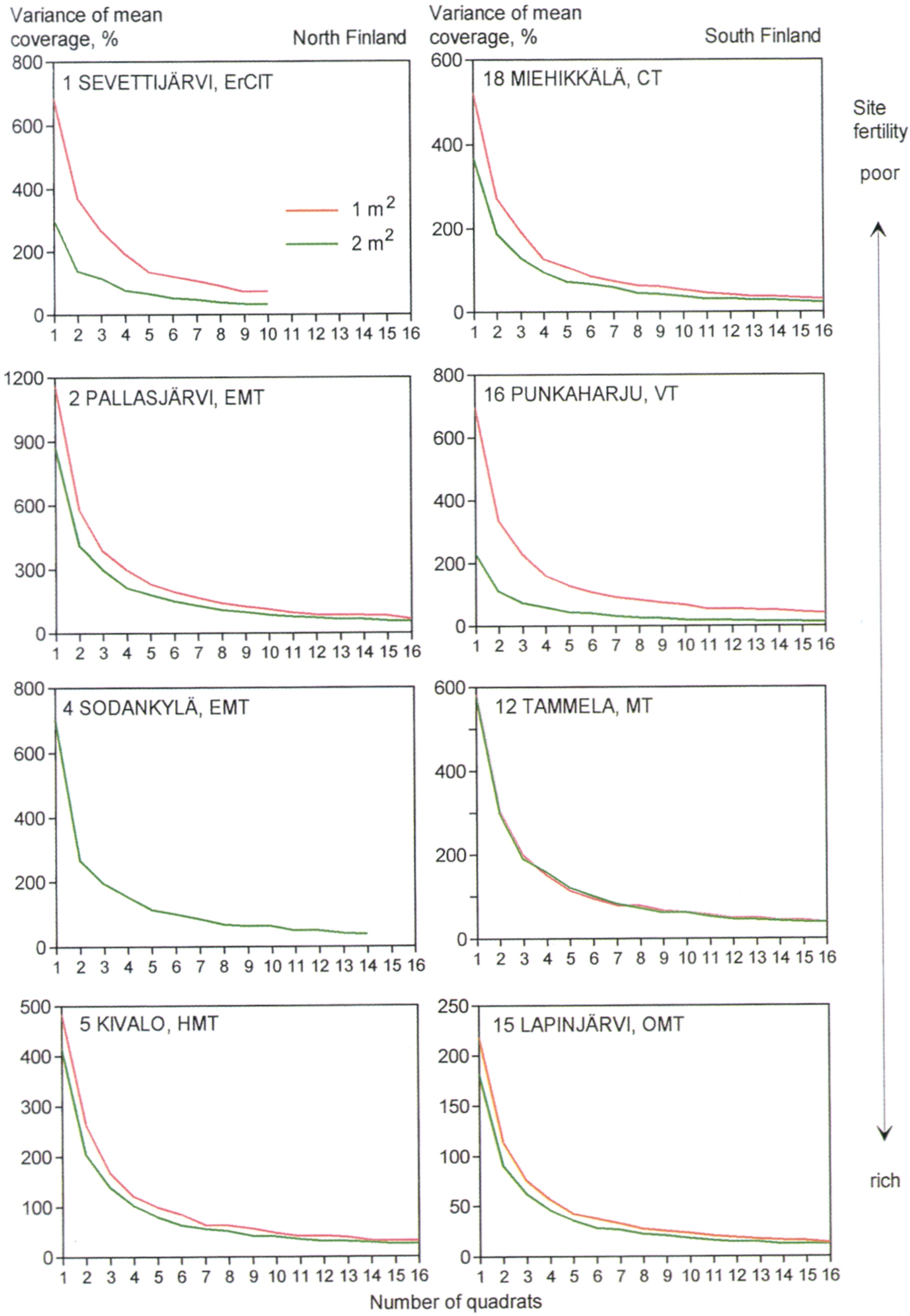

Figure 6. The variance of the estimate of the mean coverage of Pleurozium schreberi as a function of the number of the studied quadrats (1 m² and 2 m² separately) in the observation plots in northern and southern Finland. See Fig. 5 for details.

A systematic sample design with 4 x 4 square-grid was applied. The spatial correlation between the quadrats would have been even less if the design had been according to equilateral triangles but, in practice, the square-grid gives almost the same result and is easier to implement. Systematic sampling is effective in studying spatially distributed variables (Matérn 1960). It gives a lower mean square error for the coverage and the number of the plant species than e.g. random sampling.

In the final design the location of the quadrat was not moved if it included a tree trunk. This was done in order to ensure that all the components of the forest vegetation, including those under the tree crowns, are fully represented in the monitoring work. Species growing on decaying wood substrate, e.g. tree stumps or fallen trunks, were not estimated.

Acknowledgements

We are grateful to Jyrki Jalonen, Pekka Pakarinen and Erkki Tomppo for valuable comments. We also thank Horst Haug for participating in the field work.

References

Analytical Software 1996. Statistix for Windows. Tallahassee.

Braun-Blanquet, J. 1932. Plant Sociology; the study of plant communities. McGrow-Hill. New York and London. 438 p.

Bråkenhielm, S. & Liu, Q. 1998. Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. Biodiversity & Conservation 7(2): 207–220.

Bruce, P.C. 1993. The New Statistics. User guide for Resampling Stats software. IBM version 3.14. Resampling Stats Inc.

Cajander, A.K. 1926. The theory of forest sites. Acta Forestalia Fennica 29(3): 1–108.

Catchpole, W.R. & Wheeler, C.J. 1992. Estimating plant biomass: A review of techniques. Australian Journal of Ecology 17: 121–131.

Efron, B. & Tibshirani, R.J. 1993. An introduction to the bootstrap. Monographs on statistics and applied probability 57. Chapman Hall, London and New York. 436 p.

Folkeson, L. 1984. Deterioration of the moss and lichen vegetation in a forest polluted by heavy metals. Ambio 13(1): 37–39.

Gorshkov, V.V. & Bakkal, I.J. 1996. Species richness and structure variations of Scots pine forest communities during the period from 5 to 210 years after fire. Silva Fennica 30(2–3): 329–340.

Haapasaari, M. 1988. The oligotrophic heath vegetation of northern Fennoscandia and its zonation. Acta Botanica Fennica 135: 1–219.

Havas, P. & Kubin, E. 1983. Structure, growth and organic matter content in the vegetation cover of an old spruce forest in Northern Finland. Annales Botanici Fennici 20: 115–149.

Hämet-Ahti, L. 1963. Zonation of the mountain birch forests in the northernmost Fennoscandia. Annales Botanici Soc. "Vanamo" 34(4): 1–127.

Jalonen, J., Vanha-Majamaa, I. & Tonteri, T. 1998. Optimal sample and plot size for inventory of field and ground layer vegetation in a mature Myrtillus-type boreal spruce forest. Annales Botanici Fennici 35: 191–196.

Kenkel, N.C. & Podani, J. 1991. Plot size and estimation efficiency in plant community studies. Journal of Vegetation Science 2: 539–544.

Kenkel, N.C., Juhasz-Nagy, P. & Podani, J. 1989. On sampling procedure in population and community ecology. Vegetatio 83: 195–207.

Krebs, C.J. 1989. Ecological methodology. Harper and Row. New York. 654 p.

Kujala, V. 1964. Metsä- ja suokasvilajien levinneisyys- ja yleisyyssuhteista Suomessa. Referat: Über die Frequenzverhältnisse der Wald- und Moorpflanzen in Finnland. Communicationes Instituti

Forestalis Fenniae 59(1): 1–137. (In Finnish).

Longton, R.E. 1985. Reproductive biology and susceptibility to air pollution in *Pleurozium schreberi* (Brid.) Mitt. (Musci) with particular reference to Manitoba, Canada. Monographs in Systematic Botany from the Missouri Botanical Garden 11: 51–69.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 1998. 4th edition. Part VIII. Assessment of ground vegetation. UN-ECE. Programme coordination centre, Hamburg. 12 p.

Matérn, B. 1960. Spatial variation. Medd. Statens Skogsforskningsinstitut 49(5). 114 p. Also appeared as number 36 of Lecture Notes in Statistics. 1986. Springer-Verlag, New York.

Mäkipää, R. 1995. Sensitivity of forest floor mosses in boreal forests to nitrogen and sulphur deposition. Water, Air, Soil Pollution 85: 1239–1244.

Mälkönen, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Communicationes Instituti Forestalis Fenniae 84(5): 1–87.

Oksanen, J. 1990. Vegetation science in Finland. Journal of Vegetation Science 1: 277–282.

Pakarinen, P. 1984. Cover estimation and sampling of boreal vegetation in northern Europe. In: Knapp, R. (Ed.). Sampling methods and taxon analysis in vegetation science. Handbook of vegetation science 4: 35–44. The Hague. Dr. W. Junk Publishers.

