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Forest Condition Monitoring in Finland

National report 1999

Edited by
Liisa Ukonmaanaho and Hannu Raitio

PARKANON TUTKIMUSASEMA

METLA

The observation plot (Juupajoki, Plot No. 10) of the Finnish programme for the intensive monitoring of forest ecosystems. Photo: Hannu Raitio / Metla.

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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 460 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.

This report presents the results of monitoring carried out within the Finnish ICP Forests programme, and the results of other studies related to forest health, during 1998 and 1999.

Summary

Since 1985 Finland has been participating in the Pan-European forest condition monitoring programme – The International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) – which is based on international agreements on the long-range transportation of air pollutants. In member countries of the European Union, forest condition monitoring is based on regulations enacted in 1986 and 1994, and on modifications subsequently made to these regulations. In Finland, the Finnish Forest Research Institute (Metla) is responsible for carrying out annual forest vitality and health surveys on a 460 permanent plot network (Level I, extensive monitoring), and for studying the relationships between forest condition and air pollution and other stress factors on a network of 31 stands located throughout the country (Level II, intensive monitoring). This report presents the results of monitoring carried out within the Finnish ICP Forests programme, and the results of other studies related to forest health, during 1998 and 1999.

Crown defoliation on all tree species in Finland has remained relatively stable during the last years. The average tree-specific defoliation degree in the Level I network was 9 % in Scots pine, 18 % in Norway spruce and 11 % in broadleaves. Although discoloration was rare in broadleaves, the proportion of discoloured conifers increased slightly. In Finland, forest condition is primarily determined by stand age, the climate and by weather conditions. The extremely dry summer in 1999 favoured insect attacks. Mass outbreaks of the pine sawfly caused extensive damage in pine stands in a wide zone extending from North Karelia, through North Savo and Central Finland, to Pohjanmaa and the southern parts of Kainuu. Growth disturbances caused by boron deficiency occurred widely on Norway spruce in North Savo, and crown dieback on birch (Betula pubescens) in SW Lapland. However, these damage outbreaks were not reflected in forest condition on the Level I network. Moose and deer damage to seedlings and young stands reached record proportions, and snow, storm and drought damage was severe in some areas. Altogether 35 % (32 % in 1998) of the Scots pines, 32 % (35 %) of the Norway spruces and 33 % (33%) of the broadleaves had some kind of abiotic or biotic damage symptom.

The weather in 1998 was characterised by high precipitation; during the summer months precipitation was almost double the long-term average. Precipitation was also high in January, February and October, but April, September and November were drier than normal in most parts of the country. The annual mean temperature was close to normal; the mean temperature was below normal only in Eastern Lapland, and January and February were mild in the southern part of the country. Total solar radiation, which is important for many chemical reactions in the atmosphere (e.g. ozone formation), was 30 % lower than normal in the southern part of Finland, and in northern areas solar radiation was lower than the long-term mean during April–September.

The temperature on the level II plots in 1998 was relatively normal compared to the long-term mean. The 1998 growing season at most of the plots was longer than that in 1997, despite the relatively low temperatures in early summer. The results clearly demonstrate the effect of latitude, soil characteristics and tree species on the soil temperature regime. The temperature in the uppermost soil layer (10 cm depth) did not fall below 0 °C at all during winter 1997–98 on one of the plots in southern Finland. In contrast, subzero temperatures persisted for approximately 31 weeks at one of the plots in northern Finland. The soil under the Scots pine stands cooled down and warmed up more rapidly than that under the spruce stands at the same latitude.

The acidification is no loger a general problem in Finland, although there are still areas where the critical loads of sulphur and/or nitrogen are exceeded. During the last 10 years the pH of precipitation has increased slightly

(0.2 pH units) along with the decrease in the deposition of acidifying and gaseous pollutants. The downward trend of gaseous pollutants in the air during the ten last years is steeper in the winter compared to the summer. The largest decrease occurred in the south-western part of the country, whereas the change was smallest in the far north and north-east. There was a clearly decreasing south-north trend in lead, cadmium and chromium deposition. The relatively high copper deposition in northern and north-eastern Finland was due to copper emissions from smelters on the Kola Peninsula, NW Russia. Pollutants carried from industrial areas in Central Europe, as well as from the St. Petersburg area and the Kola Peninsula, can cause serious damage to the vegetation.

Sulphate and nitrogen deposition on the Level II plots in southern Finland was higher than that on the plots in the north. Sulphate and base cation deposition in the open is lower than that within the stand owing to leaching and the wash-off of dry deposition from the canopies. The lower nitrogen deposition within the stand compared to that in the open is due to the uptake of nitrogen by the tree crowns. Sulphate deposition has decreased in recent years (1996–98) in southern Finland especially, but there have been no significant changes in nitrogen deposition. The chemical composition of soil solution on 12 of the Level II plots indicated that the soil on these plots is not suffering from accelerated soil acidification. The plot on the west coast of Finland was an interesting exception since it is located on so called sulphate soil that is naturally strongly acidified.

The effects of deposition from an iron-ore pelleting plant at Kostamus, NW Russia, on forest condition in adjacent areas in Finland and Russia were investigated during 1992–98. Deposition of sulphate, base cations and heavy metals was much higher close to the plant than in Kainuu on the Finnish side of the border, where deposition was at approximately background levels. Deposition has decreased considerably in recent years owing to a fall in production at the plant. Emissions from Kostamus have had only minor effects on forest ecosystems in the region, apart from forests in the immediate vicinity of the pelleting plant.

Yhteenveto

Suomi on vuodesta 1985 lähtien osallistunut yleiseurooppalaiseen metsien terveydentilan seurantaohjelmaan, joka perustuu kansainväliseen ilman epäpuhtauksien kaukokulkeutumista koskevaan sopimukseen. Euroopan unionin jäsenmaissa metsien terveydentilan seuranta pohjautuu vuosina 1986 ja 1994 vahvistettuihin säädöksiin ja niihin myöhemmin tehtyihin täydennyksiin. Metsäntutkimuslaitos (Metla) inventoi puiden kunnon vuosittain kansainvälisesti sovituin menetelmin noin 460 pysyvällä havaintoalalla (Taso I, ekstensiivinen seuranta). Metsien kunnon ja ilman epäpuhtauksien sekä muiden stressitekijöiden välisiä vuorosuhteita tutkitaan 31 metsikössä eri puolilla Suomea (Taso II, intensiivinen seuranta). Tässä vuosikatsauksessa esitetään sekä seurantojen että muiden metsien terveydentilaan liittyvien tutkimusten tuloksia vuosilta 1998 ja 1999.

Suomessa puiden latvusten kunto on säilynyt viime vuodet melko vakaana. Vuonna 1999 ekstensiivisen seurannan (Taso I) havaintometsiköissä mäntyjen keskimääräinen harsuuntumisaste oli 9 %, kuusten 18 % ja lehtipuiden 11 %. Värivikoja puissa oli vähän, havupuilla värivikojen osuus lisääntyi hieman. Suomessa metsien kuntoon vaikuttavat ennen kaikkea puuston ikä, ilmasto ja sää. Vuosi 1999 oli erittäin kuiva, mikä osaltaan suosi hyönteisiä. Laaja-alaisimmat metsätuhot aiheutuivat pilkkumäntypistiäisistä, joiden toukat söivät männyn neulasia yhtenäisellä leveällä vyöhykkeellä, joka ulottui Pohjois-Karjalasta Pohjois-Savon ja Keski-Suomen kautta Pohjanmaalle ja Kainuun eteläosiin. Pohjois-Savossa esiintyi yleisesti kuusissa boorin puutoksesta aiheutuvia kasvuhäiriöitä ja Lounais-Lapissa hieskoivujen kuivalatvaisuutta. Näitä ilmiöitä ei kuitenkaan havaittu ekstensiivisen seurannan (Taso I) havaintometsiköissä. Hirvien aiheuttamat taimikkotuhot olivat suuremmat kuin koskaan aikaisemmin, myös lumi ja myrskyt sekä kuivuus aiheuttivat näkyviä, paikoin vakaviakin tuhoja. Kaikkiaan 35 % (32 % vuonna 1998) männyistä, 32 % (35%) kuusista ja 33 % (33 %) lehtipuista kärsi jonkinasteisista abioottisista tai bioottisista tuhoista.

Säätila vuonna 1998 oli sateinen, kesäkuukausina satoi lähes kaksi kertaa enemmän verrattuna pitkän ajan keskiarvoon. Tammi-, helmi- ja lokakuu olivat myös sateisia, sen sijaan huhti-, syys- ja marraskuu olivat suurimmassa osassa maata kuivempia kuin normaalisti. Koko vuoden keskilämpötila oli lähellä normaalia, vain Itä-Lapissa keskilämpötila oli alle normaalin ja eteläisimmässä Suomessa tammi- ja helmikuu olivat leutoja. Auringon säteily, jolla on merkittävä vaikutus ilmakehässä tapahtuviin kemiallisiin reaktioihin (esim. otsonin muodostumiseen), oli Etelä-Suomessa 30 % alle normaalin arvon, myös Pohjois-Suomessa huhti-syyskuussa auringonsäteilyä oli vähemmän kuin keskimäärin.

Vuonna 1998 ilman lämpötilat metsäekosysteemien intensiivisen seurannan havaintoaloilla eivät poikkenneet merkittävästi pitkän ajan keskilämpötiloista. Kasvukausi oli pidempi kuin vuonna 1997 alkukesän viileydestä huolimatta. Maaperän lämpöolot vaihtelivat huomattavasti sijainnin, maaperätekijöiden ja puulajin vaikutuksesta. Talven 1997–98 aikana Etelä Suomessa sijaitsevan havaintoalan maan pintakerroksen (10 cm) lämpötila ei laskenut alle 0 °C, kun taas Pohjois-Suomessa sijaitsevan havaintoalan pintamaa oli jäätyneenä lähes 31 viikkoa. Mäntyvaltaisella havaintoalalla maan lämpötila laski ja vastaavasti nousi nopeammin kuin samalla leveysasteella sijaitsevalla kuusivaltaisella havaintoalalla.

Suomessa happamoituminen ei ole enää yleinen ongelma, vaikkakin rikki- ja typpilaskeumien kriittiset arvot ylittyvät vielä paikoin. Sadeveden happamuus on vähentynyt yli 0,2 pH-yksikköä kymmenen vuoden aikana. Kaasumaisten ilman epäpuhtauksien pitoisuudet ilmassa etenkin talvella ovat vähentyneet vuodesta 1985 lähtien. Suurin muutos on tapahtunut Lounais-Suomessa ja pienin Suomen koillisosissa. Lyijy-, kadmium- ja kromilaskeumassa on selkeä etelästä Pohjois-Suomea kohden laskeva trendi. Poikkeuksena on kuparilaskeuma, joka on suhteellisen korkea

Pohjois- ja Itä-Suomessa, johtuen Kuolan alueen päästöistä. Keski-Euroopasta, Pietarista ja Kuolan niemimaalta tulevat ilmamassat sisältävät ajottain poikkeuksellisen korkeita ilmanepäpuhtauspitoisuuksia, jotka saattavat aiheuttaa vakavia haittoja kasvillisuudelle.

Rikki- ja typpilaskeuma olivat Etelä-Suomen intensiivisen seurannan havaintoaloilla suurempia kuin Pohjois-Suomen aloilla. Avoimen paikan sulfaatti- ja emäskationilaskeuma oli pienempi kuin metsiköstä mitattu laskeuma, johtuen latvustosta liukenevien ja kuivalaskeuman mukana kertyneiden aineiden huuhtoutumisesta. Typpiyhdisteiden alhaisempi määrä metsikkösadannassa johtuu siitä, että latvusto pidättää osan typpiyhdisteistä ravinnokseen. Kuluneiden vuosien aikana sulfaattipitoisuus (1996–98) on vähentynyt etenkin Etelä-Suomessa, typpilaskeumassa vastaavaa ilmiötä ei todettu. Maaveden kemiallinen koostumus 13 havaintometsikössä osoitti puolestaan, ettei metsiköiden maaperä ole happamoitunut. Poikkeuksena on länsirannikolla sijaitseva kuusikko, joka on luonnostaan hapan maaperän korkean luontaisen sulfaattipitoisuuden vuoksi (alunamaa).

Tutkimus Kostamuksessa sijaitsevan rautapellettitehtaan vaikutuksista Kainuun ja tehdasta ympäröivien metsien terveydentilaan tehtiin vuosina 1992–98. Tehtaan välittömässä läheisyydessä sulfaatti-, emäskationi- ja raskasmetallilaskeumat olivat korkeammat kuin Kainuussa, missä laskeumat olivat taustaalueen tasoa. Seurantajakson aikana laskeumat ovat voimakkaasti vähentyneet tehtaan tuotannon vähentymisestä johtuen. Tehtaan päästöjen metsävaikutukset osoittautuivat kuitenkin vähäisiksi tehtaan lähialuetta lukuunottamatta.

1 Forest condition monitoring under the UN/ECE and EC programmes in Finland

Hannu Raitio and Jarmo Mäkinen

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Introduction

The International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was established in 1985 under the UN/ECE Convention on Long Range Transboundary Air Pollution (CLRTAP). In 1986 the European Union adopted the Scheme on the Protection of Forests against Atmospheric Pollution, and a legal basis for the co-financing of the assessments in EU member states was provided through Council Regulation (EEC) No. 3528/86. The monitoring activities therefore pursue the objectives of resolution S1 of the Strasbourg, resolution H1 of the Helsinki, and resolution L2 of the Lisbon Ministerial Conference on the Protection of Forests in Europe. Since then, the monitoring of forest condition and development has been carried out in 38 participating countries within these UN/ECE and EC programmes.

Large-scale, extensive monitoring takes place on a network of 5 700 plots arranged on a systematic grid covering the whole of Europe. This Level I network provides an annual picture of large-scale trends in crown condition at the European level. It also offers the possibility to investigate relationships between stress factors and forest condition at the same scale. Finland has been participating since 1985 in the Level I monitoring of forest condition.

In order to gain a better understanding of the effects of air pollution and other stress factors on forests, the Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems (Level II) was implemented in 1995. Approximately 860 intensive monitoring plots have been established in the participating countries. Investigations are carried out on these plots on site and stress factors, as well as on the biological and chemical status of the forest ecosystems. By the end of 1997, 31 intensive monitoring plots had been established in different parts of Finland.

The Finnish Forest Research Institute (Metla) is responsible for forest condition monitoring under the UN/ECE and EC programmes in Finland. The Parkano Research Station of the Finnish Forest Research Institute is responsible for the tasks of the National Focal Centre, and Dr. Hannu Raitio acts as the national coordinator.

Extensive monitoring of forest condition – Level I

The Finnish Forest Research Institute annually inventories tree condition, using internationally standardised methods, on a representative sample of tree stands. The inventory is carried out on about 460 sample plots selected from the permanent National Forest Inventory sample plot network established in 1985 (Fig. 1). A number of parameters are measured on the trees. In addition, soil samples have been collected from all the plots, as well as needle samples for elemental analysis on a reduced number of plots.

Intensive and continuous monitoring of forest ecosystems – Level II

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

Observation network

By 1997, 31 intensive monitoring plots had been established in different parts of the country (Fig. 2, Table 1): 27 of the plots on mineral soil sites and 4 on peatlands. 17 of the plots consist of Scots pine stands and 14 Norway spruce stands. All the plots, except for the four Integrated Monitoring (ICP-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 of the 31 permanent observation plots in Finland have been established on peatlands. The 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 has low mineral nutrient concentrations, but usually relatively high nitrogen concentrations. This may result in an unbalanced nutrient status in the tree stand.

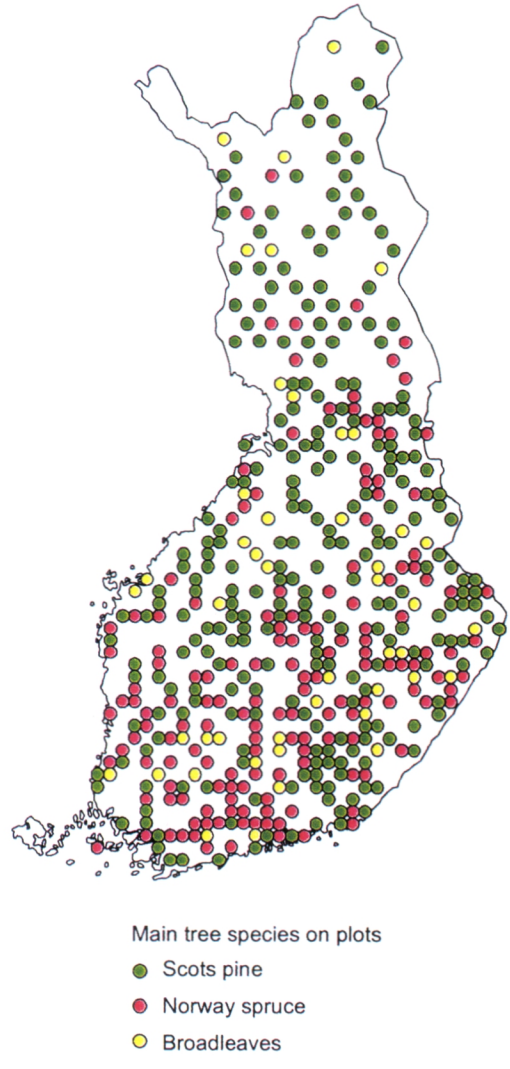

Figure 1. The network of the annual, large-scale crown condition survey (Level I) in Finland.

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 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.

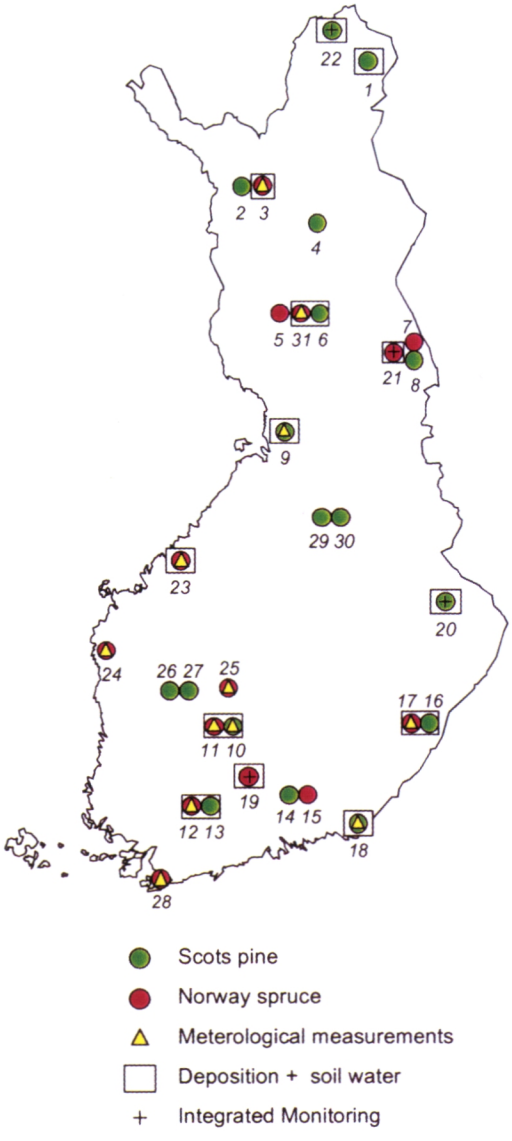

Figure 2. The intensive monitoring network of forest ecosystems in Finland in 1998.

Table 1. Overview of the intensive monitoring network of forest ecosystems in Finland in 1998.