Poore, M. 1955. The use of phytosociological methods in ecological investigations. I. The Braun-Blanquet system. Journal of Ecology 43: 226–244.

Økland, R.H. 1990. Vegetation ecolgy: theory, methods and applications with reference to Fennoscandia. Sommerfeltia Supplement 1: 1–233.

Reinikainen, A., Mikkola, K., Vanha-Majamaa, I., Nousiainen, H. & Tamminen, M. 1998. Metsä- ja suokasvillisuuden seuranta VMI:n yhteydessä. In: Annila. E. (Ed.). Monimuotoinen metsä. Metsäluonnon monimuotoisuuden tutkimusohjelman väliraportti. The Finnish Forest Research Institute. Research Papers 705: 19–73. (In Finnish)

Tomppo, E., Henttonen, H., Korhonen, K.T., Aarnio, A., Ahola, A., Ihalainen, A., Mikkelä, H., Tonteri, T. & Tuomainen, T. 1998. Etelä-Pohjanmaan metsäkeskuksen alueen metsävarat ja niiden kehitys 1968–97. Folia Forestalia 2B/1998: 298–374. (In Finnish).

Vanha-Majamaa, I. 1999. Tulen vaikutus taimettumiseen, aluskasvillisuuden sukkessioon ja sienilajistoon. In: Annila. E. (Ed.). Monimuotoinen metsä. Metsäluonnon monimuotoisuuden tutkimusohjelman väliraportti. The Finnish Forest Research Institute. Research Papers 705: 99–129. (In Finnish).

Zobel, M. 1989. Secondary forest succession in Järvselja, southeastern Estonia: changes in field layer vegetation. Annales Botanici Fennici 26: 171–182.

7.2 Determination of aluminium fractions in soil water

John Derome[1], Antti-Jussi Lindroos[2], Kirsti Derome[1] and Kaarina Niska[1]

1) Finnish Forest Research Institute
Rovaniemi Research Station
P.O. Box 16, FIN-96301 Rovaniemi, Finland

2) Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Background

Soil changes induced by acidic deposition can include the release of aluminium into the soil water as a consequence of H^+ buffering processes (Matzner & Murach 1995). Soil water Al concentrations are widely used in estimating soil acidification and the exceedance of critical loads of acidifying compounds (Sverdrup & De Vries 1994). At high concentrations, the monomeric form of aluminium (Al^{3+}) is known to be toxic to plants (Foy 1988). Aluminium can have an adverse and even toxic effect on plants through the physical precipitation of aluminium compounds on the outer surfaces of the roots or as a result of the uptake of metabolically toxic Al^{3+}. The soil solution contains many different aluminium fractions. At soil solution pH values of ca. 4, aluminium hydroxy compounds are common. Organic aluminium complexes are widely considered to be non-toxic Al species in soil solution. In coniferous forest ecosystems, the soil solution in the uppermost layers of podsolic soils contain large amounts of dissolved organic matter (DOC) (Lindroos et al. 1995, Lundström 1993). The DOC concentration and pH of the soil solution are the key factors regulating Al dissolution and precipitation in forest soils. Dissolved organic-Al complexes are very common in the rooting zone of the soil. Organic-Al complexes occur in both a solid and soluble form, and the Al in such complexes is relatively resistant to decomposition as a result of an increase in soil acidity (Derome 1989).

In many of the soil water studies carried out in Finland, it has not been possible, for analytical reasons, to distinguish between different Al species. The soil acidification estimations have been based on total Al concentrations in soil water and not on the toxic exchangeable fraction (e.g. Al^{3+}).

Aims

The aims of the pilot study were 1) to determine a suitable method for determining different aluminium species in soil water, 2) to develop methods for transporting, storing and pre-treatment of soil water samples prior to analysis, and 3) to estimate the proportion of exchangeable Al fraction out of total soil water aluminium.

Implementation

The soil water samples were obtained from three (Rovaniemi, Scots pine; Tammela, Norway spruce, Scots pine) of the Finnish intensive (level II) continuous monitoring plots The samples represented both percolation water (zero-tension lysimeters) and soil solution (suction-cup lysimeters). The gravity lysimeters were located at a depth of 5, 20 and 40 cm, and the suction-cup lysimeters at 20 and 40 cm.

Samples were collected at about two-week intervals during June–August, 1996.

The effects of transportation and filtration on sample pH were investigated by means of a number of different pre-treatment combinations carried out on parallel sub-samples: 1) pH measurement prior to filtration in the field, 2) pH measurement in the field following filtration, 3) pH measurement in the laboratory prior to filtration, and 4) pH measurement following filtration in the laboratory. The effect of storage on aluminium fractionation was investigated by keeping the samples at +4 °C for two weeks, and of freezing by subjecting the samples to storage for two weeks at -20 °C. Dissolved Al was speciated by two methods using a cation exchange technique.

1) The ICP/AES method. Inductively coupled plasma atomic emission spectrometry (ICP/AES) is an analytical technique used to determine total amounts of elements (e.g. Al) in aqueous solutions, irrespective of the chemical compounds in which they occur. Thus the ICP/AES result obtained by analysing the solution before it passes through the cation exchange column containing Amberlite IR 120 is called "total Al", and that for the solution after passing through the column is "total, non-exchangeable Al". Subtracting the two gives "exchangeable Al", i.e. Al^{3+}.

2) The FIA method. The flow injection analysis (FIA) method used for determining aluminium is a colorimetric method in which certain aluminium species react with a reagent to give a coloured solution. The FIA result obtained by analysing the solution before it passes through the cation exchange column is called "reactive Al", and that for the solution after passing through the column is "reactive, non-exchangeable Al". Subtracting the two components gives "exchangeable Al".

In the cation exchange treatment positively charged Al species (mainly inorganic cations) are retained in the exchange column, while non- and negatively charged species (mainly organic complexes and polymorphic Al hydroxides) pass through the column.

Results

The concentration of exchangeable Al determined indirectly by the ICP/AES and FIA methods is shown in Fig. 1. The exchangeable Al concentrations by ICP/AES were only slightly higher than the corresponding values by FIA. Thus, either of these two techniques can be used for determining exchangeable Al. It is recommended, however, to choose only one method for monitoring purposes to minimise the variation in the results caused by the small differences between these two Al speciation methods.

A time lag of a few hours to two days between sampling and analysis appeared to have no effect on total Al concentrations, even though the samples were not conserved with acid. Freezing the samples was not an appropriate storage technique because it resulted in a strong decrease in total Al concentrations. Storage (+4 °C) had a detrimental effect on the proportions of exchangeable and non-exchangeable Al, but this problem can be overcome by fractionating the samples immediately on arrival at the laboratory before storage. When the pH of the fraction was adjusted to <3.7, the fractionated sample could be stored for at least 2 weeks before analysis by ICP/AES or FIA. Transportation and filtration had only a very small effect on sample pH. The potential toxicity of soil water Al to forest ecosystems was estimated only at the plots located at Tammela, southern Finland. The mean concentrations of exchangeable Al in the spruce stand were 0.40 mg/l (ICP/AES method) and 0.29 mg/l (FIA method) at a depth of 20 cm (Fig. 1). The corresponding values at 40 cm depth were 0.27 and 0.20 mg/l. The exchangeable Al concentrations in the pine stand were 0.95 mg/l (ICP/AES method) and 0.71 mg/l (FIA method) at a depth of 20 cm. The concentration decreased with increasing soil depth. The mean concentrations of exchangeable Al were 0.58 mg/l (ICP/AES method) and 0.49 mg/l (FIA method) at 40 cm depth in the pine stand at Tammela. These values are well below the soil solution Al^{3+} concentration of 2 mg/l that is considered critical with respect to root and mycorrhizal activity (De Vries 1993).

The relative proportion of exchangeable Al out of the total Al concentration was lower at a depth of 5 cm compared to that at 20 and 40 cm (Fig. 2). This indicates that a high proportion of the Al in the soil solution is in the form of organic complexes at a depth of 5 cm. Because the organic complexes are non-toxic Al species, Al speciation is an important tool in estimating Al toxicity.