Plot number	Plot name	Tree species
1	Sevettijärvi_P	Scots pine
2	Pallasjärvi_P	Scots pine
3	Pallasjärvi_S	Norway spruce
4	Sodankylä_P	Scots pine
5	Kivalo_S	Norway spruce
6	Kivalo_P	Scots pine
7	Oulanka_S	Norway spruce
8	Oulanka_P	Scots pine
9	Ylikiiminki_P	Scots pine
10	Juupajoki_P	Scots pine
11	Juupajoki_S	Norway spruce
12	Tammela_S	Norway spruce
13	Tammela_P	Scots pine
14	Lapinjärvi_P	Scots pine
15	Lapinjärvi_S	Norway spruce
16	Punkaharju_P	Scots pine
17	Punkaharju_S	Norway spruce
18	Miehikkälä_P	Scots pine
19	Evo_Sim	Norway spruce
20	Lieksa_Pim	Scots pine
21	Oulanka_Sim	Norway spruce
22	Kevo_Pim	Scots pine
23	Uusikaarlepyy_S	Norway spruce
24	Närpiö_S	Norway spruce
25	Vilppula_Spro	Norway spruce
26	Ikaalinen_P	Scots pine
27	Ikaalinen_Pfer	Scots pine
28	Solböle_Spro	Norway spruce
29	Pyhäntä_P	Scots pine
30	Pyhäntä_Pfer	Scots pine
31	Kivalo_Spro	Norway spruce

P = Scots pine
S = Norway spruce
pro = provenance
Pim = Scots pine, Integrated Monitoring
Sim = Norway spruce, Integrated Monitoring
fer = fertilization

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 the 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). Twenty additional trees representing different diameter classes have been selected and numbered on the buffer zone (sub-plot 5). In addition to the above

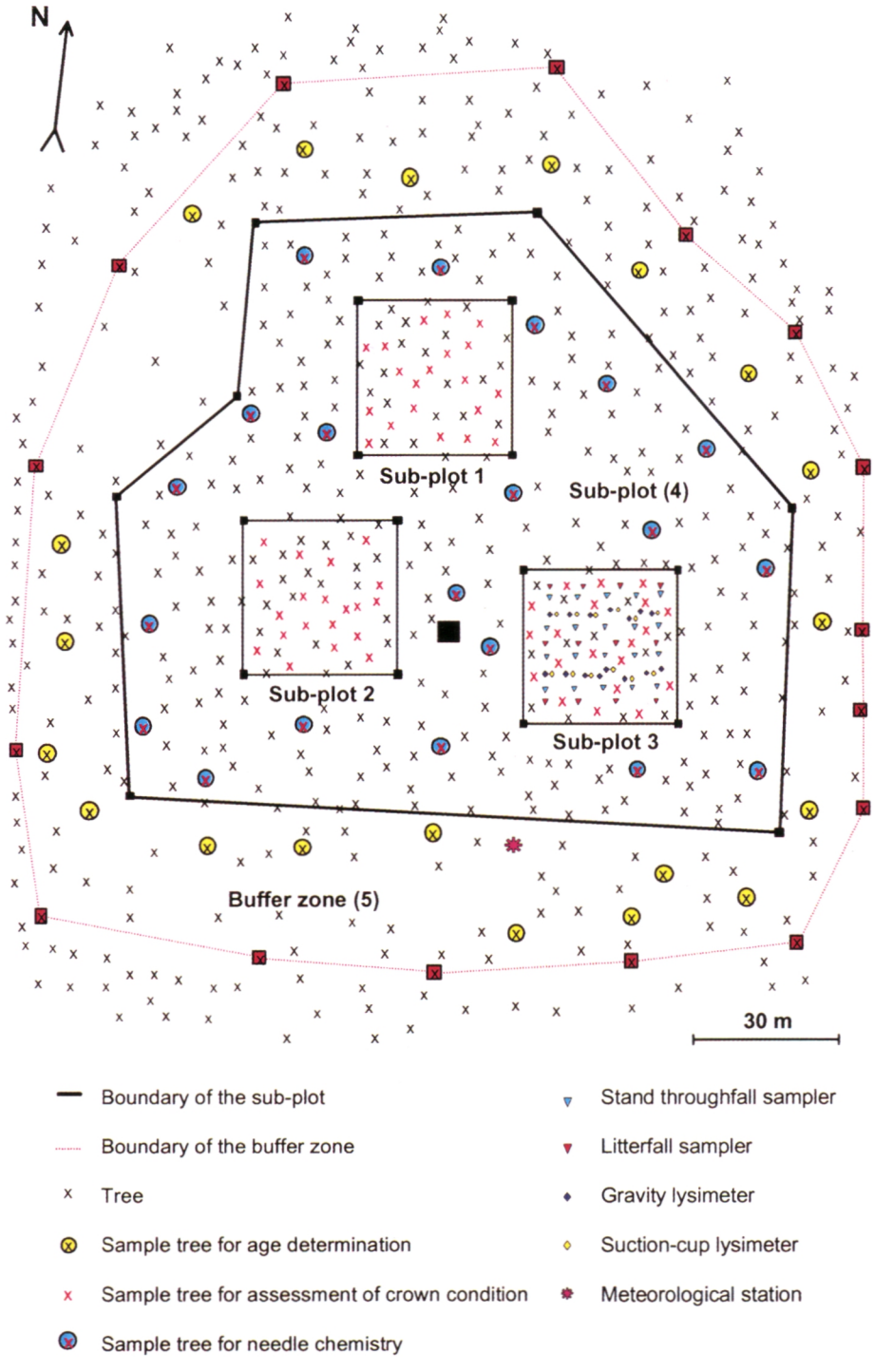

Figure 3. The design of the observation plot and location of the sub-plots.

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	Continuous*
Deposition	16	Continuous (Sampling every 4 weeks, but every 2 weeks during the snowfree period)
Soil solution		
- gravity lysimeter	16	Continuous (Sampling every 4 weeks during the snowfree period)
- suction-cup lysimeter	16	Continuous (Sampling every 2 weeks during the snowfree period)
Meteorology	12	
- air temperature (13 m & 20 m)		Continuous*
- relative humidity		Continuous*
- soil temperature (-10 cm & -20 cm)		Continuous*
- precipitation		Continuous*
- wind speed		Continuous*
- wind direction		Continuous*
- photosynthetically active radiation (PAR)		Continuous*
- solar radiation		Continuous*
- soil frost (-10, -20, -30, ... -100 cm)		Continuous*
Ground vegetation	31	Every 5 years
	6	Every year
Litterfall	13	Every 2 weeks
Phenology	5	Three times/week during the critical period

* = Hourly measurements

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 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

A database has been set up for handling and archiving the Level II data, access to which is restricted to persons participating in the

programme. The database is maintained by Jarmo Mäkinen at the Parkano Research Station (Metla) and Olavi Kurttio at the Vantaa Research Centre (Metla).

The database consists of 14 main directories:

WORK: researchers' working directory
ASCII: raw data files in ASCII format
FIMCI: files in ASCII format, prepared from the raw data, for forwarding to the European Forest Intensive Monitoring Co-ordinating Institute (FIMCI) in the Netherlands
DATA: files forwarded annually to FIMCI in the form of Paradox database tables, and information about the tables, and about the tree stands on the monitoring plots
METEO: raw meteorological data from the weather stations, information and instructions about how to download the dataloggers, and descriptions of the weather stations and their maintenance logs
FMI: air quality and deposition data provided by the Finnish Meteorological Institute in the form of Paradox database tables
BAND: raw data from the girth bands, and information and instructions about how to handle them
SCNEED: scanning data from needle samples for the determination of length and surface area
MAP: map directory
PHOTO: photograph directory
FIG: drawing directory
DOCS: information about directory protection, data accompanying report (DARs) questionnaires, reports of meetings abroad, minutes of project meetings, instruction manuals, reports and structure and description of the database
PILOT: pilot study files and financial status files
FIN: financial status directory

A review of the results of the individual surveys and the summaries of the pilot projects are 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 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 is regularly submitted for inclusion in the database of the Arctic Monitoring and Assessment Programme (AMAP).

2 Background air quality in Finland in 1998

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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 1998 air quality measurements were conducted at seventeen stations throughout Finland. The network of air quality measurement stations in background areas is presented in Fig. 1.

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 for winter. Bulk deposition includes the wet deposition and that part of the dry deposition (gases and particles) that settles in the sampler. Sampling periods 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 1999).

Quality assurance of the results is based on guidelines given in EMEP Data Quality Objectives (EMEP 1996) and GAW (Mohnen et al. 1992). Samples are analysed in an accredited testing laboratory. The laboratory participates annually in intercomparisons of deposition sample measurements within the EMEP and GAW programmes in order to achieve international comparability for the results. However, intercalibration exercises are not regularly employed for gases and particles.

The weather in 1998

The meteorological conditions affecting air quality and deposition have been described in the previous year's report (Waldén et al. 1999). This review of the main features of the weather is based on the Finnish Meteorological Institute's meteorological data base and on issues 1–12/98 of Ilmastokatsaus (IL 1998) published by the FMI.

Figures 2–4 show some of the meteorological parameters (precipitation, temperature and global radiation) for 1998 compared to their long-term means.

The weather in 1998 was characterised by the exceptionally high amount of precipitation



Figure 1. Finnish background air quality measuring stations in 1998.

compared to the long-term average. Especially June, but in many parts of the country also July and August, were unusually wet. The total amount of summer precipitation was 1.3–2 times the average. January, February and October were also wet, whereas in most parts of the country April, September and November were drier than normal. Compared to the long-term average, the highest amount of precipitation was measured at the Oulanka air quality station, in the hilly district of the eastern part of Central Finland.

The annual temperature was close to the long-term average throughout the country. The annual average temperature was below normal only in Eastern Lapland. January and February were mild in the southern parts of the country. Rather low temperatures were measured in Central and Northern Finland during the months of February and March. The average temperature for the summer was close to the normal value, the night temperatures being higher and the day values lower than the long-term average.

Solar radiation is essential for many chemical reactions in the atmosphere, e.g. reactions involved in the formation of ozone and the oxidation of sulphur and nitrogen oxides, are photochemical, and are initiated by solar radiation. In the southern part of the country, the solar radiation during June–August was about 30 % lower than normal, the northern areas receiving somewhat less sunshine than the long-term average during April–September.

Deposition

Annual deposition of acidifying components, comparison with mean values for the years 1987–96

Annual depositions in 1998 at four stations in different parts of the country are given in Fig. 5. The stations have been arranged along the abscissa from south to north.

Depositions of the major components

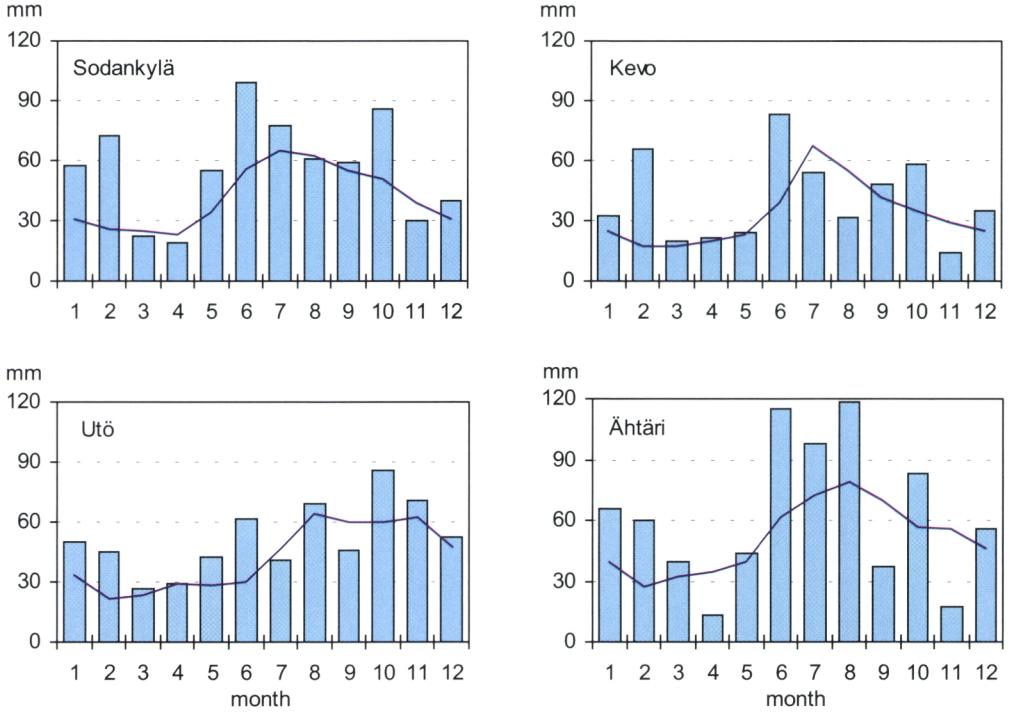

Figure 2. Monthly precipitation in 1998 (bars) and long-term (1961–1990) averages (line) at Utö, Ähtäri, Sodankylä and Kevo.

affecting acidification clearly decrease from south to north, the southern part of the country receiving 2–11 times that in the northernmost part. The geographical difference is the strongest for calcium and ammonium, and the weakest for hydrogen ion depositions.

Annual deposition values are lower in 1998 than the mean values for 1987–96, except for nitrate, ammonium and hydrogen ion deposition at the northernmost station of Kevo. The overall result is in agreement with the decreasing acidification trend observed in Finland during the last ten years (Kulmala et al. 1998, Waldén et al. 1999). The decrease in 1998 compared to the period 1987–96 is strongest for sulphate deposition: about 40 %

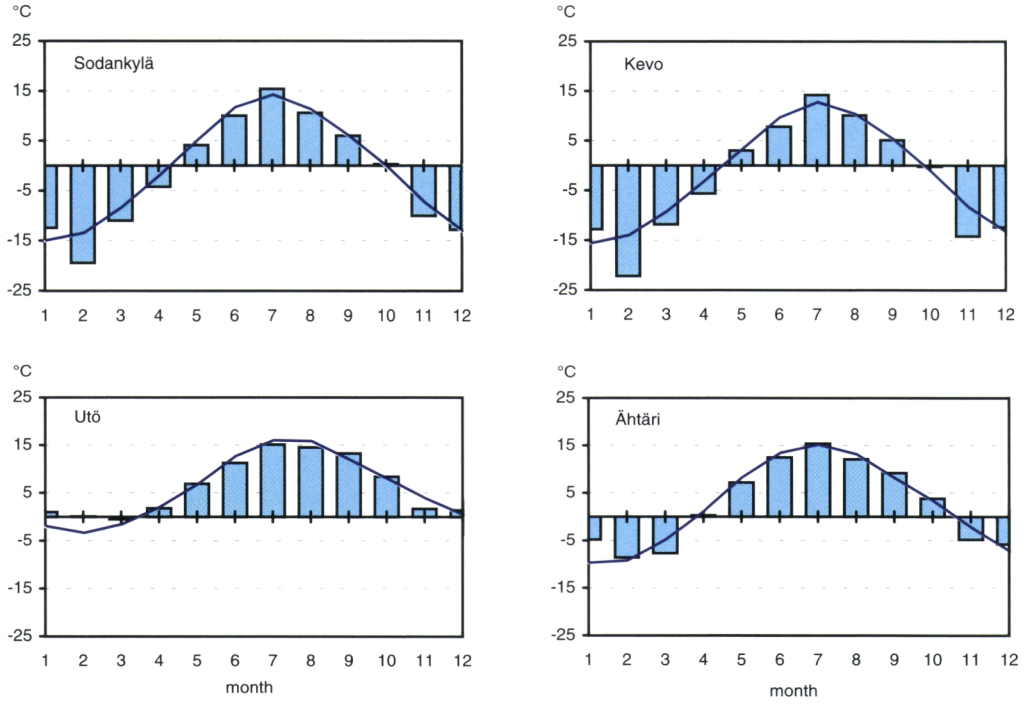

Figure 3. Mean monthly temperatures in 1998 (bars) and long-term (1961–1990) averages (line) at Utö, Ähtäri, Sodankylä and Kevo.

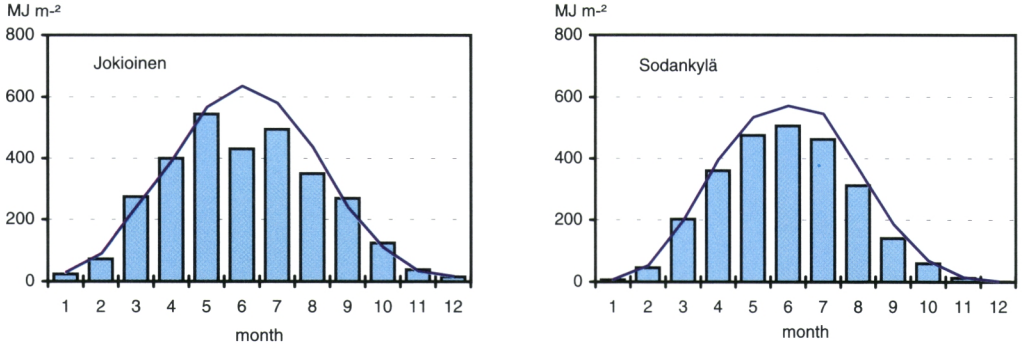

Figure 4. Monthly amounts of global radiation in 1998 (bars) and long-term (1961–1990) averages (line) at Jokioinen and Sodankylä.

at the southern and central Finland stations, and 10–20 % in the north. The decline in ammonium depositions was 20–40 % at all stations except for Kevo in the far north, where deposition increased by 30 %. Hydrogen ion deposition decreased by between 20 and 30 % in the southern and central parts of the country, respectively, and by 10 % in the southern part of Lapland, but remained unchanged in the far north. The deposition of ammonium and nitrate decreased by 10 % at all stations except at the northernmost, where it increased slightly. The deposition of calcium, which neutralises acidic deposition, has also declined during recent years. At all stations the deposition in 1998 was 20–40 % lower than the mean for 1987–96.

The acidity of precipitation presented in this report has been calculated from the measured pH values. Increasing pH values mean less acidic precipitation. An overall decrease in precipitation acidity has been observed during the last decade (Leinonen 1999). The annual mean pH of precipitation (weighted by the amount of precipitation) at those stations with a 10-year data set has increased from 4.47 to 4.70 (Fig. 6).