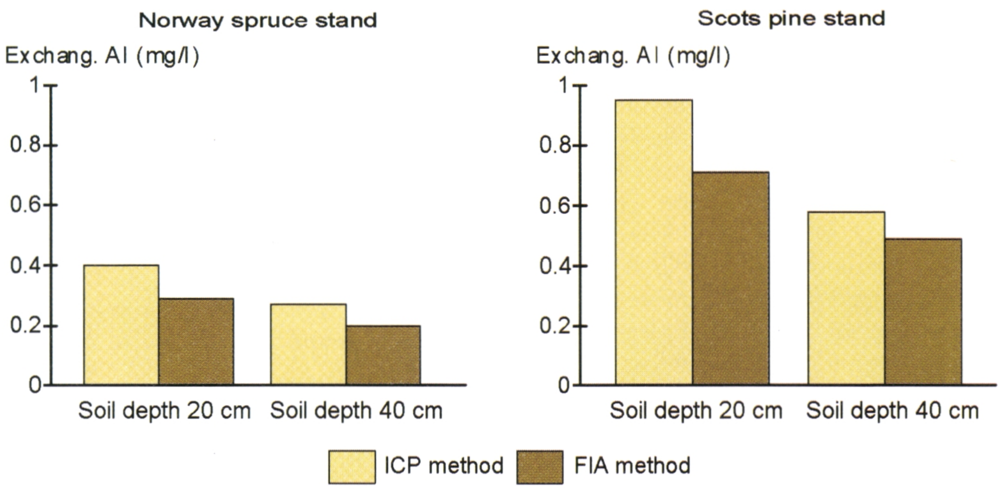

Figure 1. The mean concentration of soil solution exchangeable Al in two level II plots located at Tammela in southern Finland. The samples have bee collected using suction-cup lysimeters.

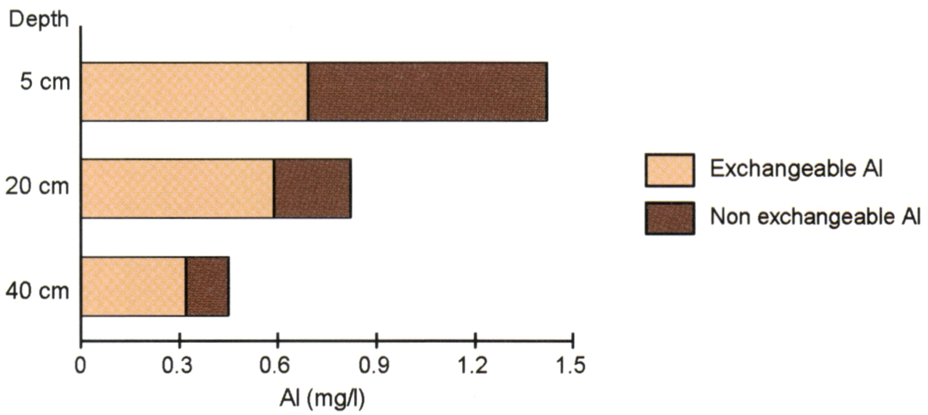

Figure 2. The mean concentration of total Al in soil water collected by suction cup and percolation water lysimeters. The concentrations of exchangeable and non exchangeable Al are also presented. The samples have been collected from the Tammela level II plot (Spruce stand) at depths of 5, 20 and 40 cm, and Al concentrations.

Conclusions

The results of this pilot study are rather promising as regards the major problem in analysing a relatively large number of samples during the growing period, namely how to fractionate and analyse soil water samples as rapidly as possible at a time when many of the laboratory staff are taking their summer vacation. If the samples are fractionated on a cation exchange column immediately after arrival in the laboratory, the actual analysis of the fractions by FIA can be postponed for up to two weeks. This considerably increases the flexibility of the laboratory.

There do not appear to be any major problems associated with the transport, pre-treatment and storage of the samples, as long as the first two steps are carried out as rapidly as possible. Adjustment of the pH of both unfractionated and fractionated water samples to a constant value appears to be extremely important in the determination of reactive Al by FIA.

References

Derome, J. 1989. Acid induced aluminium mobilization in Finnish mineral soils. In: Kämäri, J., Brakke, D.F., Jenkins, A., Norton, S.A. & Wright, R.F. (Eds.). Regional acidification models, Springer-Verlag, Berlin. pp. 23–30.

de Vries, W. 1993. Average critical loads for nitrogen and sulphur and its use in acidification abatement policy in the Netherlands. Water, Air and Soil Pollution 68: 399–434.

Foy, C.D. 1988. Plant adaptation to acid, aluminium soils. Communicationes in Soil Science and Plant Analysis 19: 959–987.

Lindroos, A-J., Derome, J. & Niska, K. 1995. The relationship between dissolved organic matter and percolation water chemistry in Northern Finland. Water, Air and Soil Pollution 79: 191–200.

Lundström, U.S. 1993. The role of organic acids in soil solution chemistry of a podsolized soil. Journal of Soil Science 44: 121–133.

Matzner, E. & Murach, D. 1995. Soil changes induced by air pollutant deposition and their implication for forests in Central Europe. Water, Air and Soil Pollution 85: 63–76.

Sverdrup, H. & De Vries, W. 1994. Calculating critical loads for acidity with the simple mass balance method. Water, Air and Soil Pollution 72: 143–162.

7.3 Comparison of soil water and percolation water quality

John Derome[1], Antti-Jussi Lindroos[2] and Kaarina Niska[1]

[1] Finnish Forest Research Institute
Rovaniemi Research Station
P.O. Box 16, FIN-96301 Rovaniemi, Finland

[2] Finnish Forest Research Institute
Vantaa Research Centre
P.O. Box 18, FIN-01301 Vantaa, Finland

Background

Soil water and percolation water quality have been widely used in monitoring and estimating the acidity and nutrient status of forest soils. For example, several of the studies carried out in Finland on forest soil processes have been based on soil water quality, soil solution having been sampled by means of suction-cup lysimeters (e.g. Starr 1985, Starr & Ukonmaanaho 1995, Lindroos 1991) or zero-tension lysimeters (e.g. Helmisaari & Mälkönen 1989, Lindroos et al. 1995, 1996). The choice of method is important because the water obtained using suction lysimeters can comprise different fractions of the water present in the soil. Contact between the gravity water percolating down through the soil profile and the soil particles is much weaker than that between the soil particles and soil water bound on the particle surfaces. Zero tension lysimeters collect percolation water filtering down through the soil profile, while suction-cup lysimeters sample percolation water as well as to some extent the water bound on the soil particles. In theory, the chemical composition of the different fractions of the soil solution reflect different processes taking place in the soil, thus leading to problems when attempting to make direct comparisons between soil solution data obtained using different techniques.

Aims

The aim of the project was to compare soil water (suction cup lysimeters) and percolation water (gravity lysimeters) quality on 4 of the plots (Juupajoki, Norway spruce and Scots pine; Tammela, Norway spruce and Scots pine) established as part of the Finnish intensive (level II), continuous observation plot network. Soil water quality was compared on the basis of the concentrations of inorganic components in the water samples obtained during two growing seasons (1995 and 1996).

Implementation

In this study two types of lysimeter were used: zero-tension lysimeters (for details see Derome et al. 1991) and suction-cup lysimeters (porcelain cups, P80, pore size <2 mm). The zero-tension lysimeters were inserted at depths of 5, 20 and 40 cm measured from the ground surface. Suction-cup lysimeters were installed only at depths of 20 and 40 cm. The lysimeters were located systematically on the plots, with 5 replications per depth in the case of the zero-tension lysimeters, and 6 replications per depth for the suction-cup lysimeters. The water samples were collected at approximately 1-month intervals at the same time as deposition samples. The samples were filtered through membrane filters (0.45 mm). The filtrate was conserved with suprapure concentrated HNO_3 for the determination of Ca, Mg, K, Na, Al, Fe, Mn and total S and P by inductively coupled plasma atomic emission spectrometry (ICP/AES), as well as DOC on a TOC analyser. NH_4-N, Ca, Mg, Na, K, NO_3-N, Cl, SO_4-S, PO_4-P were determined on unconserved samples by ion chromatography (IC), and total-N by flow injection analysis (FIA).

Results

The pH of soil water collected by the zero-tension lysimeter (percolation water) and suction-cup lysimeters (soil water) showed relatively little variation throughout the growing season (Fig. 1). However, mean percolation water pH was more acidic at both 20 and 40 cm depths than that of soil water (Tables 1 and 2). There was considerable variation during the growing season in the total Al concentration of percolation and soil water (Fig. 2). Mean total Al concentrations in percolation water at 20 and 40 cm depths were higher than those in soil water (Tables 1 and 2).

There was relatively little variation in the Ca, Mg and K concentrations of percolation and soil water during the growing season. The mean Ca and Mg concentrations in percolation water and soil water were very similar and there were no clear trends between 20 and 40 cm depths. Mean K concentrations in percolation water were significantly higher at 20 cm than those in soil water. There were no clear trends in the NH_4-N concentrations during the growing season between the two types of lysimeter at 20 or 40 cm depths. In contrast, the mean SO_4-S concentrations in soil water were higher than those in percolation water.

Conclusions and recommendations

The most marked differences in the chemical composition of soil solution collected using zero-tension lysimeters and suction cup lysimeters were restricted to pH and total Al, K and SO_4 concentrations. This supports the assumption that the chemical composition of percolation water reflects soil-formation processes (pH and Al), nutrient cycling (especially K) and the anthropogenic input derived from deposition in the forest. The soil water obtained using suction-cup lysimeters, on the other hand, appears to rather well reflect the situation after buffering/neutralisation processes have taken their course. It is therefore recommended that both types of lysimeter should be used in monitoring work on forest condition, since the information they provide is complementary rather than repetitive. Although it is generally accepted that zero-tension lysimeters are the best solution for sampling soil solution immediately below the organic layer, they can also be inserted successfully on stony till soils. This is primarily a technical problem and, if inserted carefully without excessively disturbing the soil structure, they appear to provide a relatively correct picture of percolation water quality.

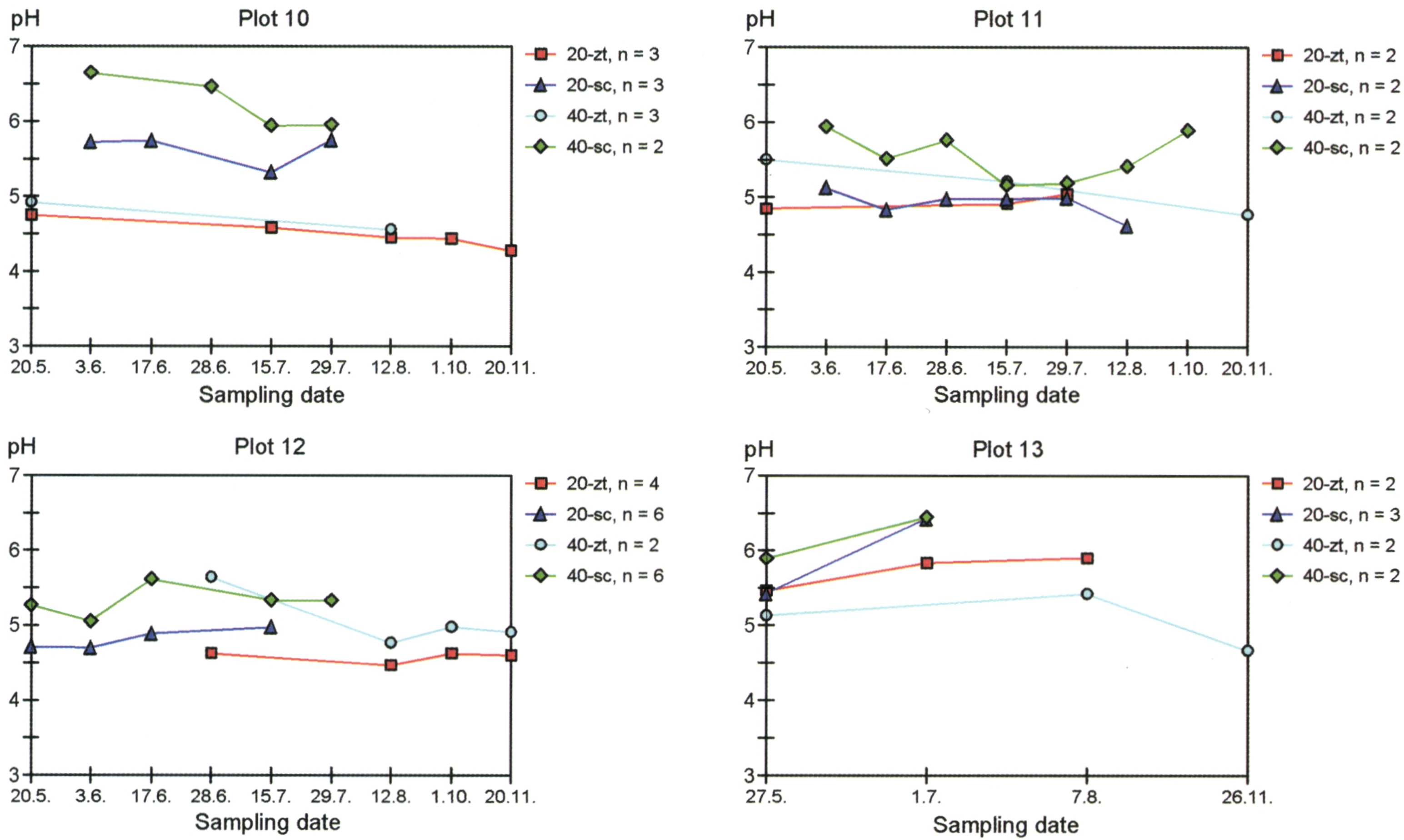

Figure 1. Mean pH of soil water on different sampling dates at 20 and 40 cm depths obtained using zero-tension lysimeters (zt) and suction-cup lysimeters (sc). Plots 10-14. The thick lines join values obtained on consecutive sampling dates. The thinner lines join non-consecutive values, and have been added to assist in interpretation.

Table 1. Mean pH and K, Mg, Ca, NH4-N, SO4-S and total Al concentrations in soil water obtained using zero-tension lysimeters (ZT) and suction-cup lysimeters (SC) at a depth of 20 cm at the four intensive monitoring plots in 1996. The number in paranetheses indicates the number of observations.

	Juupajoki, pine		Juupajoki, spruce		Tammela, spruce		Tammela, pine	
	ZT	SC	ZT	SC	ZT	SC	ZT	SC
	(15)	(12)	(5)	(12)	(1)6	(21)	(6)	(6)
pH	4.50	5.64***	4.87	4.92	4.59	4.80***	5.73	5.93
	0.21	0.40	0.10	0.40	0.11	0.26	0.33	0.57
K	2.04	0.38***	0.26	0.05**	0.98	0.35**	2.77	0.86*
	0.86	0.16	0.27	0.02	0.90	0.16	1.69	0.58
Mg	0.50	0.44	3.12	0.30***	0.62	0.62	0.38	0.46
	0.34	0.12	2.47	0.12	0.15	0.16	0.21	0.03
Ca	0.99	1.18	1.36	1.50	1.18	1.14	2.29	1.94
	0.62	0.33	0.60	0.42	0.30	0.38	1.12	0.27
NH4-N	0.06	0.04*	0.19	0.01**	0.08	0.13*	0.42	0.08
	0.03	0.01	0.23	0.01	0.06	0.08	0.66	0.04
SO4-S	1.64	1.79	2.85	2.57	3.71	8.65***	4.80	5.67
	1.43	0.61	0.86	1.17	0.95	3.24	2.40	0.48
Altot	0.85	0.24***	1.02	0.68	1.09	0.99	0.46	0.43
	0.33	0.08	0.50	0.37	0.46	0.40	0.20	0.16

Table 2. Mean pH and K, Mg, Ca, NH_4-N, SO_4-S and total Al concentrations in soil water obtained using zero-tension lysimeters (ZT) and suction-cup lysimeters (SC) at a depth of 40 cm at four intensive monitoring plots in 1996. The number in paranetheses indicates the number of observations.

	Juupajoki, pine		Juupajoki, spruce		Tammela, spruce		Tammela, pine	
	ZT	SC	ZT	SC	ZT	SC	ZT	SC
	(6)	(8)	(6)	(14)	(8)	(28)	(6)	(6)
pH	4.74	6.26***	5.16	5.56*	5.08	5.33	5.08	6.17***
	0.27	0.36	0.41	0.35	0.56	0.58	0.38	0.43
K	1.20	2.06	0.09	0.07*	0.25	0.21	0.46	0.44
	0.57	3.89	0.02	0.03	0.22	0.12	0.15	0.18
Mg	0.39	0.45	0.35	0.58*	0.72	0.21***	0.39	0.61**
	0.16	0.19	0.14	0.24	0.39	0.12	0.12	0.08
Ca	0.96	0.96	2.47	2.76	1.26	1.96***	2.50	3.13
	0.42	0.32	1.22	2.18	0.46	0.29	1.57	0.33
NH_4-N	0.07	0.96***	0.02	0.00	0.09	0.15	0.18	0.15
	0.05	0.32	0.03	0.01	0.11	0.09	0.08	0.11
SO_4-S	2.09	2.00	3.77	4.33	3.65	9.65***	4.52	6.71
	1.36	0.32	1.37	2.13	0.66	4.78	2.10	1.37
Altot	0.52	0.04***	0.28	0.31	0.54	0.48	0.28	0.62***
	0.18	0.04	0.25	0.14	0.42	0.42	0.13	0.06