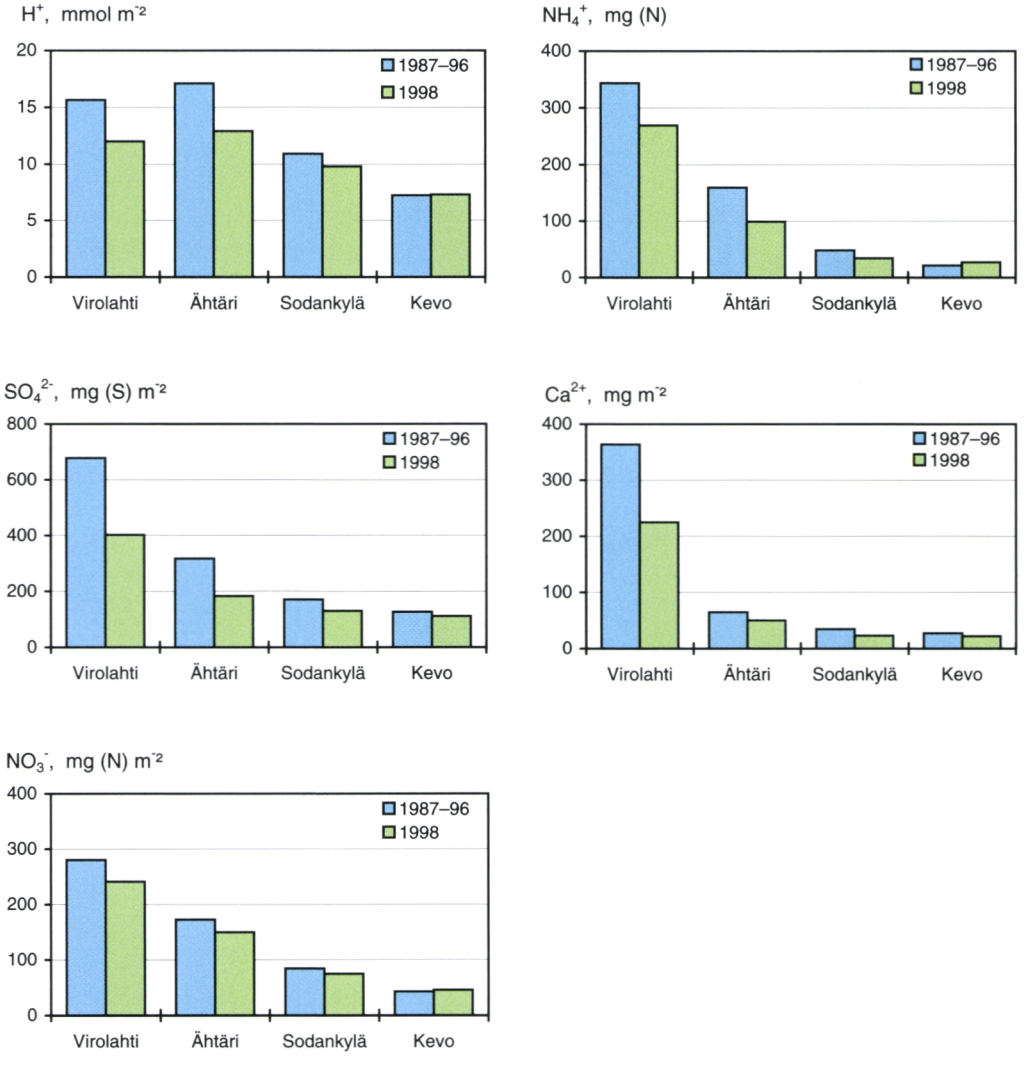

Figure 5. Deposition of H^+, NH_4^+, SO_4^{2-}, Ca^{2+} and NO_3^- in 1998 compared with average values for 1987–96 data.

Annual deposition of some heavy metals

The annual depositions of some heavy metals in 1998 are presented in Fig. 7. The stations have been arranged along the abscissa from south to north.

The deposition mostly decreases from south to north. The difference in depositions from south to north is rather similar for lead, cadmium and chromium: the deposition measured in the far north is only 20–25 % of that on the south coast. The south-north gradient in copper deposition is weaker. The relatively high copper deposition at the northern and eastern stations is presumably connected with the huge copper emissions from the Kola Peninsula (AMAP 1997). The unusually high annual deposition of chromium at Hietajärvi and Vuoskojärvi is due to high monthly deposition in January and August, respectively.

Seasonal variation of deposition

The seasonal variation in the amount of precipitation and deposition of components affecting acidification at 12 stations are given in Figs. 8a–f. They have been grouped according to their 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. The results from the Kotinen station differ from those of the three other southern stations, which are located on the coast, and correspond better to the results of the central Finland stations. In order to make the figures as clear as possible, four stations were chosen for each sub-figure.

On the rocky outer island of Utö, the collection efficiency of precipitation samples is poor. Raindrops are transported by the wind over the mouth of the collector, and evaporation is also higher. For these reasons no monthly means could be calculated for March, April, November and December 1998, the precipitation analysed representing less than half of the official amount of precipitation

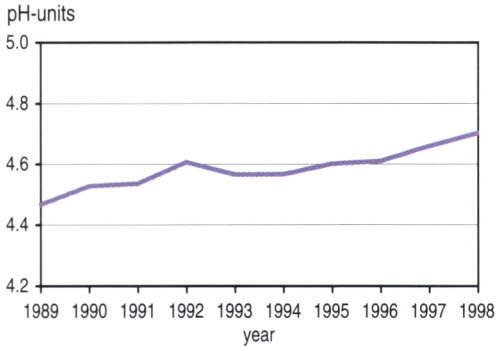

Figure 6. Increase in the mean pH of precipitation in Finland during the last 10 years. The value is the precipitation-amount-weighted mean value of the annual averages of 12 air quality stations covering the whole country.

(Leinonen 1999). Annual values of the components in precipitation were calculated from the analysed daily values, the proportion of the missing deposition being corrected by means of the annual mean concentration and the daily precipitation amounts measured by the official rain gauge.

Bulk deposition is highly dependent on the amount of precipitation (Fig. 8a). In south and central Finland, the summer of 1998 was exceptionally wet compared to the average values for 1961–90 (FMI 1991). In the north, the precipitation amount was high in the first months of the year, as well as in June and October, but the other months were near to the average values. The distribution and amount of precipitation at the southernmost station of Utö on an island in the Baltic were rather close to the average values.

The seasonal variation of hydrogen ion deposition (Fig. 8b) usually follows rather closely the variation in the amount of precipitation. The wet summer months of 1998 led to a relatively high summer deposition maximum. In southern and central Finland, deposition peaks occurred at the beginning of the year as well as in October.

The normal maximum deposition of sulphate in summer is very clear at the stations in central Finland (Fig. 8c). The large amount of precipitation in October caused a weaker maximum. The monthly deposition values at

the southern and northern stations fluctuated more, but maximum values were also measured during the summer months. At Oulanka a high monthly value was measured in April, caused mainly by an exceptionally high sulphate concentration on one day at the end of the month.

The overall seasonal variation for nitrate deposition in central Finland (Fig. 8d) closely resembled that for sulphur deposition. The high amounts of precipitation at the beginning of the year, in summer and in October caused deposition peaks. The seasonal variation in the north as well as at the Kotinen and Guttorp stations in the south and south-west, respectively, was weak.

The overall seasonal variation in ammonium was relatively normal (Fig. 8e), although the summer maximum was higher than average at stations in the central part of the country. The autumn maximum was also weak there because of the low amounts of precipitation. At Oulanka, the high April deposition was mainly caused by the same acidic episode at the end the month that also raised sulphate deposition to an annual maximum. The deposition in August at Virolahti was exceptionally high and cannot be explained by the amount of precipitation alone. Despite the very high amount of precipitation in summer at the southern station of Kotinen, rather low depositions was measured there, and the largest monthly deposition occurred in May.

Figure 8f shows the variation in calcium deposition. In the north the seasonal variation is rather low, the summer values being slightly

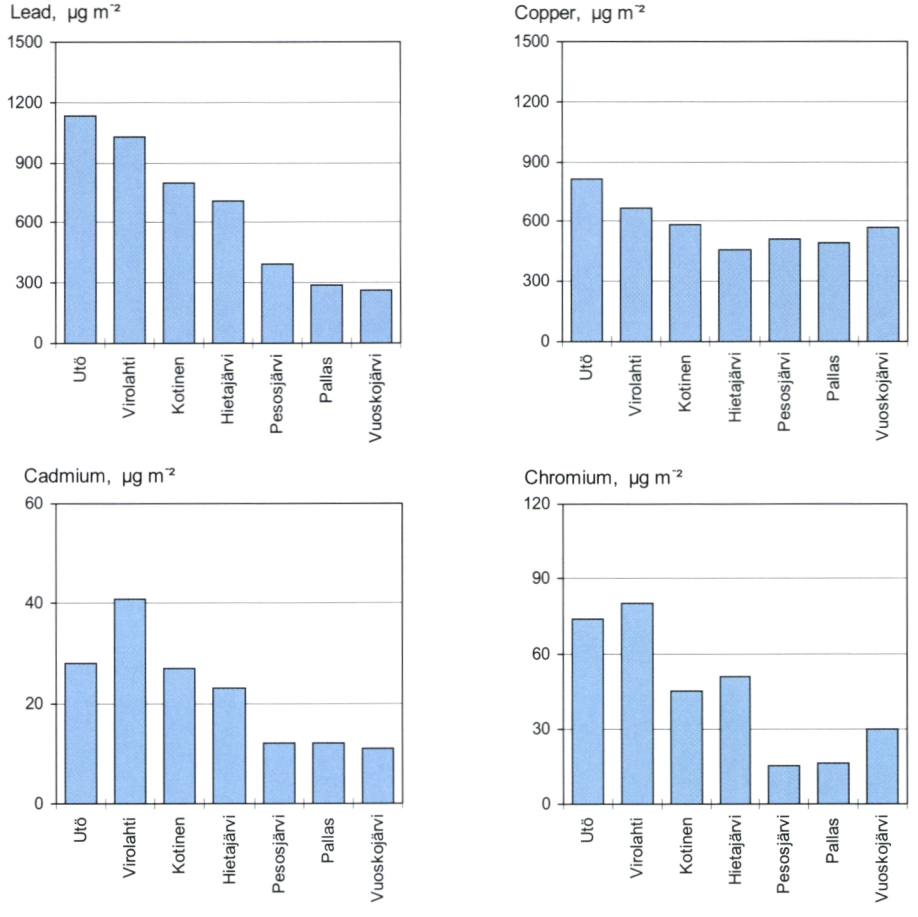

Figure 7. Deposition of lead, copper, cadmium and chromium in 1998.

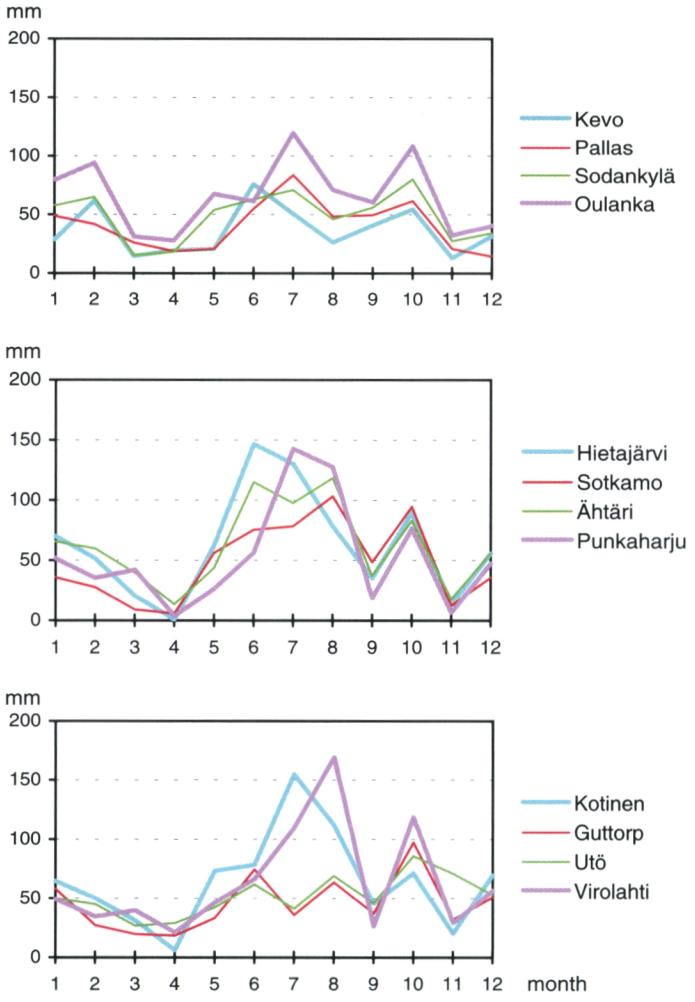

Figure 8a. Seasonal variation in the amount of precipitation in 1998.

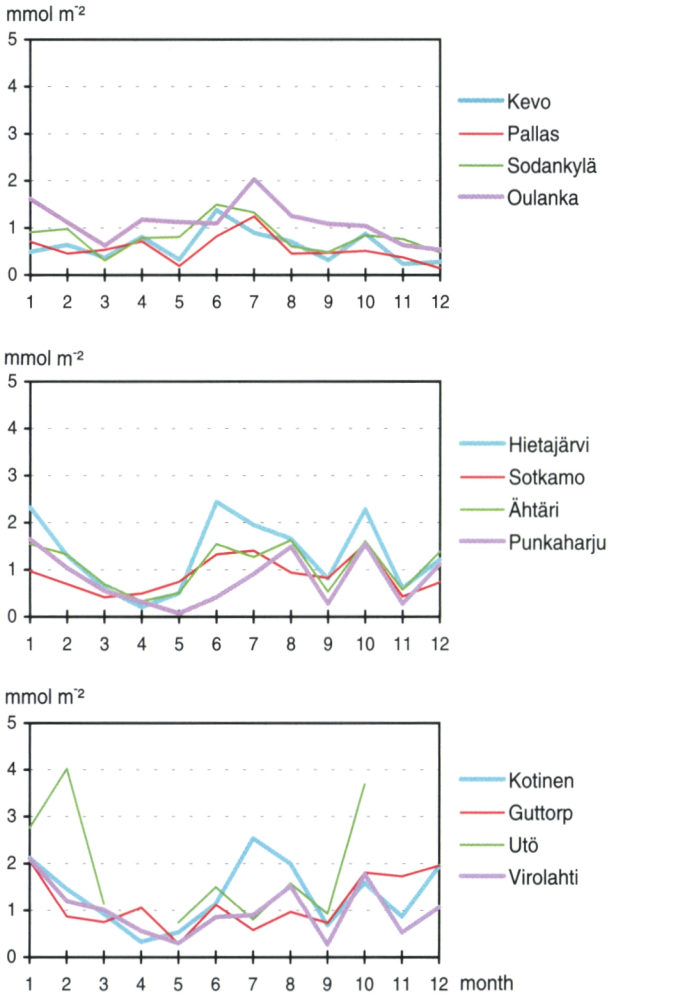

Figure 8b. Seasonal variation in hydrogen ion depositions in 1998.

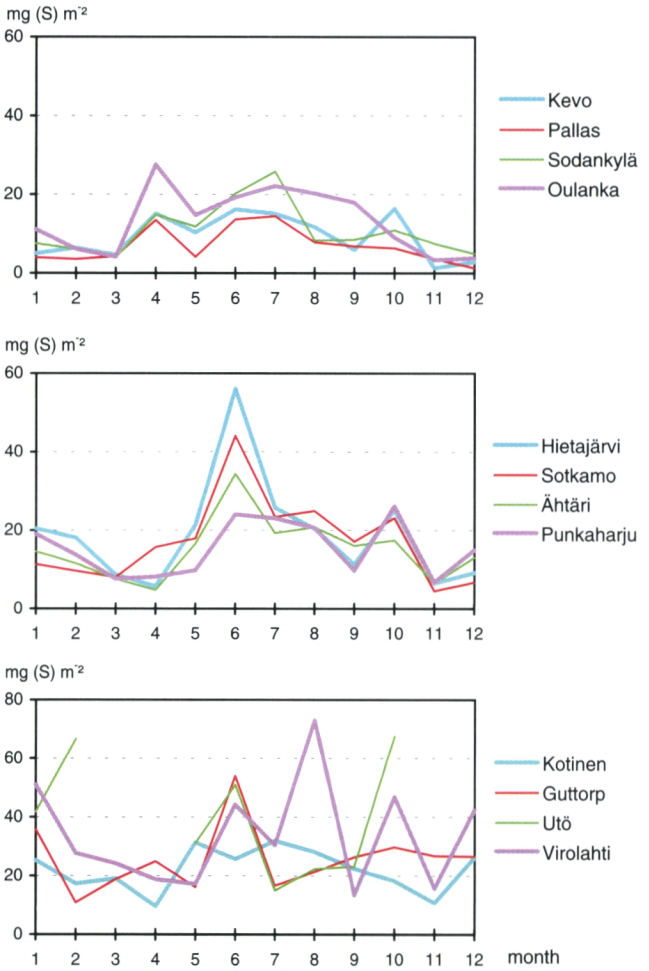

Figure 8c. Seasonal variation in sulphate (SO_4^{2-}) depositions in 1998.

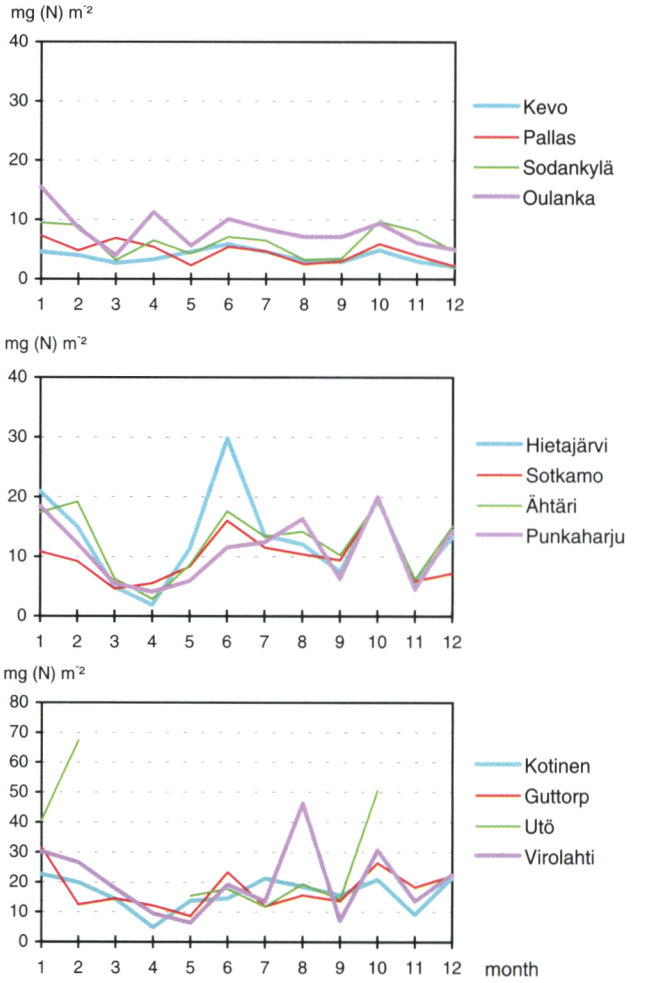

Figure 8d. Seasonal variation in nitrate (NO_3^-) depositions in 1998.

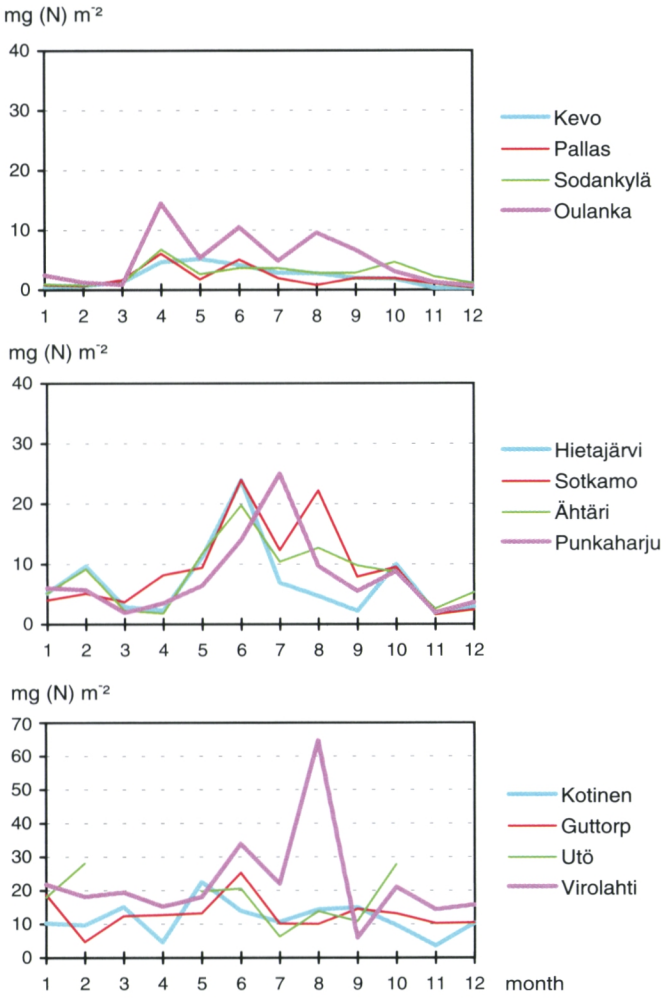

Figure 8e. Seasonal variation in ammonium (NH_4^+) depositions in 1998.