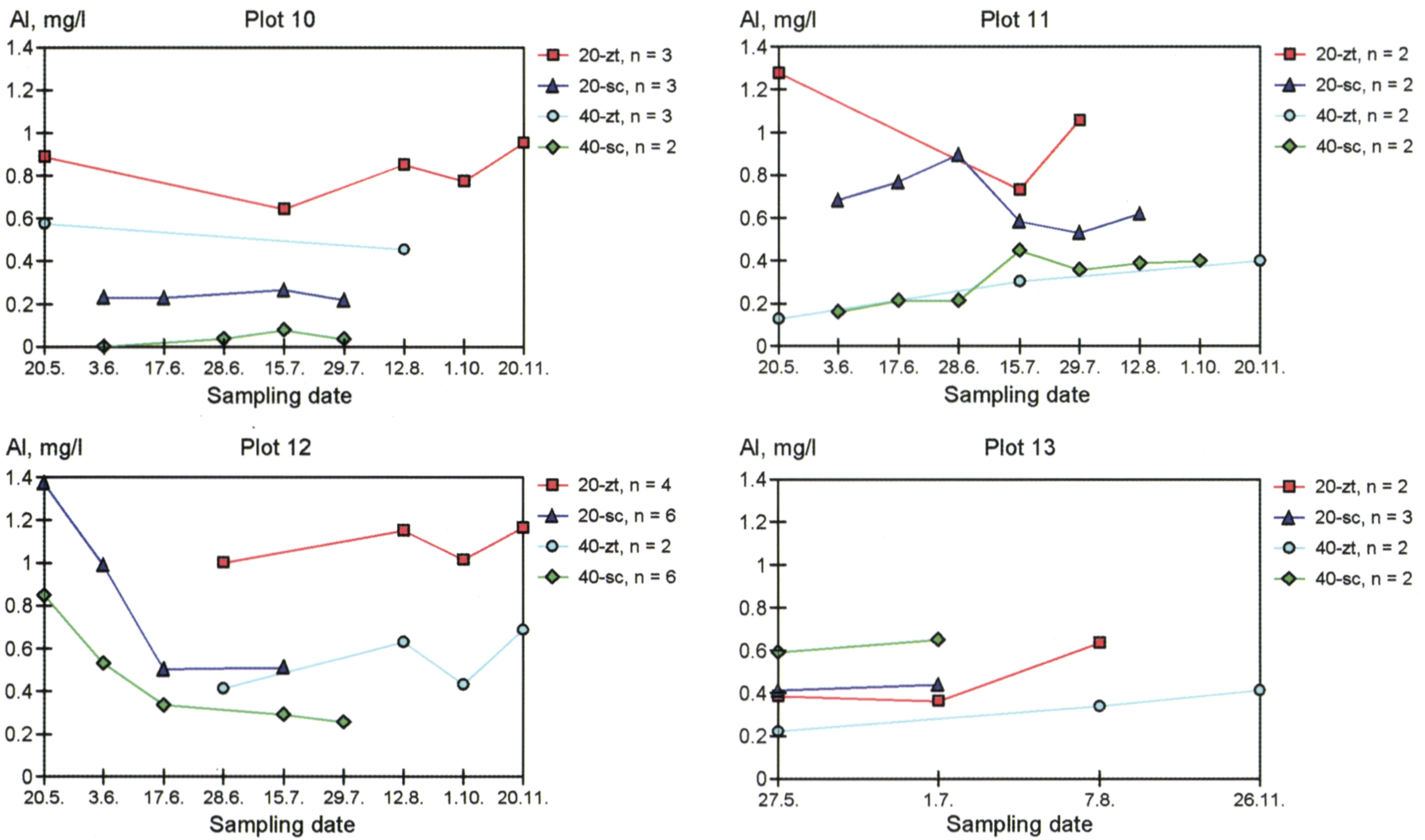

Figure 2. Mean total Al concentration of soil water on different sampling dates at 20 and 40 cm depths obtained using zero-tension lysimeters (zt) and suction-cup lysimeters (sc). Plots 10-14. The thick lines join values obtained on consecutive sampling dates. The thinner lines join non-consecutive values, and have been added to assist in interpretation.

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: Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. Tikkanen, E. & Varmola, M. (Eds.). The Finnish Forest Research Institute. Research Papers 373: 49–76.

Helmisaari, H.S. & Mälkönen, E. 1989. Acidity and nutrient content of throughfall and soil leachate in three Pinus sylvestris stands. Scandinavian Journal of Forest Research 4: 13–28.

Lindroos, A.-J. 1991. The neutralization of acidic rainwater in soil. Geological Survey of Finland. Report of Investigation 105: 57–63. (In Finnish with English summary).

Lindroos, A.-J., Derome, J. & Niska, K. 1995. The relationship between dissolved organic matter and percolation water chemistry in Northern Finland. Water, Air and Soil Pollution 79: 191–200.

Lindroos, A.-J., Derome, J., Nikonov, V. & Niska, K. 1996. Influence of sulphur and heavy metal emissions from Monchegorsk, Northwest Russia, on percolation water quality in Pinus sylvestris stands. Scandinavian Journal of Forestry Research 11: 97–103.

Starr, M. 1985. Variation in the quality of tension lysimeter soil water samples from a Finnish forest soil. Soil Science 140: 453–461.

Starr, M. & Ukonmaanaho. L. 1995. Soil water. In: Bergström, I., Mäkelä, K. & Starr, M. (Eds.). Integrated monitoring programme in Finland. First national report. Ministry of Environment, Environment policy department, Report 1: 74–75.

7.4 Seasonal variation in the size and chemical composition of Scots pine and Norway spruce needles in different weather conditions

Hannu Raitio and Päivi Merilä

Finnish Forest Research Institute
Parkano Research Station
Kaironiementie 54, FIN-39700 Parkano, Finland

Background

Chemical foliar analysis is a widely used diagnostic and monitoring method in forestry and environmental studies. The results of the first survey of the chemical composition of needles and leaves carried out on the systematic grid in the framework of the ICP Forests Level I and the European Union Scheme on the Protection of Forests against Atmospheric Pollution were published in 1997 (EC-UN/ECE et al. 1997). The ICP Forests Level II monitors also both the size and chemical composition of tree foliages through chemical analyses conducted every second year. The first results of this monitoring were published in 1998 (EC-UN/ECE et al. 1998).

A large number of factors affect the concentration of elements in needles and leaves (Raitio 1995). One of the main factors is the seasonal variation. These factors need to be taken into account for sampling and for an adequate interpretation of the results.

Aims

The aim of the pilot study was to investigate the seasonal variation in the size and chemical composition of Scots pine and Norway spruce needles under different climatic conditions, and thus to improve the sampling and interpretation of the chemical foliar analysis used in the Pan-European Intensive Monitoring Programme of Forest Ecosystems.

Sampling and analyses

The needle samples were collected from 6 intensive (level II) monitoring plots in the Finnish network, three of which are spruce stands and the other three pine stands (Raitio & Merilä 1998). The current (C), one-year-old (C+1) and two-year-old (C+2) needles were collected at two-week intervals during the growing season (May–October), and the C and C+1 needles were collected once a month during the rest of the year (January–April, November–December). The shoot length, and the dry mass and length of the needles were determined. A total of five composite samples of each needle year class/plot/sampling time were prepared for the chemical analyses. The total concentrations of C, N, P, K, Ca, Mg, S, Fe, Cu, Zn, Mn, Al and B in the needles were determined. The weather conditions (air temperature, precipitation) were measured on 3 of the 6 monitoring plots.

Results and discussion

Needle elongation of pine began when the temperature sum (threshold +5 °C) had reached approximately 200 d.d. Needle growth ceased on the southern plots when the temperature sum was ca. 800 d.d. This value was not reached at the northernmost plot at Pallasjärvi. The shoot elongation period for pine was from ca. 150 d.d. to 300 d.d. For spruce, both needle and shoot elongation began when the temperature sum had reached ca. 100 d.d., and continued up to a temperature sum of ca. 300 d.d.

The pattern of seasonal variation in element concentrations was rather similar in both tree species. However, the concentrations in spruce and pine needles were at different levels. Seasonal variation in the element concentrations is highly dependent on changes in the dry weight of the needles, especially in pine: needle dry weight explained 53–84 % of the variation in the N concentration of the C+1 and C+2 pine needles. Nutrient retranslocation was more evident in the north than in the south. This difference might reflect the higher growth rate of the needles in the north.

The current spruce needles in Pallasjärvi became infected with spruce needle rust (*Chrysomyxa ledi* (Alb. & Schw.) deBary). They had clearly higher K, Zn, B, Fe and Al concentrations already before the needles showed visual symptoms.

Conclusions

In order to ensure the comparability of the results of needle nutrient analysis, it is essential to sample needles during the period when there is no needle dry weight fluctuation and nutrient retranslocation. In Finland this covers the time period from the beginning of November up until the end of March, continuing in northern Finland up until the end of April.

References

EC-UN/ECE, Stefan, K., Fürst A., Hacker R. & Bartels, U. 1997. Forest Foliar Condition in Europe – Results of large-scale foliar chemistry surveys (survey 1995 and data from previous years). EC, UN/ECE, Austrian Federal Forest Research Centre. 207 p.

EC-UN/ECE, De Vries, W., Reinds, G.J., Deelstra, H. D., Klap, J.M. & Vel, E. 1998. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report 1998. EC-UN/ECE, Brussels, Geneva. 193 p.