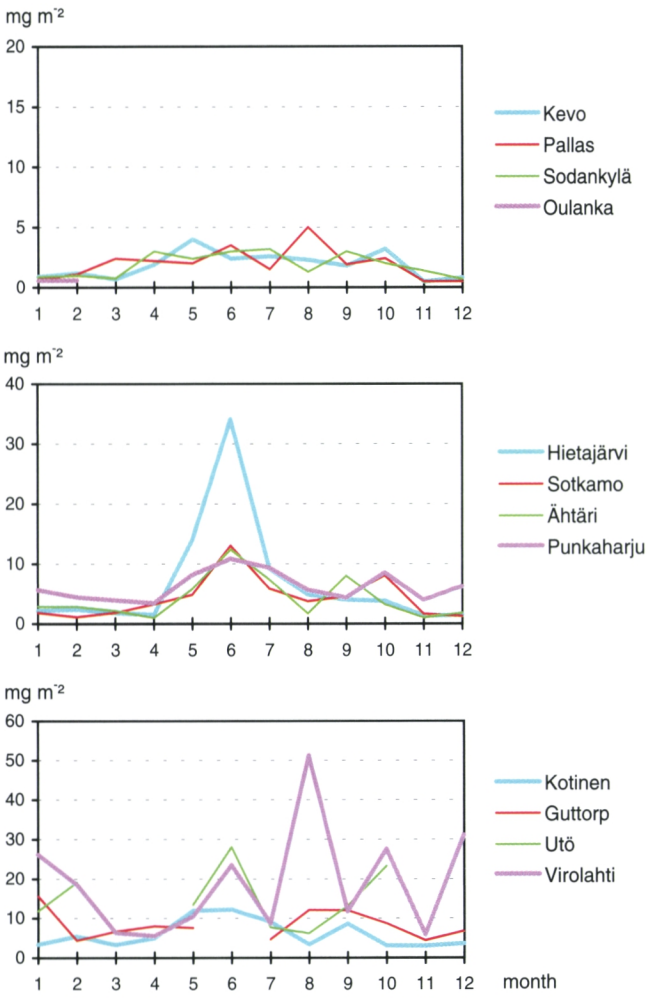

Figure 8f. Seasonal variation in calcium (Ca^{2+}) depositions in 1998.

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

	H^+	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}
Oulanka (190 days with precipitation amount > 0.2 mm)					
largest, %	5.8	11.6	6.8	17.2	18.4
5 largest, %	16.7	25.5	15.6	38.2	39.1
10 largest, %	26.3	37.0	24.5	52.5	52.2
Ähtäri (182 days)					
largest, %	3.8	4.7	4.6	7.2	9.2
5 largest, %	14.8	18.6	15.0	23.6	27.2
10 largest, %	24.1	29.9	24.0	38.2	39.7
Virolahti (158 days)					
largest, %	3.8	8.5	9.4	14.5	16.7
5 largest, %	16.1	19.9	22.2	32.0	32.0
10 largest, %	29.0	28.9	32.5	43.1	41.4
Utö (165 days)					
largest, %	8.1	4.7	7.4	5.2	5.4
5 largest, %	19.0	16.3	18.9	19.0	20.4
10 largest, %	27.8	24.9	27.1	28.4	31.2

higher than the winter values. A clear summer maximum is visible at all other central and southern Finnish stations, except for Virolahti in the south-east. The high deposition at this station, e.g. those at the beginning and end of the year, are often a result of calcium emissions transported 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 deposition values of annual deposition are listed in Table 1 for the major components and the four stations with daily bulk deposition measurements. Samples from days with precipitation of more than 0.2 mm have been analysed and are included in the calculations. The number of rainy days with precipitation of more than 0.2 mm is given in parentheses after the name of the station. At all the stations there were 20–30 more rainy days than the year before.

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

The south-western and central Finnish stations show weaker episodicity in 1998 than those in other areas. At Utö and Ähtäri, the load of the worst day for all the components is between 5 and 10 % of the annual total load, the ten worst days bringing a total of 20–30 % at Utö and 20–40 % at Ähtäri.

The episodicity at all stations, except for Utö in the south-west, is weakest for hydrogen ion deposition. The largest daily fraction is less than 10 %. During the ten worst days, 25–30 % of the annual load is sampled in all parts of the country.

The episodicity for nitrate deposition is similar to that for hydrogen ion deposition, the worst rainy day being responsible for 5–10 % and the ten worst for 25–35 % of the annual load.

In the north-east, sulphate deposition accumulates even more unevenly than that of nitrate. In other areas the episodicity is similar to that for nitrate deposition. The largest daily fraction for sulphate deposition is 10 % at Oulanka, where almost 40 % of the annual deposition is accumulated during the ten worst days.

One day with highly polluted rain at Oulanka at the end of April accounted for 17–18 % of the annual ammonium and calcium deposition. The load for the ten worst days there was over 50 %. A high episodicity for these compounds was also observed at Virolahti: 15 % of the annual load during the worst day and over 40 % during the ten worst days. In other parts of the country the largest daily fraction is 5–10 %, and the ten largest deposition values account for 25–40 % of the annual load.

Gases

Sulphur dioxide

Sulphur dioxide is one of the most important primary pollutants in the atmosphere. It is the key component of the so-called acidification problem in the environment. Its main source is industry and energy production. In Finland, as well as all over Europe, sulphur dioxide concentrations in background areas have decreased rather dramatically since the 1980's (Kulmala et al. 1998).

The main reason for the decrease in the sulphur dioxide concentration in ambient air is the decrease in emissions resulting from 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 emission limit for Finland is 116 kt a^{-1} as sulphur dioxide by the year 2000. Since 1995 emissions of sulphur dioxide have remained below this target limit, as is the case in many other countries in Europe (SYKE 1999).

The annual mean concentrations of sulphur dioxide at the stations of Utö, Virolahti and Ähtäri are presented in Fig. 9a and at Oulanka, Sodankylä and Kevo in Fig. 9b. The reader is reminded of the change in the sampling method for sulphur dioxide within the EMEP-programme that occured in June 1989. This applies to data from the Utö, Virolahti, Ähtäri and Oulanka stations. The sampling methods for sulphur dioxide at EMEP stations include both filter pack sampling on a daily basis since 1989 (EMEP 1996), and continuous monitoring by UV-fluorescence analysers starting in 1990. At Kevo and Sodankylä stations the sampling and analysis method for sulphur dioxide, i.e. the so-called bubbler method (EMEP 1996), has remained the same over the years. Although the decrease in sulphur dioxide is evident, the decreasing trend since 1989 has not been as clear as earlier. The trend calculated by the Kendall method (Gilbert 1987) is shown for

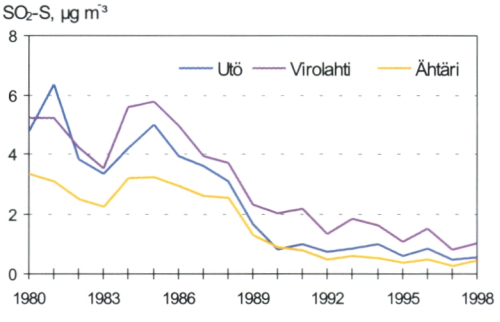

Figure 9a. Mean annual sulphur dioxide concentrations (expressed as sulphur) at Utö, Virolahti and Ähtäri.

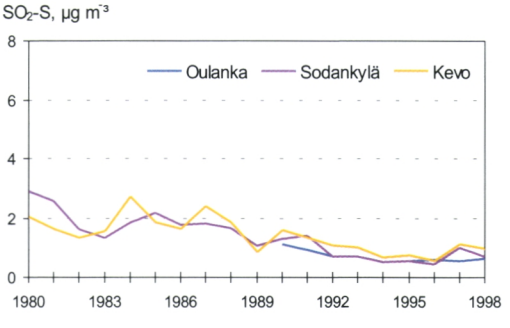

Figure 9b. Mean annual sulphur dioxide concentrations (expressed as sulphur) at Oulanka, Sodankylä and Kevo.

Utö, Virolahti, Ähtäri, Oulanka, Sodankylä and Kevo stations in Fig. 10.

There are spatial differencies in sulphur dioxide concentrations across the country. There is an overall decrease in concentrations on moving northwards from the southern coast of the country. In the south-east of Finland, sulphur dioxide concentrations are also relatively high. The high concentrations in this region originate from local sources, as well as from transboundary pollution from the St. Petersburg area and the Baltic countries.

The seasonal pattern in sulphur dioxide is primarily due to the heating period in winter time, as is shown in Fig. 11. However, although January is the coldest month of the year, the highest sulphur dioxide concentration is reached in February. The strongest seasonal behaviour occurs at Virolahti where the concentrations are also the highest.

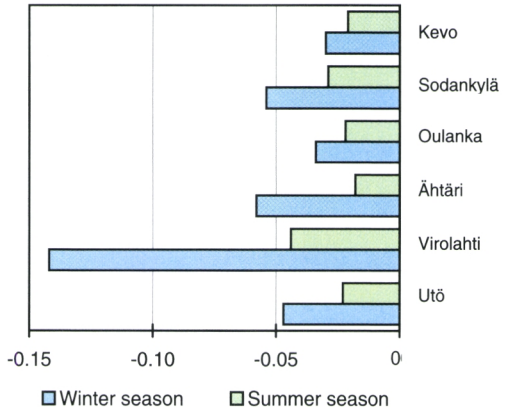

Figure 10. Summer and winter trends, slope estimates from Utö, Virolahti, Ähtäri, Oulanka, Sodankylä and Kevo from 1989 to 1998.

Nitrogen oxides and ozone

Nitrogen is the most abundant gas in the atmosphere. It also oxidizes into several other compounds, of which nitrogen monoxide and nitrogen dioxide are the principal components, and are referred to as nitrogen oxides and expressed as $NO_x = NO + NO_2$. In the atmosphere, nitrogen oxides undergo several chemical reactions, some of which can be cyclic as well as reversible, before being converted into the nitrate ion in clouds or in rain. Oxidised nitrogen compounds as a whole (NO_x, nitric acid, nitrous acid, PAN, nitrate ions, etc.) are commonly known as NO_y. Nitrogen oxides are the most important components in the photochemical production of ozone in the troposphere.

The measurements of nitrogen oxides at background stations was started at Utö in 1987, where nitrogen dioxide and ozone were measured. There were difficulties in detecting low concentrations of nitrogen dioxide with the method used, and this was replaced by the measurements of nitrogen monoxide and nitrogen dioxide by chemiluminescence monitors in 1997.

The seasonal variation in nitrogen dioxide concentrations at EMEP stations is shown together with the monthly averages for the years 1991–97 in Fig. 12.

The figure shows that nitrogen oxides are also characteristed by seasonal variation. This is especially true at Ähtäri, Utö and Virolahti, where the monthly average in 1998 does not vary much from that of the long-term monthly averages. However, the pattern of the monthly averages at Utö differs from that observed at Virolahti and Ähtäri. One a special feature at Utö is the peak observed during the spring time, from April to May. The fact that traffic, i.e. cars, ships and planes, accounts for more than half of the total emissions of nitrogen compounds does not explain the spring peak found at Utö. One explanation may be transboundary pollution, which could cause the observed peak in spring time with a low level of dry deposition.

The ozone concentrations in background areas show a more even pattern. Compared to the other atmospheric pollutants, ozone is not a primary pollutant, i.e. it has no sources other than atmospheric chemical reactions. The annual mean ozone concentrations at the stations are shown in Fig. 13. The increasing trend in the ozone concentration, reported in Kulmala et al. (1998), is also evident at every station. There are also some spatial and

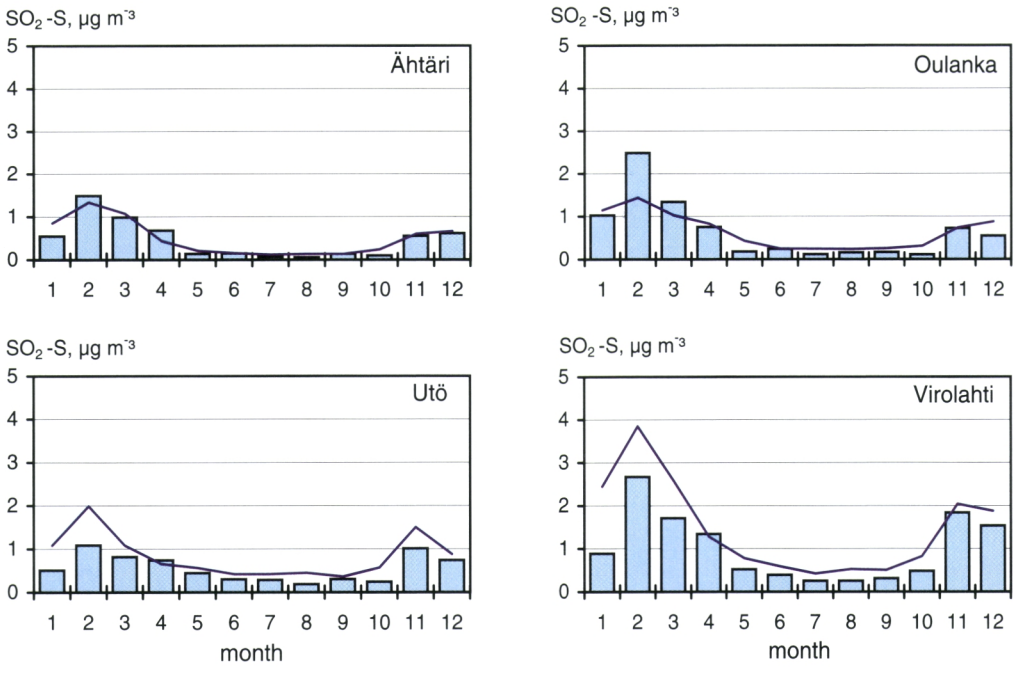

Figure 11. Monthly averages of the sulphur dioxide concentrations (expressed as sulphur) in 1998 (bars) compared with the long-term (1991–97) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.

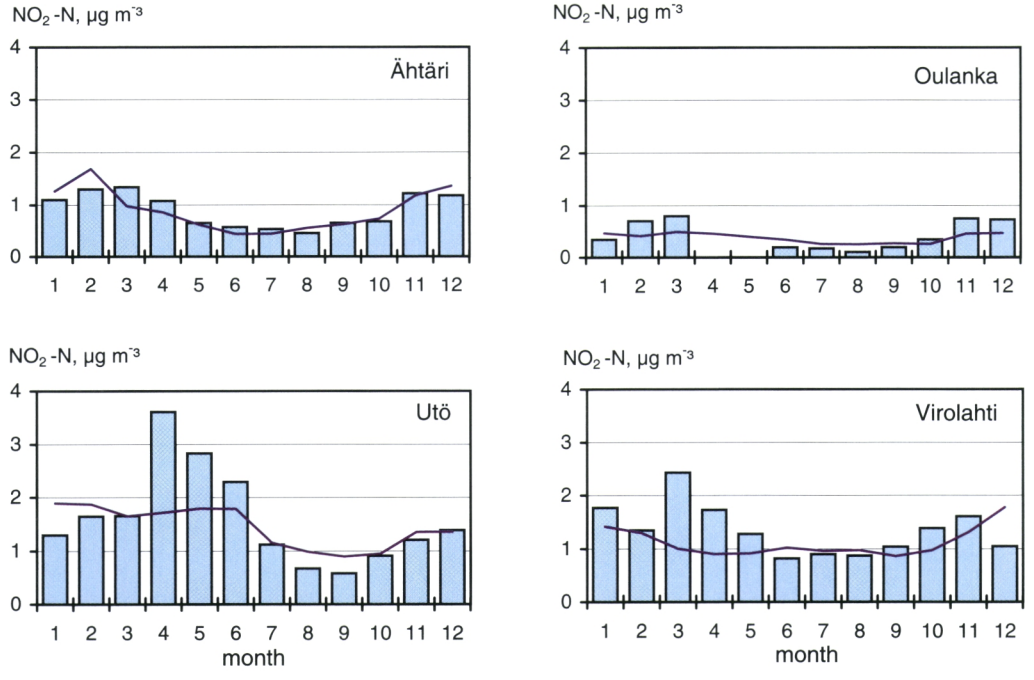

Figure 12. Monthly averages of the nitrogen dioxide concentration (expressed as nitrogen) in 1998 (bars) compared with the long-term (1991–97) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.

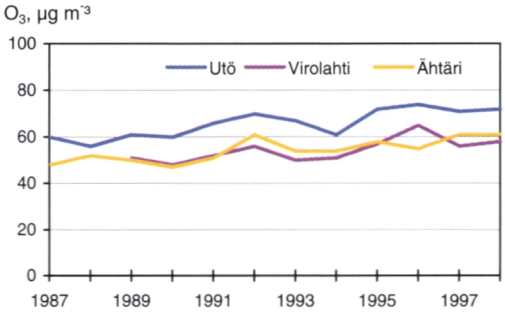

Figure 13. Mean annual concentrations of ozone at Utö, Virolahti and Ähtäri.

temporal features. Ozone concentrations at Utö are slightly higher than those in other parts of the country. This may be due to the weaker rate of ozone deposition attributable to the marine location of the station. Elsewhere, the deposition of ozone onto vegetation is more effective and also causes damage to crops.

The seasonal pattern of ozone concentrations has some typical features (Fig. 14). In spring-time there is often a so-called spring peak, which is mainly caused by increased sunlight and a lower deposition rate onto vegetation. In late spring and summer, due to 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 at a relatively high level, 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 relatively well-known process under atmospheric conditions. Sulphate is a product of the oxidation process of primarily-emitted sulphur dioxide. Particulate sulphate has a seasonal variation with a peak in late winter or early spring. The aerosol sulphate

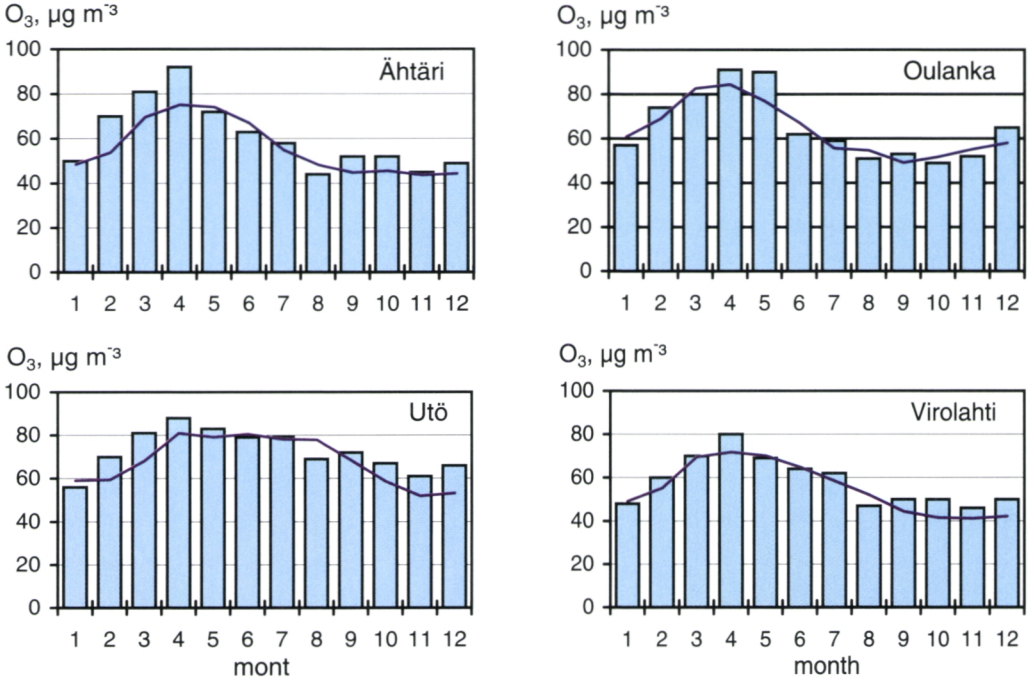

Figure 14. Monthly averages of the ozone concentration in 1998 (bars) compared with the long-term (1991–97) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.

concentration therefore behaves similarly to that of sulphur dioxide with a short time lag.