Raitio, H. 1995. Chemical needle analysis as a diagnostic and monitoring method. In: Nilsson, L. O., Hüttl, R. F., Johansson, U. T. & Mathy, P. (Eds.). Nutrient uptake and cycling in forest ecosystems. Proceedings of a symposium held in Halmstad, Sweden 7–10 June 1993. European Commission Ecosystem research report No. 21: 197–206

Raitio, H. & Merilä, P. 1998. Seasonal variation in the size and chemical composition of Scots pine and Norway spruce needles in different weather conditions. Technical Report of the EU research project No. 96.60.SF.003.0. Finnish Forest Research Institute, Parkano Research Station. 44 p.

7.5 Airborne imaging spectrometer (AISA) in forest inventory and forest health monitoring

Erkki Tomppo, Anssi Pekkarinen, Ville Kankaanhuhta, Kai Mäkisara and Helena Henttonen

National Forest Inventory, Finnish Forest Research Institute,
Unioninkatu 40 A, 00170 Helsinki, Finland

Introduction

Background

Concern about forest health increased in Europe in the end of 1970s. Several reasons were behind the forest decline observed in wide areas. Examples are depositions of pollutants, transboundary air pollution, and some dry growing seasons. People have also been worried about the environment and the degree of utilisation of forests world-wide. Several special studies related to forest condition assessments were conducted in Europe and forest health monitoring networks were established. One of the most important efforts is the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), established by the United Nations Economic Commission for Europe (UN/ECE). Today, 35 European countries (including all EU Member States), the United States of America, and Canada participate in the monitoring which comprises both extensive (Level I) and intensive (Level II) monitoring (United Nations / Economic Comission for Europe 1997).

Forest ecosystem is very complicated and causes of damage and causalities in forests are not fully understood. Other than air pollution damage, e.g. biotic damage cause economically higher losses in many areas, e.g. in the Boreal Zone. However, the lowered vitality of trees may also increase biotic damage.

A problem in many forest health studies, especially in large area monitoring systems, is that either very expensive measurements on each plot have to be done or some indirect measurements about forest vitality have to be applied. The conclusion is that many experts are not fully satisfied with the present systems, and new ways for efficient forest and forest health monitoring are needed.

The Finnish multi-source national forest inventory

Finland's forest resources have been investigated by means National Forest Inventories since the year 1921 (Ilvessalo 1927). So far, eight inventories have been completed. During the eighth inventory (1986–1994), a multi-source inventory system was developed. It utilises satellite images and digital map data in addition to ground measurements (Tomppo 1991, 1993). The nineth inventory, began in 1996. It also contains the measurement of some additional characteristics describing forest biodiversity. The Finnish Forest Research Institute has been responsible for all the inventories.

The multi-source inventory produces both statistics and digital thematic maps for the computation units. Compared to the inventory methods employing only sampling and field measurements, the multi-source inventory provides much more detailed information about forests at very low additional costs. The method can be applied with minor modifications to very different types of forests and to different remote sensing material.

The most serious problem in applying the satellite image based multi-source inventory method are clouds which often prevent from obtaining images from the growing season of field measurements. This difficulty can be avoided with new air- and space-borne remote sensing instruments which will also bring more accurate information. These have already been studied by Finnish National Forest Inventory team (Mäkisara & Tomppo 1996, Tomppo et al. 1995).

Field measurements of the Finnish NFI

Field sample plots are used to estimate results for large areas and also as ground truth data in the satellite image analysis.The field sampling design was renewed during the eighth inventory rotation and further improved for the ninth inventory.

The distance between two sampling clusters varies from south to north according to the density and variability of forests. The distance is 7 kilometres in Southern and Central Finland both in the south-north and east-west directions. Every fourth cluster consists of permanent field plots and other clusters consists temporary field plots. One cluster contains 18 temporary or 14 permanent sample plots. The coordinates of the trees on permanent plots are registered in order to identify them during the next inventory.

Bitterlich sample plots is used. Tallied trees are selected with a relascope. The relascopic factor varies by region, from south to north and west to east, depending on the density of the forests and is 2 in Central Finland. The maximum radius is 12.52 metres (corresponding to the breast-height-diameter of 34.5 cm with the relascope factor 2).

The characteristics measured in the field were checked and revised and some characteristics were added for the ninth rotation. Examples of the new characteristics are variables describing forest biodiversity. The characteristics related to forest health were also checked, modified and completed. The number of the damage causing agents and the number of damage types recorded were increased. The defoliation assessment methodology was also improved in co-operation with the Finnish ICP Forest group to make the NFI and ICP results directly comparable in future.

Field measurements can be divided into stand level data and tree level data. The total number of measured variables amounts to about 150. A part of stand level data is given by crown layer classes. Tree level data area measured at two different levels of intensity. Few variables are measured from tally trees. Variables which do not vary much at stand level (or can be estimated from tally tree measurements) are measured for sample trees (every nth tally tree, with n e.g. 7). Totally 70 000 field plots and 0.5 million trees were measured in the eighth inventory.

Variables describing forest health and damages are assessed concerning the whole stand and also for sample trees. Forest health is assessed in the National Forest Inventory by recording several attributes. The attributes recorded from sample plots are 1) description of damage, 2) age of damage, 3) damaging agent and 4) degree of damage. Effect of damaging agents are also taken into account when assessing the silvicultural quality of stand. Amount of beard lichen and leaf lichens on tally trees and amount of Scoliciosporum clorococcum and Desmococcus olivaeus are recorded from permanent sample plots. Damages in sample trees are recorded with same attributes as in stand level, although e.g. degree of damage is recorded more precisely concentrating on a vitality of single tree.

Description of damage defines visual observation of the damage. Age of damage defines time, when the damage has originated. The damaging agents are divided into four main classes: 1) abiotic, 2) animals including both vertebrates and invertebrates, 3) fungal species and 4) other factors, e.g. competition between trees and between undergrowth.

Degree of damage is one of the factors which affects stand quality. Stand quality is divided into four classes: good, satisfactory, adequate and under-productive. A stand is under-productive, if the yield without special treatment has reached the limit of regeneration. Degree of damage is considered total if the stand has changed to under-productive and it has to be regenerated immediately. Severe damages decreases the quality of stand more than one class, observable damage decreases stand quality with one class and light damage does not affect the quality of stand.

Forest damages were observed in 8.30 million hectares (41 % of forestry land) in the eight National Forest inventory and its update (1989–1994). Damages decreasing stand quality was in 4.45 million ha, which is 22 % of forestry land. Total damage was observed in 37 000 ha, severe damage in 640 000 ha and observable damage in 3.47 million ha.

Further improvement of the Finnish multi-source NFI (MSNFI)

Forestry and the forest industries are changing rapidly and new information needs have appeared. Mechanised mobile harvesting machinery and high speed processing facilities have reduced the time between the decision to harvest and delivery of a specific timber end product to less than one week. On the other hand, forestry has to increasingly meet strict environmental standards and to achieve "sustainability" in its widest sense.

An increasing concern about the loss of biological diversity, caused, e.g., by forestry and other human activities and human induced climate changes, has increased interest in the whole forest ecosystem. Forests have also been seen as having a role in slowing down the of global warming by binding the increasing amount of carbon dioxide in the atmosphere.

With new remote sensing data and new methods to analyse the data the multi-source inventory method will further be developed to meet the coming information needs related to monitoring of forest resources, forest biodiversity and forest health.

Main advantages of the MSNFI

The multi-source inventory method developed at the Finnish Forest Research Institute has been tested also in some other countries. The main advantages of the method are:

- much more detailed information about forests can be obtained with very low additional costs compared to the inventory methods which employ only sampling and field measurements
- the method is more statistically oriented than the old classification-based approach to use satellite images
- in principle, all variables can be estimated for each computation unit, which is not possible with ordinary classification methods
- the method preserves the natural dependency structure between the forest parameters
- the method can be applied with minor modifications to very different types of forests
- the method can directly use different optical remote sensing material

Objectives of the study

The object of the project was to develop forest health monitoring method which utilises field observations and airborne imaging spectrometer measurements.

The problems to be studied are:

1. Is it possible to utilise AISA instrument in an operative large area forest health monitoring system?
2. What kind of diseases can be detected from the spectrum of trees?
3. Is it possible to recognise early defects of trees?
4. Is it possible to estimate needle mass and biomass of trees with AISA measurements and what will be the accuracy?
5. What is the connection between increment of a tree and a coming disease, how early a coming disease affects on the increment of the system?

In addition to find new methods for forest health monitoring, one goal was to further develop multi-source Finnish National Forest Inventory.

The AISA spectrometer data

Metla has purchased an AISA (Airborne Imaging Spectrometer for Applications) spectrometer (Mäkisara et al. 1993) in 1995. The instrument was the first so-called pre-series AISA delivered by the company Karelsilva in Finland. The AISA spectrometers are currently developed, manufactured, and marketed by Spectral Imaging, Ltd., in Finland.