Particulate sulphate is collected together with sulphur dioxide in a two-stage filter pack system where sulphate is first collected on a Whatman 40 filter while sulphur dioxide is collected in the second stage on an impregnated filter (EMEP 1996). The filter material used is capable of collecting submicron particle sizes.

The annual mean concentration of particulate sulphate at stations in 1998 is shown in comparison with the mean values for 1993–97 in Fig. 15. The concentrations of particulate sulphate along the south coast of Finland are higher than those in other parts of the country. The spatial variation in particulate sulphate follows that of sulphur dioxide (Fig. 11) and the total deposition of sulphate (Fig. 5).

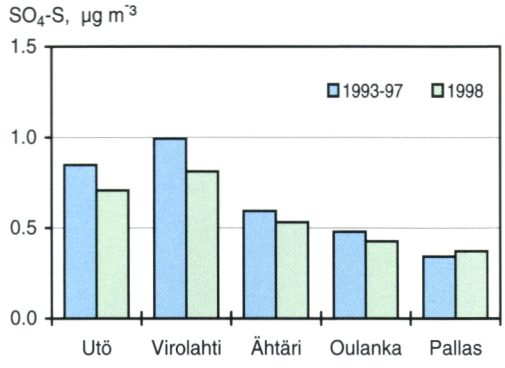

Figure 15. Aerosol sulphate concentrations (expressed as sulphur) in 1998 compared with the period averages for 1993–97.

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 converted into nitrate ions in cloud or rain. The details of the different pathways for the formation of nitrate aerosols are described by Seinfeld (1986). The size of the nitrate particles is also dependent on the process in which they are formed.

Particulate nitrate and ammonia are measured using a filter pack method by EMEP (EMEP 1996). For the analysis of nitrate, air is drawn through a Whatman 40 filter similar to that used for sulphate, and analysed with an ion chromatograph. In the case of ammonia, a Whatman 40 filter is impregnated with oxalic acid and analysed by ion chromatography.

The annual concentration of nitrate aerosol together with that of nitric acid (HNO_3) is shown in Fig. 16. The results for 1998 are compared with those for the period 1993–97. The same comparison is made for ammonium in Fig. 17.

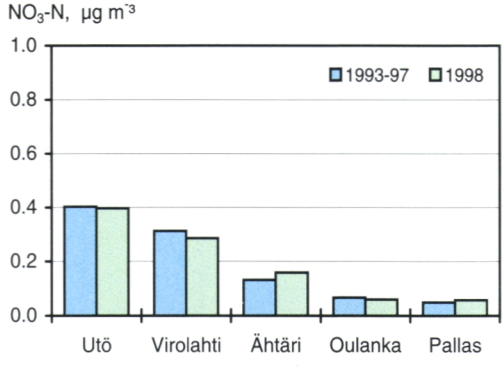

Figure 16. Aerosol nitrate concentrations (expressed as nitrogen) in 1998 compared with the period averages for 1993–97.

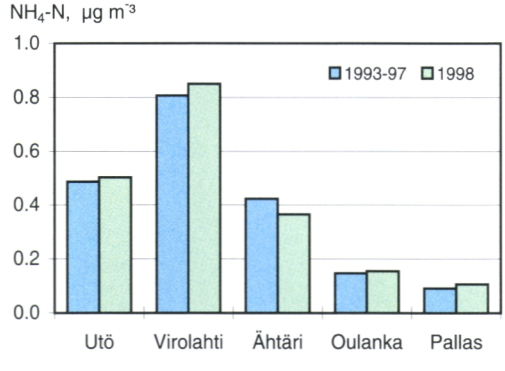

Figure 17. Aerosol ammonium concentrations (expressed as nitrogen) in 1998 compared with the period averages for 1993–97.

Summary

The climatological conditions in Finland, with its clearly-distinguishable seasons, give 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. At Finnish measuring stations, the pH of precipitation has increased by more than 0.2 pH units during the last 10 years. Acidification is no longer a general problem in the country, although there are still areas where the critical loads of sulphur and/or nitrogen are exceeded.

The weather in 1998 was characterised by the high precipitation, especially during the summer months, compared to the long-term average. As a result of this, the summer maximum in many precipitation components was higher than usual.

Episodicity is clearly a phenomenon that locally can cause serious problems to vegetation. Air masses coming from industrial areas in Central Europe, as well as from the St. Petersburg area or from the Kola Peninsula, account for a high proportion of the total deposition.

The concentrations of gaseous pollutants have decreased since 1985. The downward trend during the ten last years is steeper in the winter compared to the summer. The largest decrease was measured in the south-western part of the country, whereas the change was smallest in the far north and north-east.

Acknowledgement

This report is the work of a project group. The authors participated collectively in its production, and are specifically responsible for its various parts as follows: Liisa Leinonen acted as the co-ordinator of the project group, performed the calculations and produced the graphics, Tuija Ruoho-Airola wrote the text on meteorological conditions and deposition, while Jari Waldén wrote the text on gases and particulate matter. The weather review for 1998 is based on the Finnish Meteorological Institute's monthly meteorological review *Ilmastokatsaus*. Precipitation samples and particulate samples were analysed by the accredited 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 a number of organisations and the staff of the Observational Services Division of the Finnish Meteorological Institute. The results were stored in the data base by Tapio Poutiainen.

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3 Results of the 1999 national crown condition survey (ICP Forests/Level I)

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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 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....) 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... 1999) 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 sample plots on mineral soils (totalling 457 plots in 1999) 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 (393 plots in 1999), and that in the northern region on a 32 x 24 km grid (64 plots in 1999). 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. Nine sample plots were terminated owing to cuttings, and seven new plots were added to the sample in 1999.

In 1999, the total number of sample trees was 8662, of which 4538 were Scots pine (*Pinus sylvestris*), 2816 Norway spruce (*Picea abies*) and 1308 broadleaves (mainly *Betula spp.*). The number of common sample trees (cst) in 1998/1999 was 8412.

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

Table 1. The number of assessed trees, sample plots and observers during 1986–1999.

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
1999	8662	4538	2816	1308	457	19	8

defoliation degree was calculated by using the same defoliation-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 discolored 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 21 to August 31.

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. Two experts carried out the check survey on ca. 5 % of the sample plots. According to the comparison of defoliation levels between the observers and the check survey team, 56 % of the pines (n = 186), 39 % of the spruces (n = 120) and 30 % of the broadleaves (n = 43) were assessed uniformly. Allowing for a tolerance of the ±5%, the corresponding percentages were 93 %, 86 % and 91 % respectively.

Results

No marked changes in the defoliation level of any of the tree species were observed between 1998 and 1999 (Fig. 1). Of the 8662 trees examined in 1999, 60 % of the conifers and 64 % of the broadleaves were not defoliated (leaf or needle loss 0–10 %). The proportion of conifers in class 1 (needle loss 11–25 %) was 28 %, and in classes 2–3 (needle loss more than 25 %) 12 %. The corresponding proportions for the broadleaves were 28 % and 8 %, respectively. 14 trees (0.2 %) died during 1998–1999 (Table 2). The average, tree-specific degree of defoliation was 9 % in Scots pine, 18 % in Norway spruce and 11 % in broadleaves (Fig. 2).



Figure 1. Defoliation frequency distribution for Scots pine, Norway spruce and broadleaves during 1986–1999.

Table 2. Proportion (%) of trees in different defoliation classes in stands under 60 years old and in those more than 59 years old in 1999.

	Scots pine		Norway spruce		Broadleaves	
Defoliation class	< 60 yrs	>= 60 yrs	< 60 yrs	>= 60 yrs	< 60 yrs	>= 60 yrs
0–10 %	91.8	59.9	75.3	20.6	81.3	42.9
11–25 %	7.4	34.7	19.8	45.5	17.1	40.2
26–60 %	0.6	4.8	4.6	31.5	1.4	14.9
> 60 %	0.1	0.5	0.3	1.9	0.1	2.0
Dead	0.1	0.1	0	0.5	0.1	0

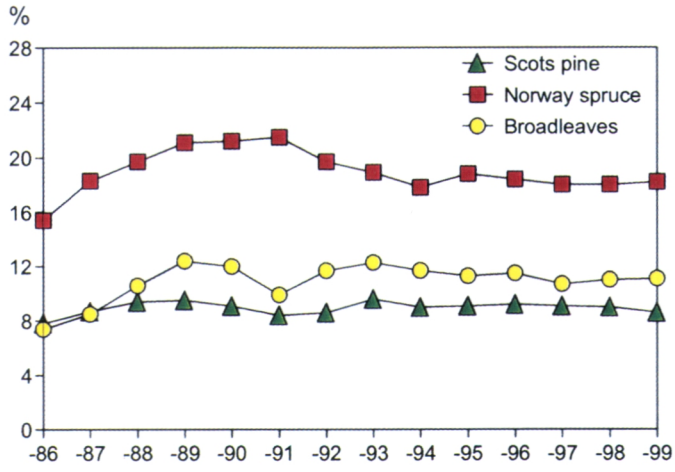

Figure 2. The average defoliation level of Scots pine, Norway spruce and broadleaves during 1986–1999.

The share of over-25 % defoliated trees (common sample trees 1986–1999) increased by 1 %-units in Scots pine (n = 1554), 12 %-units in Norway spruce (n = 935) and 4 %-units in broadleaves (n = 147).

The proportion of over 25- % defoliated trees was higher in older (= 60 years) than in younger stands (under 60 years) (Table 2). The share of over-25 % defoliated stands was 1.5 % (3 % in 1998) in Scots pine, 28 % (27 % in 1998) in Norway spruce and 3 % (6 % in 1998) in broadleaves (Fig. 3). The defoliated Scots pine and broadleaves stands were mainly situated in the Northern part of Finland. However, there was no clear pattern in the distribution of defoliated Norway spruce stands and they occurred in all parts of the country (Fig. 3).

No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 1999 (deposition data for 1993 are based on the HILATAR model, Hongisto 1998).

Discoloration was rare in broadleaves (0.2 % of trees) in 1999 (Fig. 4). However, among the conifers the proportion of discolored trees increased compared to summer 1998. The share of discolored Scots pine increased from 0.2 % to 2.5 %, and that of Norway spruces from 4 % to 6 % (Fig. 4). The most frequent discoloration symptoms were needle yellowing and needle browning. Discoloration symptoms were mainly concentrated on the needles older than two years (Fig. 5). Under 60 years old stands had

Table 3. Proportion (%) of trees in different discoloration classes in stands under 60 years old and in those more than 59 years old in 1999.

	Scots pine		Norway spruce		Broadleaves	
Discoloration class	< 60 yrs	>= 60 yrs	< 60 yrs	>= 60 yrs	< 60 yrs	>= 60 yrs
0–10 %	99.0	96.1	96.2	92.1	99.7	99.5
11–25 %	0.8	2.4	2.9	5.4	0.1	0.2
26–60 %	0.1	1.2	0.6	1.7	0	0.5
> 60 %	0	0.2	0.3	0.4	0	0

less discolored trees than older stands (Table 3). The most discolored conifer stands were situated mainly in South-Finland (Fig. 6).

Altogether 35 % (32 % in 1998) of the Scots pines, 32 % (35 %) of the Norway spruces and 33 % (33 %) of the broadleaves had some kind of abiotic or biotic damage symptom (Fig. 7). The share of moderately or severely damaged trees remained at the same level as in the 1998 crown condition inventory. Four percent of all

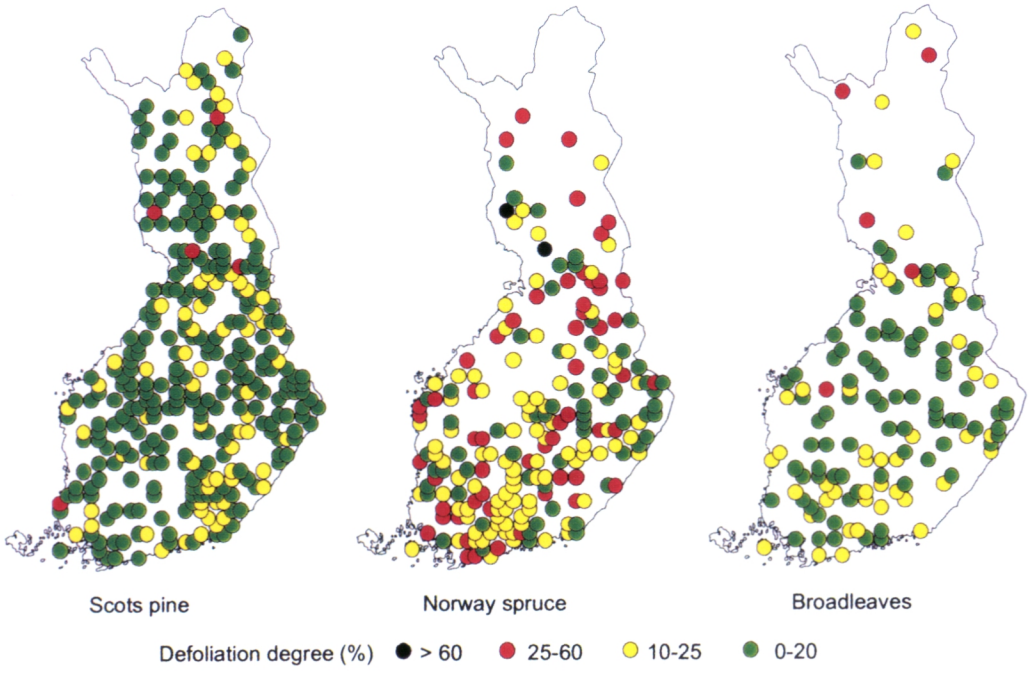

Figure 3. Average defoliation degree of Scots pine, Norway spruce and broadleaves in 1999. The colour of the circle indicates the plot-specific values (see map legend).

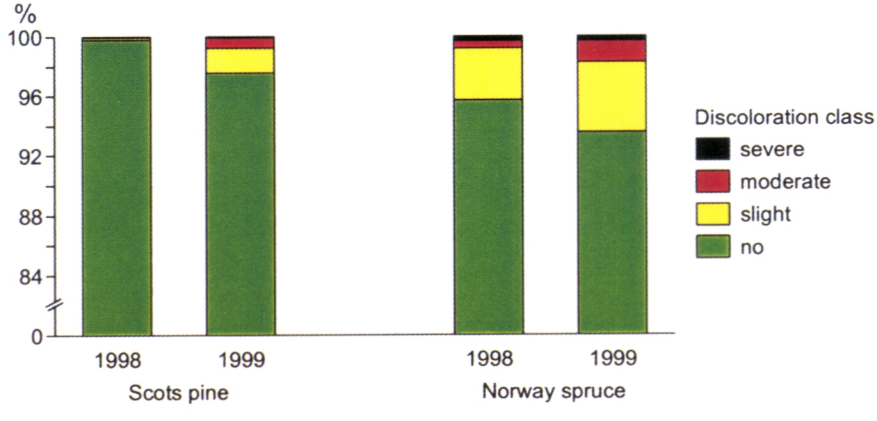

Figure 4. The proportion of trees in four discoloration classes in 1998 and 1999. The classes are based on the proportion of discolored needles: no = 0–10 %, slight = 11–25 %, moderate = 26–60 % and severe > 60 %.

the easily identifiable damage on Scots pines was classified as moderate or severe in 1999. The corresponding proportions for Norway spruce and broadleaves were 10 % and 9 %, respectively. The most common biotic agents on Scots pine were insects (*Tomicus spp., Diprionidae*) and Scleroderris pine canker (*Gremmeniella abietina*), on Norway spruce fungal pathogens, and on broadleaves insects.

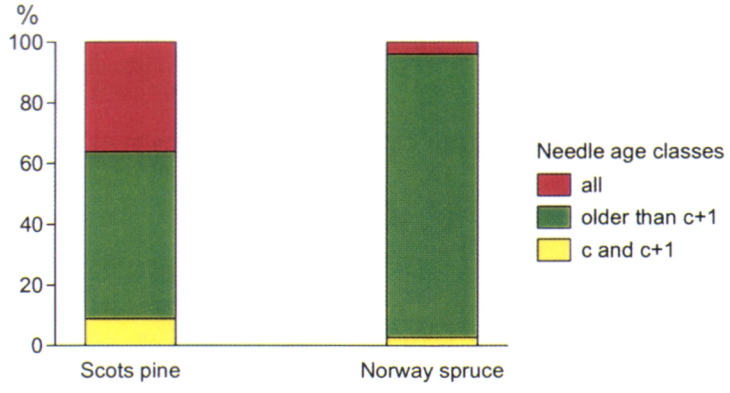

Figure 5. The distribution of discoloration in relation to the needle age in Scots pine (n = 111) and Norway spruce (n = 181) in 1999. C = current year needles.

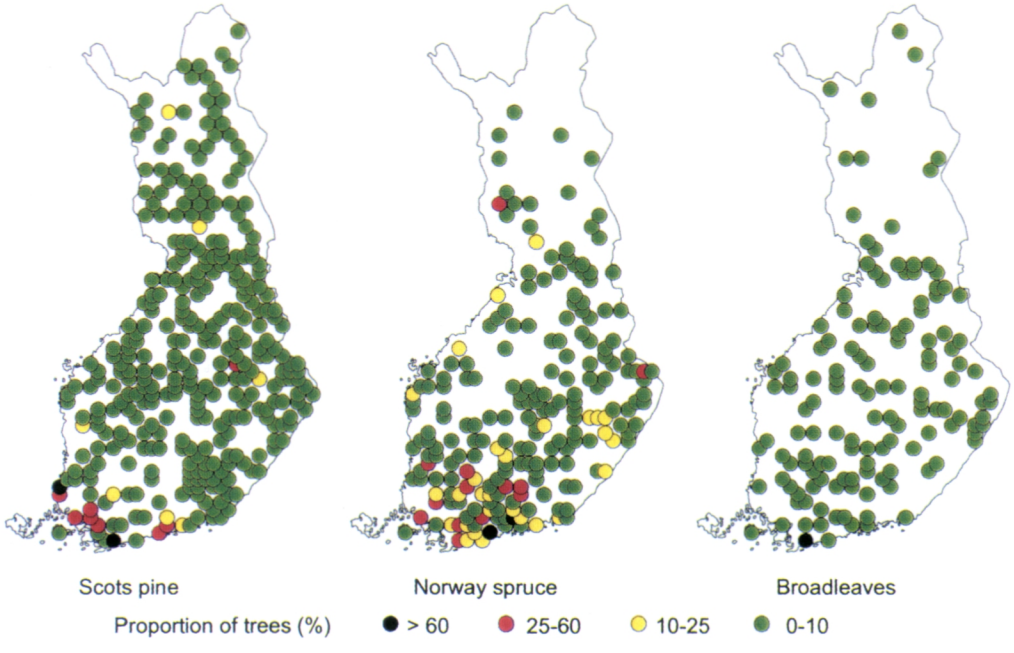

Figure 6. Proportion of discolored Scots pines, Norway spruces and broadleaves in 1999. The colour of the circle indicates the plot specific values (see map legend).

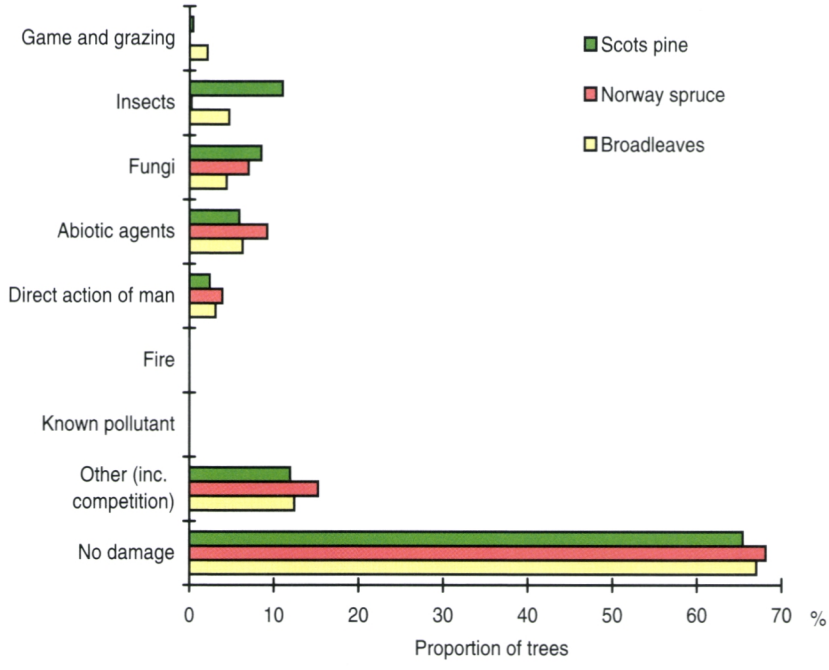

Figure 7. The proportion of trees in eight groups of easily identifiable damage in 1999.

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 1992–1993. A slight increase in Scots pine defoliation was also observed in 1993. No essential changes have been observed in the average defoliation degree of any of the tree species during the past few years. In addition to the abiotic factors such as snow, storms and summer drought which caused local damage in 1999 biotic damage factors have had a detrimental influence on crown condition e.g. an epidemic of Scleroderris pine canker (*Gremmeniella abietina*) in the latter half of the 1980's (Nevalainen & Yli-Kojola 1990). Local outbreaks of scleroderris damage were also reported during the 1990's. Other fungal diseases (e.g. the rust fungi epidemic in 1998) have also caused forest damage in some years (Lipponen et al. 1999). No extensive fungal diseases were detected during 1999. Summer 1999 was very dry and warm in some parts of Finland. This seems to have favoured insects, e.g. there was an extensive mass outbreak of the pine sawfly (*Diprion pini*) (Lipponen et al. in this report). The effects of such damage were not reflected in the annual defoliation data (Level I) in 1999; there were no marked changes in the defoliation degree of any of the tree species between 1998 and 1999. Tree mortality was also at the same level as in previous years. Although the defoliation degree remained at the same level as in 1998,

the very dry summer increased the proportion of discolored conifers in south Finland compared to the preceding summer (Lindgren 1999). Scots pine especially seemed to suffer from the summer drought, which was manifested in needle discoloration. In contrast, discoloration was rare in broadleaves in 1999. No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 1999.

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4 Results of the intensive monitoring of forest ecosystems in 1998 (ICP Forests/Level II)

4.1 Results of the individual surveys

Crown Condition

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Introduction

The 1998 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 (see Fig. 2, p. 12). Defoliation, needle discoloration, abiotic and biotic damage were assessed on 20 trees from each sub-plot, as well as on the 20 needle sampling trees. The number of assessed Scots pines was 985 (mineral soil) and 320 (peatland) and of Norway spruces 1127 (mineral soil). However, the trees used for needle sampling or trees growing on peatland are not included in the results presented here. The results for 1998 are therefore based on 720 Scots pines and 800 Norway spruces growing on Level II mineral soil plots.

Defoliation of Scots pine was estimated on 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. Two experts carried out the check survey during the field period. Because of the low number of Norway spruces in the 1998 Level II check survey, the results of Level I check survey were combined with the Level II results for those observers who carried out assessments at both levels. According to the comparison of defoliation levels between the observers and the check survey team, 91 % of the Scots pines and 88 % of the Norway spruces were assessed uniformly (±5 % tolerance) (Table 1).

Results

In 1998, 73 % of the Scots pines and 40 % 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 71 % and 35 %, respectively. The proportion of slightly defoliated Scots pines (11–25 %) was 22 % (25 %, Level I), moderately or severely defoliated (over 26 %) 5% (4 %, Level I) and severely defoliated (over 60 %) 0 % (0.3 %, Level I). The corresponding proportions for Norway spruces were 42 % (38 %, Level I), 17 % (25 %, Level I) and 1 % (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. 1). The average defoliation degree of Scots pine at Level II was 10 % (10 %, Level I), and that of Norway spruce 18 % (20 %, Level I).

In general a slight increase in the proportion of defoliated trees and average defoliation level of common sample trees was observed on both species between 1997 and 1998 at Level II but not at Level I (Fig. 2). There was a clear increase in the average defoliation degree on five

Table 1. Difference in the assessment of defoliation between the check survey team and individual observers in 1998. Results are combination of both Level I and Level II data. 0 = no difference, minus sign = observer's assessment was lower than that of the check survey team, plus sign = observer's assessment was higher than that of the check survey team.

Difference (%)	Scots pine, % of trees	Norway spruce, % of trees
-15	0	1.2
-10	2.3	4.9
-5	19.5	21.9
0	50.2	35.4
+5	20.8	30.5
+10	5.9	6.1
+15	1.3	0
number of trees	221	82

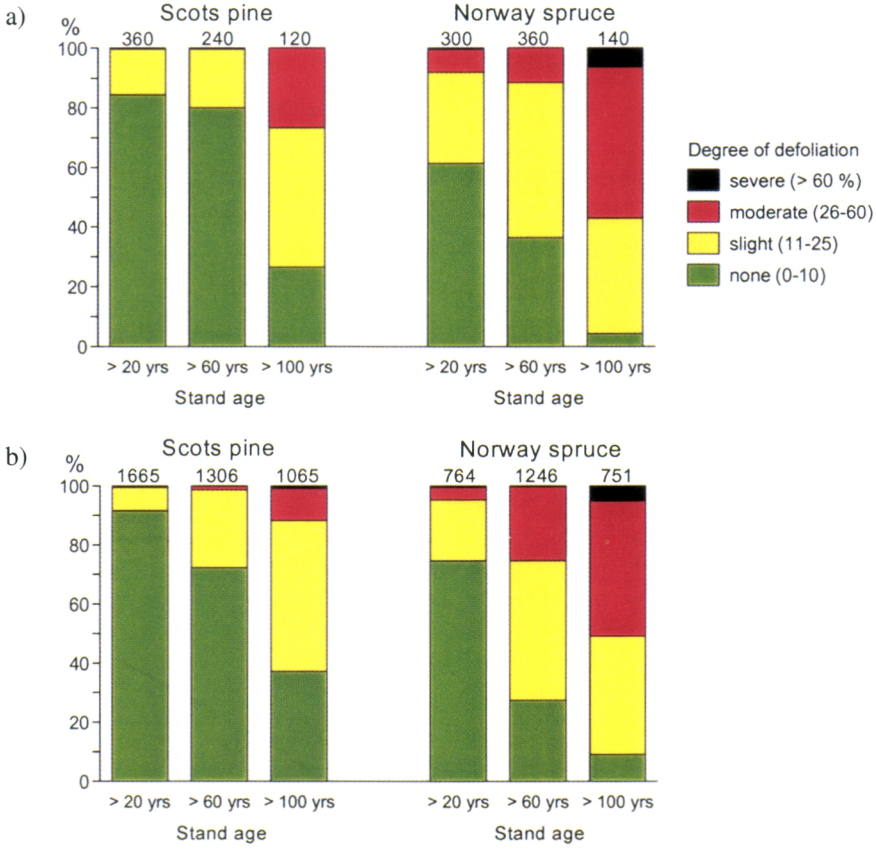

Figure 1. Defoliation frequency distribution for Scots pine and Norway spruce in three stand age classes in Level II (a) and Level I (b) in 1998. The number of trees is given above the column.

Scots pine sample plots and on three Norway spruce plots (Fig. 3). In addition to the effects of damage on defoliation, a change in the observer may also cause variability in the yearly defoliation level.

In 1998, 0.1 % (0.3 % in 1997) of the Scots pines and 7 % (4 % in 1997) of the Norway spruces were discolored (the proportion of affected needles in the crown is more than 10 %) (Table 2). The corresponding proportions for Level I were 0.2 % and 4.5 %, respectively. The most abundant discoloration symptoms on Norway spruce at Level II were overall needle yellowing (15 % of discolored spruces), needle tip yellowing (24 %) and apical yellowing (30 %) of more than one-year old needles. The overall yellowing of current needles was detected on 15 % of the discolored spruces. Most of these spruces had a fungal infection.

Altogether 24 % of the Scots pines and 34 % of the Norway spruces had some kind of damage symptom. However, about 2 % of the damage on Scots pine was classified as moderate or severe, and on spruce 13 %. Comparision of the frequencies of easily identifiable damage in 1998 (Fig. 4) with the results for 1997 showed

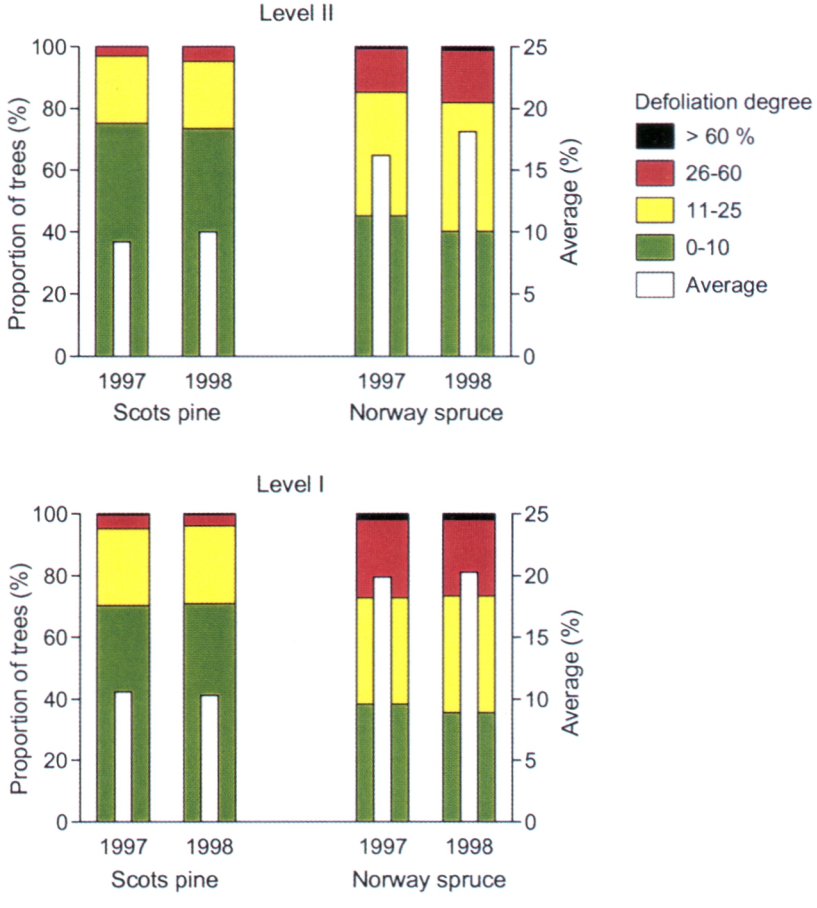

Figure 2. Defoliation frequency distribution and average defoliation degree (white column) for Scots pine and Norway spruce in 1997 and 1998 at Level II and Level I. The number of common sample trees at Level II is 714 for pine and 737 for spruce, and at Level I 3961 and 2689, respectively.

that, the proportion of undamaged trees has increased. This is due to the slight changes in the statistical handling of the very slight damage (e.g. slight competition which was omitted in the 1998 analysis). The most common biotic agents on Scots pine were insects (*Tomicus spp.*) and Scleroderris pine canker (*Gremmeniella abietina*), and on Norway spruce fungal pathogens (*Chrysomyxca spp.*). According to the results, the defoliation degree was higher on trees which had one or more cause of damage (Fig. 5).

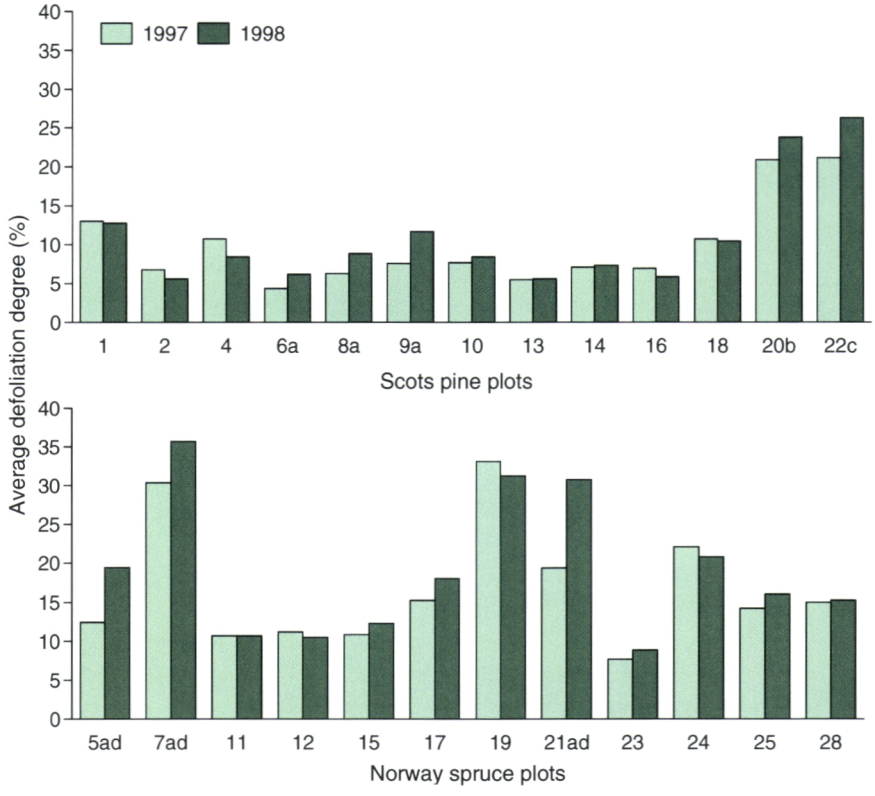

Figure 3. The plot-specific defoliation degree on Scots pine and Norway spruce in 1997 and 1998. The figure includes only the common sample plots for both survey years. a = observer has changed 1997–1998, b = clear insect damage, c = abiotic damage (snow), d = fungal damage.

Table 2. Needle discoloration in the assessable crown. A tree is classified as discolored when more than 10 % of the foliage is affected (yellow background in the table).

Species	n	Proportion of affected needles in crown (%) 0	1–5	6–10	11–15	> 15
Scots pine	720	91.7	7.9	0.3	0.0	0.1
Norway spruce	800	57.8	20.6	14.9	5.5	1.3

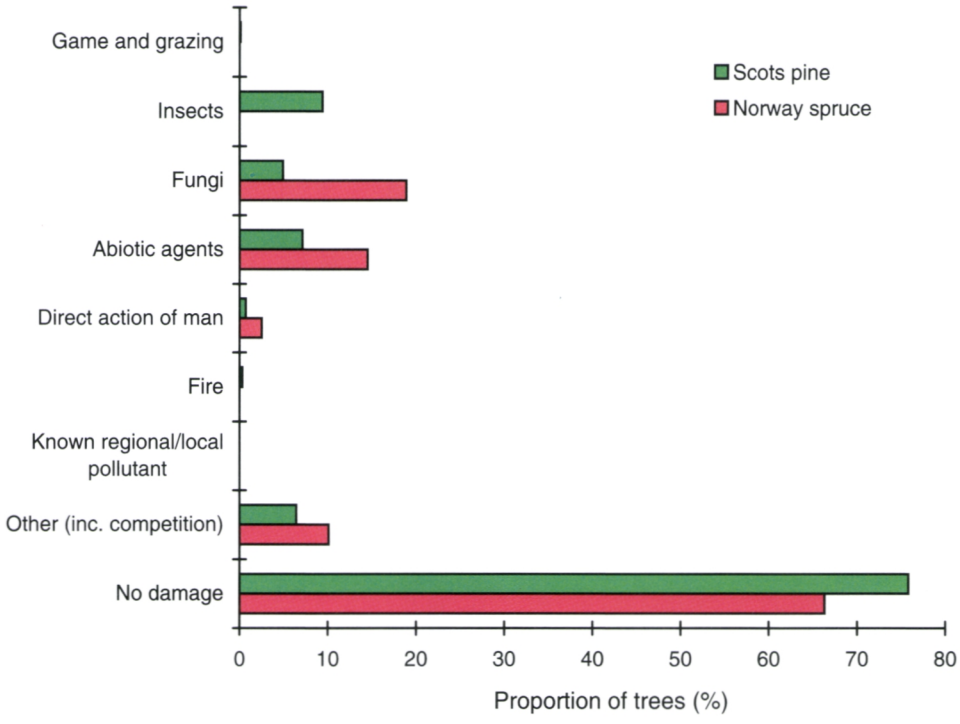

Figure 4. The proportion of trees in easily identifiable damage classes in 1998.

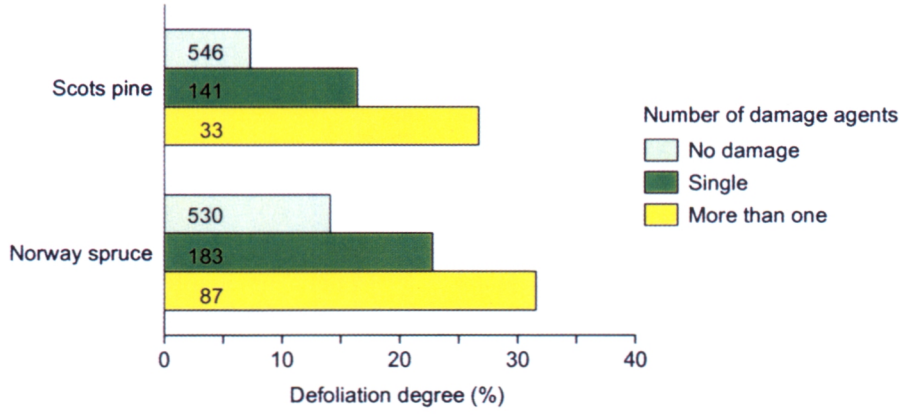

Figure 5. Defoliation degree of Scots pine and Norway spruce in relation to the number of damage agents in 1998. Number of trees is given inside the column.

Table 3. The distribution of damage into different parts of Scots pine and Norway spruce.

Species	Proportion of damaged trees (%) in different parts Foliage*	Branch**	Stem**	Number of tree
Scots pine	0.4 (1.1)	0.6 (24.3)	0.8 (5.4)	720
Norway spruce	2.8 (21.8)	4.8 (15.6)	6.6 (13.6)	800

* according to the manual (Manual on...) damage is identified when it affects more than 10 % of the foliage in the assessable crown. The figure in parentheses also includes slight foliage damage i.e. its extent is 1–10 %.