AISA is a low-cost push-broom imaging spectrometer that was designed from the beginning for both research and operational work. It uses a CCD sensor matrix with 384 columns (spatial dimension) and 286 rows (spectral dimension). The wavelength range of the system at Metla is 450–870 nm, leading to basic spectral channel of 1.6 nm. The tape recorder of the instrument can record 375 000 image samples per second (12 bits per sample), which is not fast enough for recording all data from the CCD matrix during flight. Because of this, the instrument has been made programmable so that the user can select the spectral channels and/or spatial samples that are stored.

In this study, all spatial samples were stored but only for 30 spectral channels. The channel configuration is shown in Fig. 1 together with a typical spectrum of vegetation.

The flight altitude was 1600 meters. This, together with the pixel integration time and flight velocity, determined the pixel size on ground in the raw data. It was 1.6 meters across the flight track and about 1.9 meters along the flight track.

The data was radiometrically and geometrically corrected before use with the GEOVIS system (Mäkisara et al. 1994). The radiometric correction transformed the digital numbers into unit of radiance as seen by the instrument. No atmospheric correction was performed. The geometric correction assembled geocoded images from one or more flight lines. Differential GPS data, attitude sensor data, a digital terrain model, and ground control points shown by operator were used in geometric correction. The pixel size in the geocoded images was 1.6 by 1.6 meters.

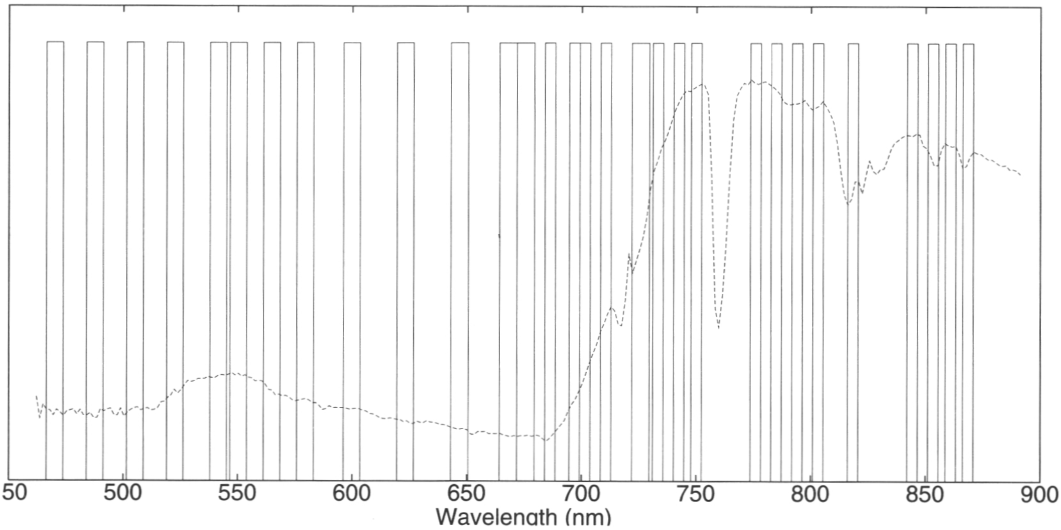

Figure 1. The spectral channel configuration (from Mäkisara et al. 1997).

Summary

The object of the project was to develop air-borne and space-borne remote sensing aided methods especially for forest health, but also for forest resource monitoring. Field measurements, Airborne Imaging Spectrometer of Metla (AISA) and Landsat TM images were applied in the study. The original aim was also to study if is it possible to recognise early defects of trees. The test material did not enable to realise this because all damages were either old or such that spreading phenomenon was not present or obvious. One goal, in addition to find new methods for forest health monitoring, was to further develop multi-source Finnish National Forest Inventory which could be use at more global level in monitoring forest condition.

The damaging agents selected for the study were (A) air pollution damage on Scots pine around smelter of Harjavalta, (B) the pine bark bug, Aradus cinnamomeus (Panzer), on young Scots pine in Valkeala, (C) defoliation of Scots pine caused by the European pine sawfly, Neodiprion sertifer (Geoffr.), in Ruokolahti, and (D) all damages found in the test area of Mäntsälä, which was used to test AISA images in large scale forest inventories. All test areas are located in southern part of the country.

The purpose of selecting Harjavalta (Fig. 2) site was to test the capability of AISA in extreme severe Finnish damage condition in detecting different severity levels of damages. One purpose of estimating needle mass of trees by means of remote sensing data was to find new compensating methods for assessing vitality of trees, instead of needle loss. Needle mass modelling sites were also in South Finland, in Harjavalta, Loppi and Karkkila.

Image analysis methods were developed and tested for identification of damages. K -nn method is already in an operative use in Finnish multi-source national forest inventory. Different versions of this, modified for AISA data and damage monitoring, as well as non-parametric discriminant analysis were tested. Regression analysis and k-nn approach were applied in modelling needle biomass. The high spatial resolution of AISA needs a special attention in image analysis. Methods were developed for handling these problems.

Severity of damages in Harjavalta area were classified into four different classes, based on the distance from the smelter. All observations were correctly classified in the training phase of the image analysis. The test results were promising even with original pixel size of AISA. However, the use of pixel size of 24 m ´ 24 m (close to Landsat TM pixel size) and simulated TM channels improved the results. (The main advantage of AISA in damage monitoring is high spectral resolution.) The proportions of correctly classified observations in test material varied between 85–95 %, but were even better with Landsat TM, 95–96 % in three damage classes and 85 % in one damage class. The mid infrared band of TM seems to be important in damage severity detection. Spatial distribution of damage classes are shown in figure 3.

Pine Bark Bug Aradus Cinnamomeus damages were classified into three different classes on the bases of needle loss and discoloration, 0–29 %, 30–60 % and over 60 %. The accuracy of 85–91 % were achieved in the training phase and 51–90 % in the test phase. The most severe class can be identified most accurately.

Storm, Bark beetle, snow and Chrysomyxa ledi rust fungi damage were analysed in Ohkola test site. The damaged area were identified. Both damaged and nearby undamaged test areas were classified and cross-validation applied. The correctly classified proportion of observations were for storm damage, 96 % for damaged, 73 % for undamaged, for Bark beetle, 89 % for damaged, 96 % for undamaged. Not large enough test sites could be found for snow and Chrysomyxa ledi damages in order to detect the damages with AISA data.

Total above ground biomass was modelled with AISA data and estimated field data. The results showed some promise with spruce. The material was not large enough to analyse the estimation of needle mass only. The final