** severity of damage was classified in three categories: slight, moderate and severe. The percentage in the column represents the proportion of moderate and severe damage. The figure in parentheses also includes slight damage.

In the 1998 inventory the cause of damage was recorded separately on three different parts of a tree; foliage, branch and stem (Manual on....). The majority of all damage was regarded as slight in all these parts (Table 3). In addition to the type of damage the extent of foliage damage was also assessed. According to the results the defoliation degree of Norway spruce correlated significantly with the extent of foliage damage (Spearmann rank correlation $r = 0.2965$, $p < 0.0001$, $df = 798$). In the case of Scots pine there was not enough foliage damage to perform proper correlation analyses.

Conclusions

Defoliation of Scots pine and Norway spruce increased with stand age at both Level II and Level I. Compared to 1997, there was a slight increase in average defoliation degree at Level II but not at Level I. In contrast to the results for 1997, the proportion of non-defoliated trees was slightly lower in older (> 100 yr.) age classes at Level II compared to Level I in 1998. The effect of different damaging agents greatly affects the degree and yearly variation of defoliation. However, the increase in defoliation on some of the sample plots might be due to the fact that the observer was changed. This change may lead to slight variation in determining the defoliation level in a tree e.g. a shift from non-defoliated trees to slight or slight to moderate defoliated trees, resulting in an increase in the defoliation level. On Scots pine the proportion of discolored needles remained at a low level. In contrast, there was a slight increase in the proportion of discolored Norway spruce compared to 1997 (Lindgren 1999). The effect of damage was also clear in relation to discoloration. For example, all the spruces where current year needle discoloration occurred also had some kind of damage, especially fungal diseases. Moreover, half of the spruces with discoloration symptoms on more than one-year old needles also had damage symptoms.

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Vegetation

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Introduction

Understorey vegetation has great indicative value in studying the effects of environmental changes in forest ecosystems. In boreal forests, especially, understorey vegetation plays an important role in the annual biomass production and nutrient cycling (Mälkönen 1974, Havas & Kubin 1983). Vegetation provides information about soil fertility, water availability and climatic conditions in a forest ecosystem (Cajander 1949, Ellenberg et al. 1991). The vegetation cover protects the soil from erosion and regulates its moisture content. Through litterfall, the understorey vegetation affects the composition of the organic layer, which, in turn, is an important medium for root growth of many tree and dwarf shrub species. Understorey vegetation also affects soil temperature, microbial activity and nutrient mineralisation (Priha 1999). Mosses and lichens, which form a well-developed bottom layer in northern coniferous forests, are often the first species to manifest the effects of air pollution (Rigina & Kozlov 1999, Mäkipää et al. 2000). Furthermore, the understorey vegetation accounts for considerable part of the total biodiversity of boreal forests, and also maintains the life of animal communities. Thus, long-term changes in the understorey vegetation could have significant impacts on a range of ecological processes in forests (Dupouey et al. 1999).

The ICP Forests programme has two main objectives in vegetation monitoring at Level II (Manual on methods ...1998):

1) characterisation of the current state of forest vegetation on the basis of the floristic composition
2) monitoring changes in vegetation in relation to natural and anthropological environmental factors.

Here we present the initial situation of the understory vegetation on the Level II observation plots in Finland (see Fig. 2, p. 12). A complete vegetation survey will be undertaken every fifth year. An annual survey is carried out on six plots representing the southern, middle and northern boreal coniferous zones in Finland.

Materials and methods

The analysis of understorey vegetation was carried out on 31 observation plots in July–August 1998. One site (Evo_Sim, No. 19) was analysed by the personnel of the Finnish Environment Centre. The forest site types, dominant overstorey trees and the age of the tree stand on the plots are given in Table 4. The sampling design was based on a pilot study carried out in 1997 (Salemaa et al. 1999). One of the three sub-plots (30 x 30 m) was selected for vegetation monitoring (see Fig. 3, p. 13). Altogether 16 sampling units (quadrats) were marked out systematically (4 x 4 design) on the sub-plots on mineral soil, apart from the Evo plot where there were 20. There were only 8 sampling units on the peatland plots. The size of the sample unit was 2 m^2 (1.41 x 1.41 m), and 1 m^2 at Evo. The quadrats were marked permanently with plastic stakes at two diagonal corners.

Visual coverage of the plant species was assessed using the following scale: 0.01, 0.1, 0.2, 0.5, 1, 2, ...99, 100 %. The bottom layer (mosses and lichens), field layer (< 50 cm trees & shrubs, dwarf shrubs, herbs, and grasses & sedges) and shrub layer (50–150 cm trees & shrubs) were analysed. Plants growing on

stones or decayed wood were excluded. The coverage of leaf and needle litter, dead plant material, fine decaying wood, dead branches, fallen tree stems, stumps, bare mineral soil and stones were also assessed. Additional species, i.e. species occurring on the vegetation plot but not found on the sample unit, were recorded.

Two pairs of botanists worked on the same plot simultaneously, each pair assessing their own quadrats. Field tests were carried out to check that the assessment level remained uniform between the observers. Samples of unknown plant species were later identified by specialists.

The number of species (S) and the mean coverage of the species groups were calculated for each vegetation plot. The diversity of the plant communities was measured by the Shannon diversity ($H' = -\sum p_i \ln p_i$, i = proportion of the ith species out of the total

Table 4. Forest site types (Cajander 1949), dominant overstorey tree species and stand age of the monitoring plots.

Plot number and name	Forest site type		Tree species	Stand age, yr.
1. Sevettijärvi_P	Uliginosum-Vaccinium-Empetrum Type,	UVET	Scots pine	101
2. Pallasjärvi_P	Empetrum-Myrtillus Type,	EMT	Scots pine	46
3. Pallasjärvi_S	Hylocomium-Myrtillus Type,	HMT	Norway spruce	71
4. Sodankylä_P	Empetrum-Myrtillus Type,	EMT	Scots pine	60
5. Kivalo_S	Hylocomium-Myrtillus Type,	HMT	Norway spruce	66
6. Kivalo_P	Empetrum-Myrtillus Type,	EMT	Scots pine	40
7. Oulanka_S	Hylocomium-Myrtillus Type,	HMT	Norway spruce	127
8. Oulanka_P	Empetrum-Myrtillus Type,	EMT	Scots pine	76
9. Ylikiiminki_P	Empetrum-Calluna Type,	ECT	Scots pine	59
10. Juupajoki_P	Vaccinium Type,	VT	Scots pine	65
11. Juupajoki_S	Oxalis-Myrtillus Type,	OMT	Norway spruce	50
12. Tammela_S	Oxalis-Myrtillus Type,	MT	Norway spruce	55
13. Tammela_P	Vaccinium Type,	VT	Scots pine	45
14. Lapinjärvi_P	Vaccinium Type,	VT	Scots pine	55
15. Lapinjärvi_S	Oxalis-Myrtillus Type,	OMT	Norway spruce	55
16. Punkaharju_P	Vaccinium Type,	VT	Scots pine	65
17. Punkaharju_S	Oxalis-Myrtillus Type,	OMT	Norway spruce	65
18. Miehikkälä_P	Calluna Type,	CT	Scots pine	90
19. Evo_Sim	Oxalis-Myrtillus Type,	OMT	Norway spruce	155
20. Lieksa_Pim	Empetrum-Vaccinium Type,	EVT	Scots pine	230
21. Oulanka_Sim	Hylocomium-Myrtillus Type,	HMT	Norway spruce	240
22. Kevo_Pim	Uliginosum-Empetrum-Myrtillus Type,	UEMT	Scots pine	180
23. Uusikaarlepyy_S	Oxalis-Myrtillus Type,	OMT	Norway spruce	55
24. Närpiö_S	Myrtillus Type,	MT	Norway spruce	55
25. Vilppula_Spro	Oxalis-Myrtillus Type,	OMT	Norway spruce	66
26. Ikaalinen_P	Oligotrophic pine peatland (drained)		Scots pine	-
27. Ikaalinen_Pfer	Oligotrophic pine peatland (drained)		Scots pine	-
28. Solböle_Spro	Oxalis-Myrtillus Type,	OMT	Norway spruce	66
29. Pyhäntä_P	Oligotrophic pine peatland (drained)		Scots pine	-
30. Pyhäntä_Pfer	Oligotrophic pine peatland (drained)		Scots pine	-
31. Kivalo_Spro	Hylocomium-Myrtillus Type,	HMT	Norway spruce	65

coverage) and the evenness (E = H'/ln S) indices. The data from all the plots were ordinated by detrended correspondence analysis (DCA) in order to find the main compositional gradients of the vegetation (PC-ORD for Windows 4.01, McCune & Mefford 1999).

Results and discussion

A total of 183 plant species, including 18 additional species, were found in the field and bottom layers of the 31 plots (Table 5). There were 13 species in the shrub layer, but some of them were also recorded as seedlings in the field layer. The species number was the highest in vascular plant species, followed by mosses and lichens.

The Shannon diversity indices and the species numbers were the highest in the spruce plots of the Oxalis-Myrtillus site type (e.g. Solböle_Spro, No. 18 and Lapinjärvi_S, No. 15). The lowest diversity was found in the spruce plot at Uusikaarlepyy_S (No. 23), where the total cover of the understorey vegetation was only 27 % (Table 6). The species diversity was rather low in the pine plots of the Vaccinium and Calluna types (Table 5). The community structure was the most even in the spruce plots of the Oxalis-Myrtillus type. Evenness was also high on the pine plot at Lieksa_Pim (No. 20) and on the oligotrophic pine peatlands located at Ikaalinen (Ikaalinen_P, No. 26 and Ikaalinen_Pfer, No. 27).

The total coverage of all species exceeded 100 % on almost all the plots (Table 6). Exceptions to this were the spruce plots at Uusikaarlepyy_S (No. 23), Evo_Sim (No. 19) and Punkaharju_S (No. 17), where the shading of overstorey trees and the large amounts of needle and leaf litter suppress the growth of the understorey plants. The understorey vegetation was not closed (< 100 %) on the northern pine plots at Sevettijärvi_P (No. 1) and Pallasjärvi_P (No. 2), where the effect of grazing by reindeers has disturbed the normal succession of the vegetation.

The majority of the vegetation plots had a well-developed moss layer (Table 6). The coverage of *Sphagnum* spp. was higher on the peatland plots at Ikaalinen_P (No. 26) and at Ikaalinen_Pfer (No. 27) (drained for forestry in the 1950's) than at Pyhäntä_P (No. 29) and at Pyhäntä_Pfer (No. 30) (drained in the 1930's), due to the longer post-drainage succession of the latter site. Liverworts *(Hepaticae)* were found on almost all the plots, but their abundances in most cases were very low. Lichens were most abundant on the northern pine plots at Sevettijärvi_P (No. 1), Pallasjärvi_P (No. 2) and Ylikiiminki_P (No. 9). Reindeer lichens (*Cladina* spp.) accounted for the highest proportion of the lichen coverage. Although the number of cup lichen species (*Cladonia* spp.) was high (Table 5), their coverage was insignificant (Table 6). The coverage of field layer vascular plants varied considerably depending on the degree of shading and the fertility level of the site. The highest coverage of the vascular plants (89 %) was found on a peatland plot at Pyhäntä_P (No. 29), which had many tall dwarf shrub species, and on the herb rich spruce plot at Solböle_Spro (No. 28) (88 %).

The amount of decaying wood on the forest floor is of considerable importance for the total biodiversity of boreal forest ecosystems, especially mosses, lichens, mushrooms and insects. The coverage of decaying wood was the highest on the pine plot at Miehikkälä_P (No. 18) and on the spruce plot at Lapinjärvi_S (No. 15) as result of the dead branches and small stems left by silvicultural practices. The amount of needle litter was the highest (77 %) on the shady spruce plot at Uusikaarlepyy_S (No. 23). The coverage of needle litter was usually lower on the spruce than on the pine plots, especially in the north, because needles had become submerged inside the thick moss (*Hylocomium splendens*) layer.

The main compositional gradient in the DCA ordination represented the change in site fertility, combined with the variation in soil moisture and location along the south-north axis. The plots were located in the ordination configuration in accordance with the fertility of the forest site types (Fig. 6a). Herb rich sites (OMT) were located on the left, followed by mesic sites (MT in the south, HMT in the north),

Table 5. The number of species occurring on the sampling units (quadrats) on the vegetation plots, and the evenness (E) and the Shannon H' indices of the plant communities. Hepat. = Hepaticae. Add. = additional species found on the vegetation plots, but outside the quadrats.

Plot number and name	Vascular species < 50 cm					Bryophytes				Lichens			Species on quadrat				Shrub layer 50-150 cm
	trees & shrubs	dwarf shrubs	herbs	grasses & sedges	tot	*Hepat.*	*Sphagnum*	other mosses	tot	*Cladonia* lichens	other	tot	all	E	H'	add. spec.	trees & shrubs
1. Sevettijärvi_P	1	4	0	0	5	4	0	9	13	10	6	16	34	0.570	2.009	2	0
2. Pallasjärvi_P	1	6	1	1	9	3	0	9	12	12	5	17	38	0.652	2.370	3	1
3. Pallasjärvi_S	2	6	6	1	15	1	0	9	10	3	5	8	33	0.481	1.681	5	2
4. Sodankylä_P	2	5	1	0	8	1	0	7	8	9	4	13	29	0.440	1.482	1	0
5. Kivalo_S	0	5	3	1	9	2	0	11	13	2	1	3	25	0.586	1.888	8	2
6. Kivalo_P	2	5	0	2	9	2	0	11	13	6	5	11	33	0.476	1.665	8	1
7. Oulanka_S	1	5	4	2	12	1	0	10	11	0	0	0	23	0.603	1.892	3	1
8. Oulanka_P	5	9	5	2	21	1	0	8	9	3	0	3	33	0.566	1.980	0	2
9. Ylikiiminki_P	1	4	0	0	5	1	0	8	9	9	5	14	28	0.532	1.772	3	0
10. Juupajoki_P	1	4	3	4	12	2	1	14	17	2	2	4	33	0.537	1.879	2	4
11. Juupajoki_S	2	3	15	6	26	4	0	13	17	1	0	1	44	0.671	2.539	8	1
12. Tammela_S	2	3	11	6	22	3	1	16	20	1	0	1	43	0.514	1.934	7	2
13. Tammela_P	2	6	5	2	15	1	0	9	10	6	2	8	33	0.431	1.507	8	3
14. Lapinjärvi_P	2	2	4	2	10	1	0	6	7	3	2	5	22	0.411	1.271	11	1
15. Lapinjärvi_S	4	4	24	8	40	4	2	13	19	2	0	2	61	0.669	2.750	8	3
16. Punkaharju_P	2	3	1	0	6	0	0	5	5	0	0	0	11	0.542	1.299	7	1
17. Punkaharju_S	2	4	9	4	19	1	2	12	15	2	0	2	36	0.415	1.489	9	3
18. Miehikkälä_P	1	4	1	0	6	1	0	4	5	10	3	13	24	0.390	1.240	3	0
19. Evo_Sim	1	4	15	4	24	1	0	9	10	0	0	0	34	0.547	1.931	0	5
20. Lieksa_Pim	2	4	2	0	8	0	0	6	6	0	4	4	18	0.626	1.809	3	1
21. Oulanka_Sim	1	7	4	1	13	2	0	8	10	3	2	5	28	0.464	1.546	4	1
22. Kevo_Pim	1	7	0	1	9	3	0	7	10	12	7	19	38	0.611	2.223	4	2
23. Uusikaarlepyy_S	2	1	7	3	13	1	0	10	11	0	0	0	24	0.368	1.170	2	1
24. Närpiö_S	4	6	13	6	29	2	2	14	18	3	2	5	52	0.551	2.179	3	5
25. Vilppula_Spro	2	3	15	7	27	2	1	15	18	0	0	0	45	0.685	2.608	2	2
26. Ikaalinen_P	3	6	2	2	13	1	4	8	13	1	2	3	29	0.698	2.325	1	1
27. Ikaalinen_Pfer	3	5	2	3	13	2	5	5	12	1	2	3	28	0.664	2.188	5	2
28. Solböle_Spro	3	3	18	10	34	4	4	17	25	1	0	1	60	0.681	2.789	8	4
29. Pyhäntä_P	3	9	1	2	15	3	4	10	17	3	3	6	38	0.555	2.017	2	2
30. Pyhäntä_Pfer	1	9	2	2	14	3	4	12	19	0	2	2	35	0.584	2.076	3	1
31. Kivalo_Spro	0	4	2	2	8	4	1	10	15	2	1	3	26	0.473	1.541	4	2
tot in quadrat	11	16	41	19	87	13	7	30	50	17	11	28	165			18	12
tot in plot	15	17	48	19	99	14	9	32	53	17	11	28	183				13

Table 6. The mean coverages of the species groups, decaying wood and needle litter on the vegetation plots.