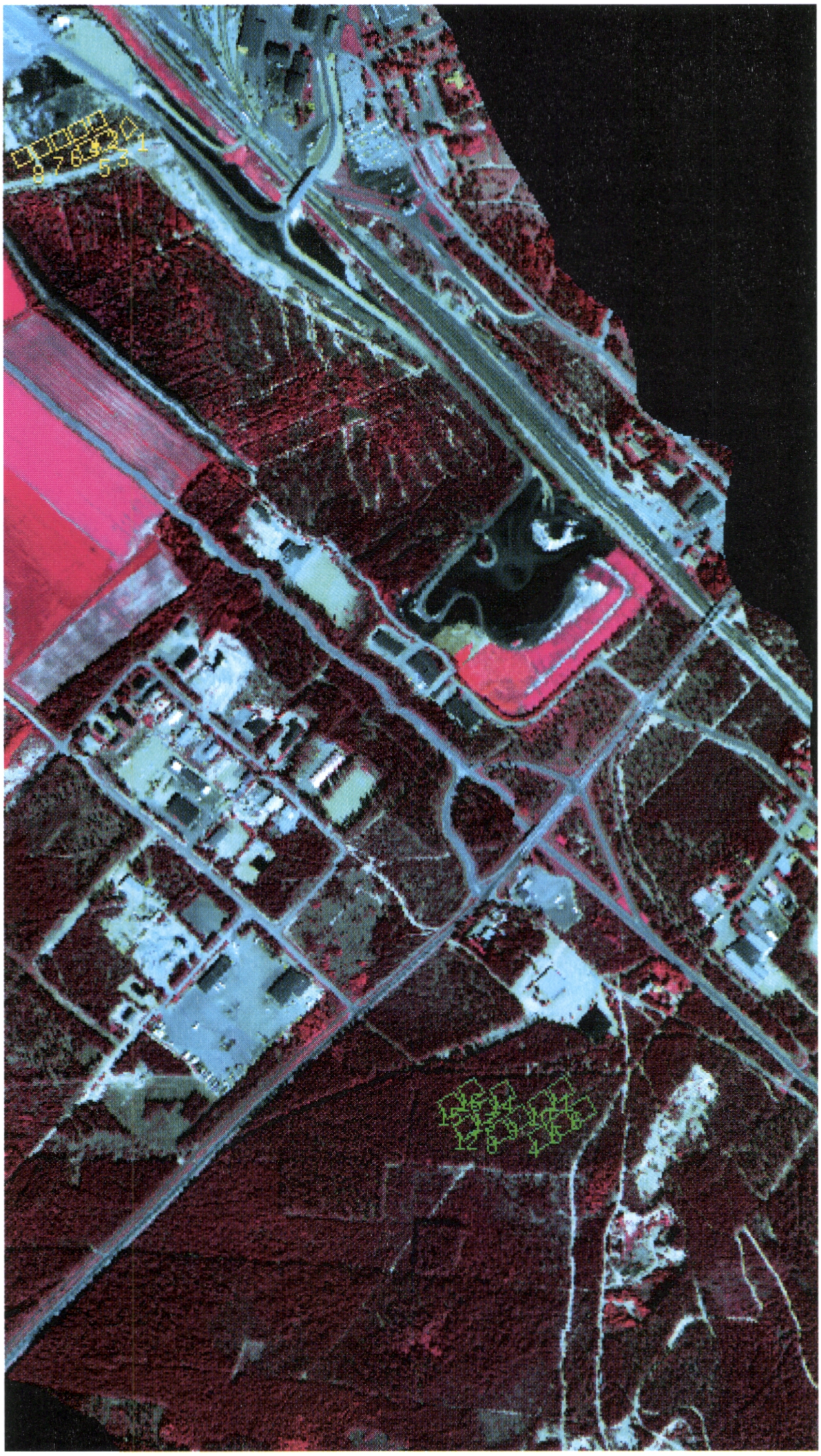

Figure 2. AISA image of the Harjavalta test area. The training areas 0.5 km from the smelter (top left corner) and the training areas 2.0 km from the smelter (lower right corner).

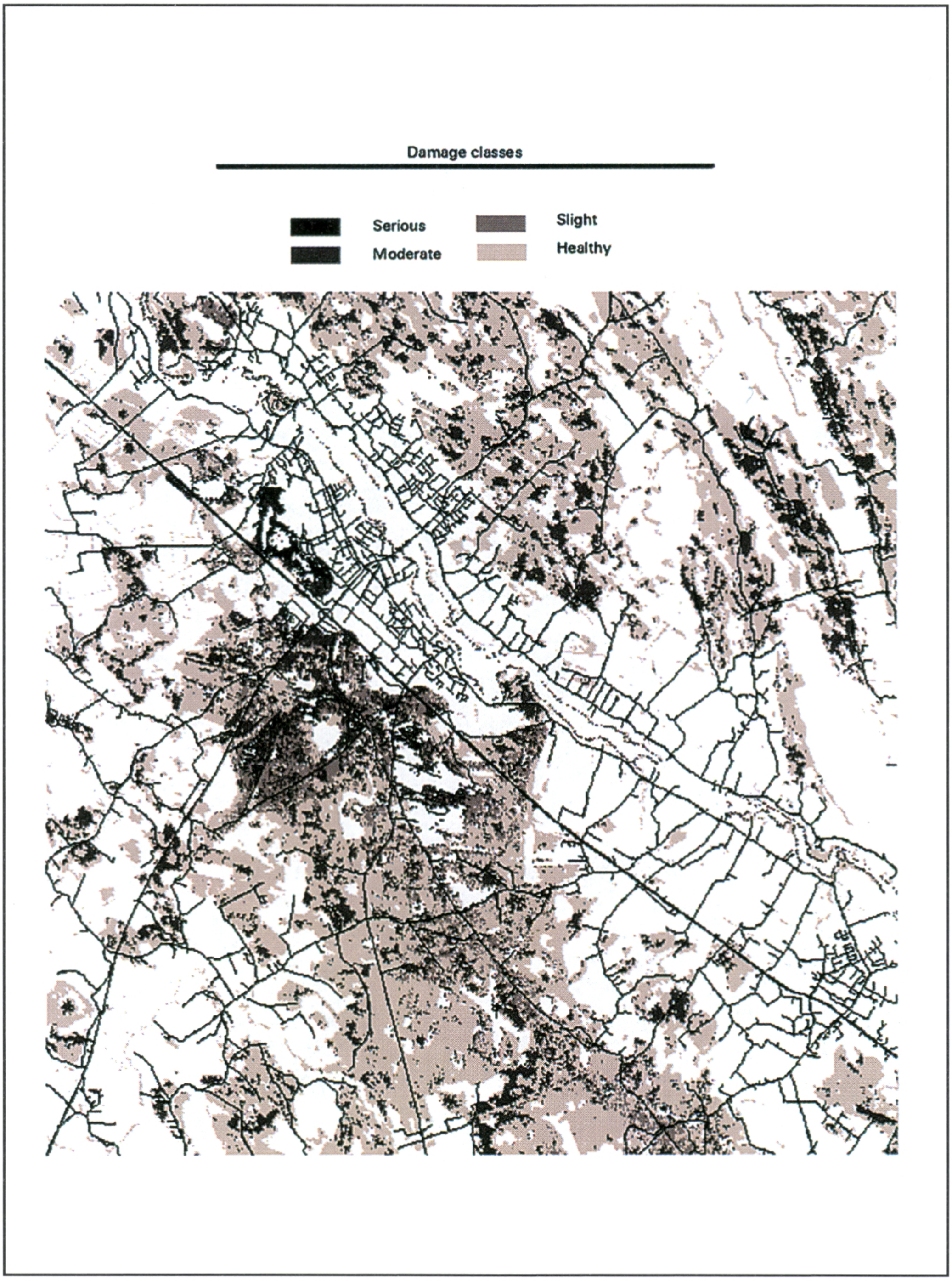

Figure 3. The results of the air pollution damage classification using Landsat TM channels 1 to 5 and 7.

conclusions regarding the feasibility of remote sensing based approach, e.g., to needle loss estimation, needs further analysis with more varying needle mass and biomass observations.

The analysis between damages and growth reduction showed that some damages clearly decrease volume growth. The most severe damage appearance class from the point of view of growth reduction is, as could be expected, top damage. The loss of relative volume increment for the damage younger than 5 years was between 20–30 %, and between 40–60 % for damage older than 5 years. Needle loss caused a growth reduction of about 10 % (for pine, damage younger than 5 years) and about 20–25 % (all tree species, damage older than 5 years). The appearance class 'abnormal dying of lower branches' caused a growth loss of 9–13 % with pine. The study will be extended to the analysis with different damage agents. The growth reduction analysis in different needle loss classes will also be done.

The study proved that air-borne remote sensing based on AISA instrument has potentiality in forest health monitoring. Landsat TM images are powerful in identifying large area damages. The studied damage areas were mostly small involving also undamaged patches wherefore the areas (except Harjavalta site) corresponded normal Finnish forests. Problems may occur in finding slight damages, especially if only small proportions of trees are affected by damages.

Development of further image analysis algorithms in recognition of each type of damage may improve slightly the accuracy. Spectral features seems to play an important role in damages identification. Spatial features may give additional information in a specific conditions.

References

Ilvessalo, Y. 1927. The Forests of Suomi (Finland). Results of the general survey of the forests of the country carried out during the years 1921–1924. Communicationes Ex Instituto Quaestionum Forestalium Finlandiae 11: 1–421.

Mäkisara, M., Meinander, M., Rantasuo, M., Okkonen, J., Aikio, M., Sipola, K., Pylkkö, P. & Braam, B. 1993. Airborne imaging spectrometer for applications ({AISA}). In International Geoscience and Remote Sensing Symposium Digest, Tokyo, Japan. p. 479–481.

Mäkisara, K., Kärnä, J-P. & Lohi, A. 1994. A system for geometric and radiometric correction of airborne imaging spectrometer data. In International Geoscience and Remote Sensing Symposium Digest. p. 851–853.

Mäkisara, K. & Tomppo, E. 1996. Airborne imaging spectrometry in national forest inventory. International Geoscience and Remote Sensing Symposium Digest. Lincoln, Nebraska, U.S.A. IEEE. p. 1010–1013.

Mäkisara, K., Heikkinen, J., Henttonen, H., Tuomainen, T. & Tomppo, E. 1997. Experiments with imaging spectrometer data in large area forest inventory context. In Proceedings of the Third International Airborne Remote Sensing Conference and Exhibition. Copenhagen, Denmark. p. 420–427.

Tomppo, E. 1991. Satellite Image-Based National National Forest Inventory of Finland. International Archives of Photogrammetry and Remote Sensing 28 (7–1): 419–424.

Tomppo, E. 1993. Multi-source National Forest Inventory of Finland. The Finnish Forest Research Institute. Research Papers 444: 52–60.

Tomppo, E., Mikkelä, P., Veijanen, A., Mäkisara, K., Henttonen, H., Katila, M., Pulliainen, J., Hallikainen, M. & Hyyppä, J. 1995. Application of ERS-1 SAR data in large area forest inventory. Proceedings of the Second ERS Applications Workshop, London, UK, 6–8 December 1995. Noordwijk. ERS Applications. p. 103–108.

United Nations / Economic Comission for Europe. 1997. Forest Condition in Europe. Executive Report. ISSN 1020-587X. 41 p.

ISBN 951-40-1692-0
ISSN 0358-4283