Plot number and name	Vascular species	Bryophytes				Lichens				All sum	Decaying wood	Needle litter
		Hepaticae	*Sphagnum*	other	sum	*Cladina*	*Cladonia*	other	sum			
1. Sevettijärvi_P	35.0	0.8	0	7.4	8.2	28.1	1.0	0.8	29.9	73.1	4.0	61
2. Pallasjärvi_P	45.4	3.0	0	32.5	35.5	10.0	2.9	1.0	13.9	94.8	6.6	61
3. Pallasjärvi_S	70.2	3.0	0	84.3	87.3	0.1	0	0.3	0.4	157.8	4.4	17
4. Sodankylä_P	39.9	0	0	74.7	74.7	4.6	0.2	0.1	4.9	119.4	9.3	29
5. Kivalo_S	35.9	9.1	0	71.2	80.3	0	0	0	0	116.2	4.2	36
6. Kivalo_P	35.7	0.1	0	88.3	88.3	3.2	0.2	0.3	3.7	127.7	3.1	7
7. Oulanka_S	72.1	3.3	0	84.6	88.0	0	0	0	0	160.0	2.1	36
8. Oulanka_P	83.3	0.2	0	82.3	82.5	0	0	0	0	165.8	6.9	38
9. Ylikiiminki_P	30.1	0	0	52.1	52.1	19.4	4.4	0.1	23.9	106.1	11.8	31
10. Juupajoki_P	31.4	0.1	0	84.8	85.0	0.3	0	0	0.3	116.7	14.1	13
11. Juupajoki_S	39.1	1.6	0	59.5	61.1	0	0	0	0	100.2	10.9	38
12. Tammela_S	47.3	0	1.6	75.8	77.4	0	0	0	0	124.7	8.8	25
13. Tammela_P	33.5	0	0	86.1	86.1	0.2	0.3	0	0.6	120.2	14.8	24
14. Lapinjärvi_P	34.7	0	0	87.6	87.6	0.1	0.1	0	0.2	122.4	19.3	19
15. Lapinjärvi_S	81.7	3.2	2.5	69.3	75.0	0	0	0	0	156.7	8.8	23
16. Punkaharju_P	18.1	0	0	98.3	98.3	0	0	0	0	116.4	10.8	10
17. Punkaharju_S	15.8	0	0.1	70.1	70.1	0	0	0	0	86.0	17.0	26
18. Miehikkälä_P	22.4	0	0	86.2	86.2	2.6	0.5	0.4	3.5	112.1	20.7	19
19. Evo_Sim	18.5	0	0	18.6	18.6	0	0	0	0	37.1	0	21
20. Lieksa_Pim	57.1	0	0	96.3	96.3	1.2	0	0.1	1.3	154.7	5.1	7
21. Oulanka_Sim	60.2	0.6	0	92.7	93.3	0	0	0	0.1	153.6	5.3	33
22. Kevo_Pim	52.0	1.6	0	34.9	36.5	3.8	0.8	1.8	6.5	95.0	5.8	56
23. Uusikaarlepyy_S	2.5	0.1	0	24.5	24.5	0	0	0	0	27.0	8.7	77
24. Närpiö_S	32.8	0.1	0.2	80.1	80.4	0.1	0.2	0	0.3	113.5	6.8	20
25. Vilppula_Spro	70.3	8.4	0.7	62.9	72.0	0	0	0	0	142.3	5.7	26
26. Ikaalinen_P	73.5	0.1	56.9	34.8	91.7	0	0	0	0.1	165.3	2.6	11
27. Ikaalinen_Pfer	53.2	0.8	29.6	55.5	85.9	0.1	0.1	0	0.3	139.3	4.1	13
28. Solböle_Spro	87.9	0.1	4.6	75.5	80.3	0	0	0	0	168.1	9.7	17
29. Pyhäntä_P	72.2	0	9.7	79.9	89.5	1.1	0	0.3	1.4	163.2	7.0	10
30. Pyhäntä_Pfer	88.6	0.1	8	83.8	91.9	0.3	0	0.1	0.4	180.9	4.7	11
31. Kivalo_SPro	71.3	1.6	0	73.2	74.8	0	0	0	0	146.2	3.6	49

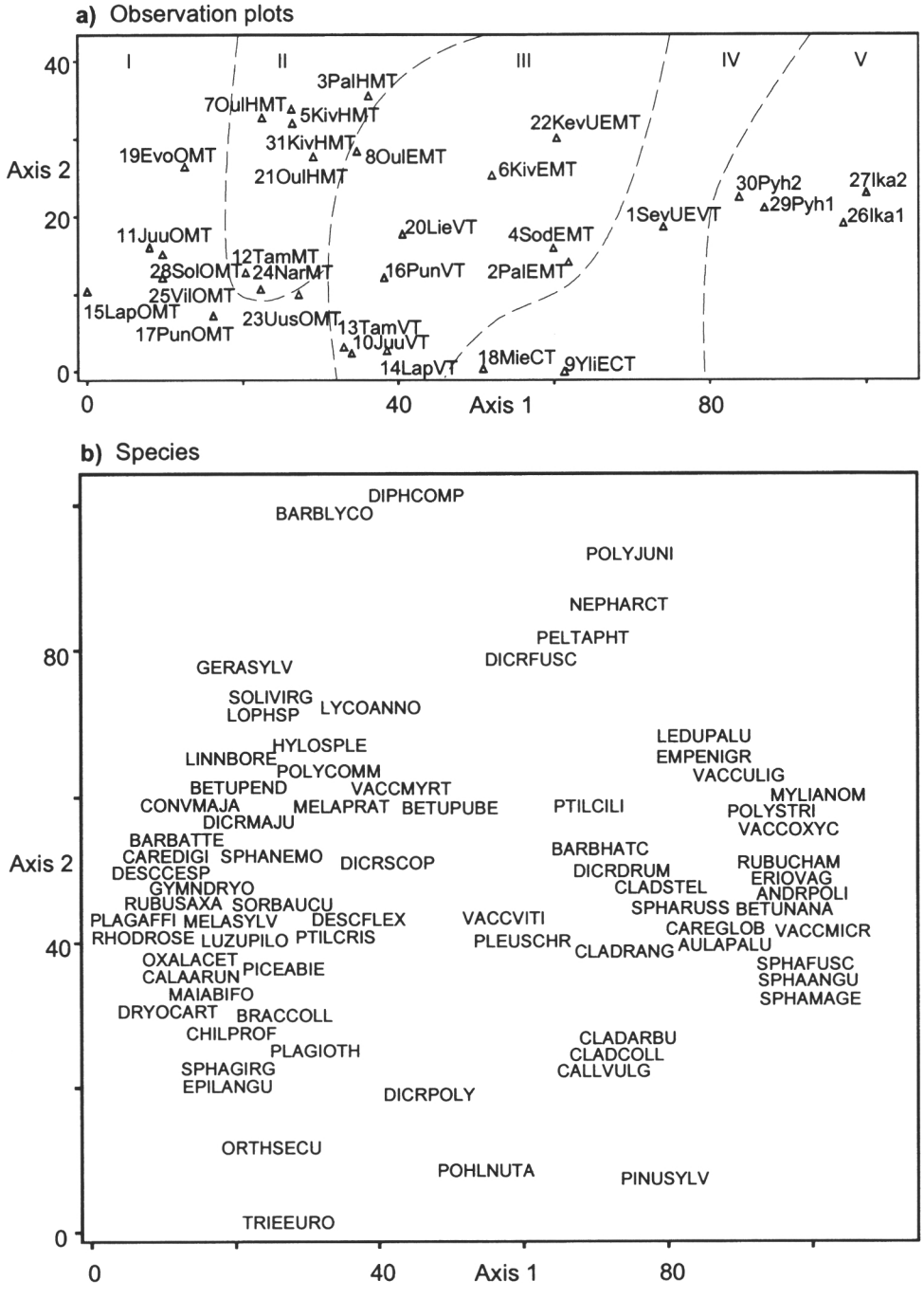

Figure 6. Detrended correspondence analysis of the vegetation data of 31 observation plots, a) sample plot ordination, b) species ordination. Abbreviation of the species names = first four letters from generic and species names. Species occurring on only three or less plots were excluded. Plot means of species coverage values were log(x+1) transformed. Rare species were downweighted. Five forest site types were distinguished: I = herb rich sites, II = mesic sites, III = sub-xeric sites, IV = xeric sites, V = oligotrophic drained pine peatlands.

sub-xeric sites (VT in the south, EMT and UEMT in the north), xeric sites (CT in the south, ECT and UEVT in the north) and oligotrophic drained peatlands (originally tall-sedge pine fens) on the right. The peatland plots at Pyhäntä (Pyhäntä_P, No. 29 and Pyhäntä_Pfer, No. 30), which had a higher post-drainage age and lower moisture status than the plots at Ikaalinen (Ikaalinen_P, No. 26 and Ikaalinen_Pfer, No. 27), were located next to the mineral soil plots. The peatland plots at Ikaalinen (Ikaalinen_P, No. 26 and Ikaalinen_P, No. 27) were located furthest away on the right. The demanding species (e.g. *Rhodobryum roseum*) on the left were replaced by typical heath forest species in the middle (e.g. *Pleurozium schreberi*) and by the modest peatland species on the right (*Sphagnum* spp.) in the species ordination (Fig. 6b). The northern plots were located slightly towards the right compared to the southern ones within each forest site type, indicating lower fertility. The second gradient in the ordination divided the moss-rich sample plots (mostly in the north) from the lichen rich sample plots (both in the south and north).

Conclusion

The coverage of moss and lichen species was considerably high on many of the vegetation plots. Special attention should be paid to the correct assessment of these species, owing to their sensitivity in indicating environmental changes. Especially liverworts *(Hepaticae)*, leather lichens (*Nephroma* sp., *Peltigera* sp.) and cup lichens (*Cladonia* spp.) have important bioindicative value.

Acknowledgements

We thank Anna-Maija Kokkonen, Anders Melamies, Minna Mäntylä, Outi Pöyhönen, Tuomas Salemaa and Katja Tilli for participating in the field work. Christoffer Bondestam, Krister Karttunen and Sampsa Lommi identified some plant specimens.

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Meteorological measurements

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Introduction

Meteorological measurements were carried out throughout 1998 on 10 of the Level II monitoring plots (see Fig. 2, p. 12): Pallasjärvi_S (No. 3), Kivalo_S (No. 5), Ylikiiminki_P (No. 9), Juupajoki_S (No.11), Tammela_S (No.12), Punkaharju_S (No. 17), Miehikkälä_P (No. 18), Uusikaarlepyy_S (No. 23), Närpiö_S (No. 24) and Vilppula_S (No. 25). In addition, two new weather stations were established, one at Juupajoki_P (plot No. 10), and one at Solböle_S (No. 28). The majority of the stations are located in Norway spruce stands (_S), apart from plot Nos. 9, 10 and 18 which are situated in Scots pine stands (_P).

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

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
8. Precipitation under the canopy

The parameters are measured and recorded automatically once a minute. The stored raw data are processed into hourly means, maxima and minima for each variable.

The following soil parameters have also been monitored:

9. Soil temperature (-10 cm and -20 cm depth)
10. Soil frost
- soil temperature with a frost probe over a depth range from 10–30 cm to 30–195 cm depending on the local conditions
11. Soil moisture

The parameters are measured and stored once an hour.

Weather conditions in 1998

The thermal conditions in 1998 were rather typical of the Finnish climate (Fig. 7). Both the winter and summer indices on the Level II plots were close to the long-term averages (Table 7). Compared to 1997, the summer indices were 144–274 d.d. lower than in 1998 despite the fact that the growing season at most of the plots was longer in 1998 than in 1997 (Merilä 1999). In the beginning of the growing season the latest minimum temperatures below zero occurred during the period 20.5.–26.5. (Table 7) but, in general, this had no adverse effect on the vegetation. The average annual precipitation was 1.1–1.8 times higher than the long-term average (Finnish Meteorological Institute 1999).

Soil temperature

Figures 8a and b show the yearly course of soil temperature down the soil profiles on a number of the Level II plots in 1998. Soil temperatures was measured at a depth of 10–15 cm and deeper in the mineral soil, but not in the organic layer or in the uppermost part of the mineral soil.

The most important factors determining soil freezing are the winter index and the depth of the snow cover which is an effective insulator

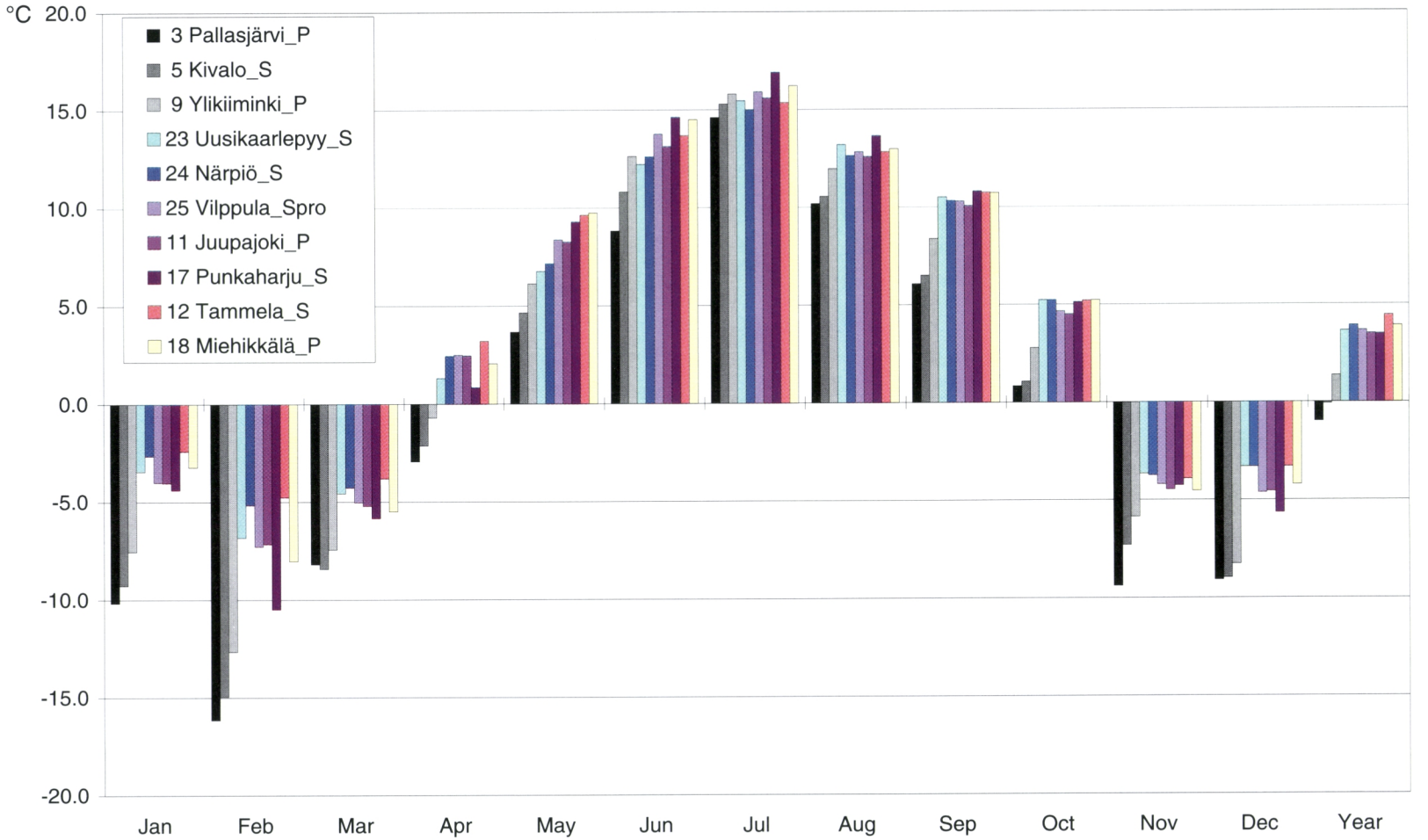

Figure 7. Mean monthly and yearly temperatures on Level II plots (from north to south) with meteorological measurements in 1998.

Table 7. Winter index, late frost, growing season and its length, average summer index in 1961–90 (Ojansuu & Henttonen 1983) and in 1998 at a number of the Level II plots. The gaps in the data set were supplemented by modelling the missing observations using the data from the nearest weather station of the Finnish Meteorological Institute.

Plot No	Plot name	Latitude	Winter index d.d. 1.10.-1.4.	Winter index d.d. total	Late frost °C, (date) max 15 d before g.s.	Late frost °C, (date) during g.s.	Growing season period	Growing season length, d	Summer index °Cd. 1961-90	Summer index °Cd. 1998
3	Pallasjärvi_S	67°60'	-1582	-1707	-2.4 (4.5.)	-2.4 (24.5.)	14.05.–22.09.	132	684	663
5	Kivalo_S	66°20'	-1445	-1553	-1.0 (20.5.)	-1.0 (20.5.)	13.05.–22.09.	133	826	777
9	Ylikiiminki_P	64°58'	-1164	-1256	-15.8 (11.4.)	-2.1 (4.5.)	24.04.–23.09.	153	1029	965
11	Juupajoki_S	61°51'	-748	-794	-8.6 (10.4.)	-4.6 (24.5.)	22.04.–28.09.	160	1140	1123
12	Tammela_S	60°39'	-559	-593	-10.0 (4.4.)	–	19.04.–27.10.	189	1253	1233
17	Punkaharju_S	61°49'	-946	-1007	-9.9 (10.4.)	-0.6 (25.4.)	25.04.–17.10.	176	1289	1281
18	Miehikkälä_P	60°42'	-792	-841	-9.2 (9.4.)	-0.8 (24.4.)	21.04.–28.09.	160	1351	1244
23	Uusikaarlepyy_S	63°34'	-641	-697	-14.5 (11.4.)	-1.4 (4.5.)	23.04.–25.09.	156	1131	1056
24	Närpiö_S	62°28'	-576	-618	-8.9 (9.4.)	-1.9 (22.5.)	22.04.–16.10.	178	1187	1081
25	Vilppula_Spro	62°03'	-723	-769	-8.3 (10.4.)	-0.4 (26.5.)	22.04.–28.09.	160	1179	1170

The key parameters presented in Table 7 are:

Winter index equals the sum of daily mean temperatures below 0 °C during the period from 1 October to 1 April (degree days below 0 °C). The sum was also calculated for the whole period with 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 on June 30. In addition, the lowest minimum temperature of the period from the beginning of the growing season till the end of June is also presented.

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

Growing season is the period during which the summer index accumulates.

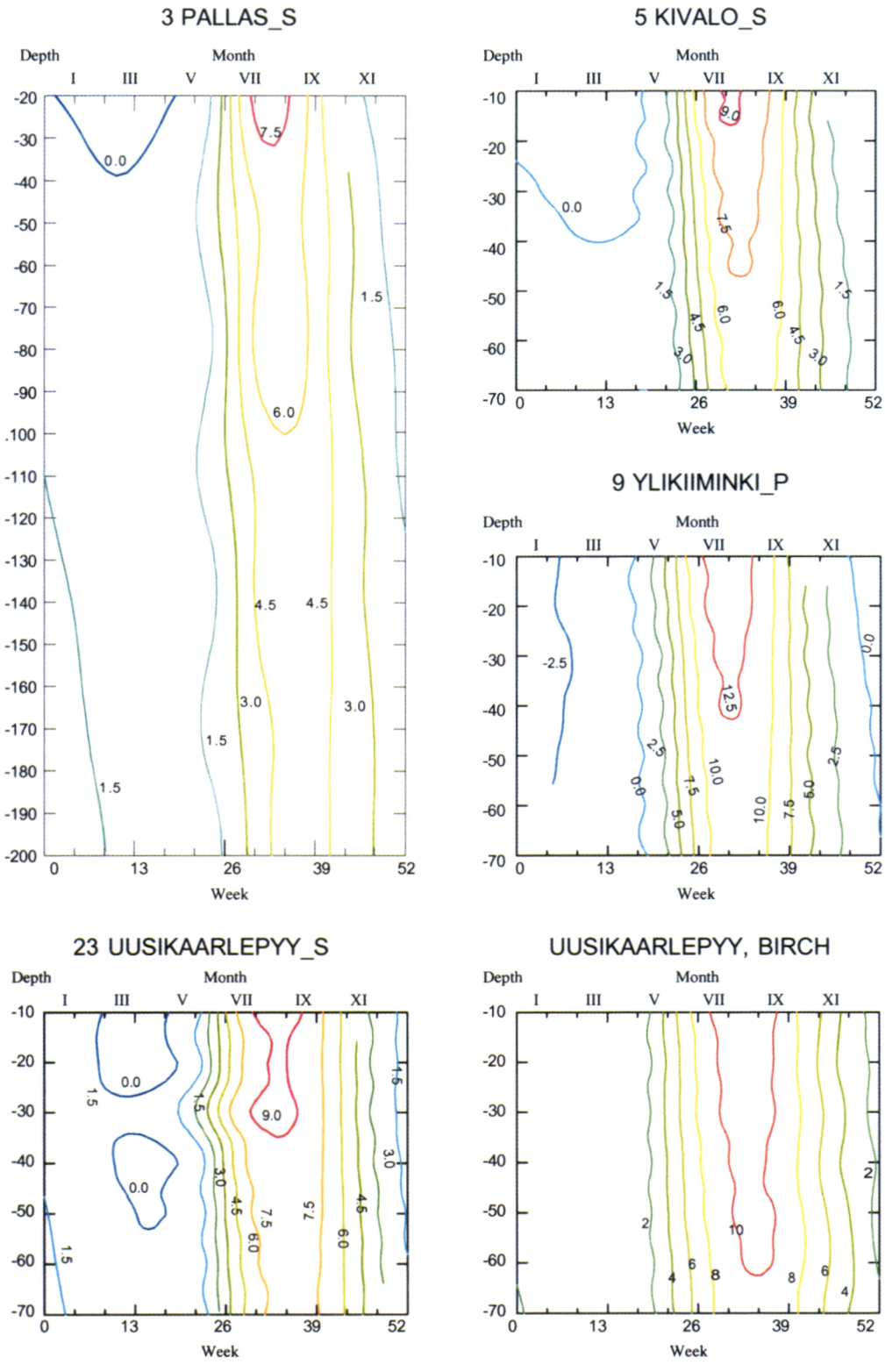

Figure 8a. The isotherms (°C) down the soil profiles of some of the Level II plots during 1998.

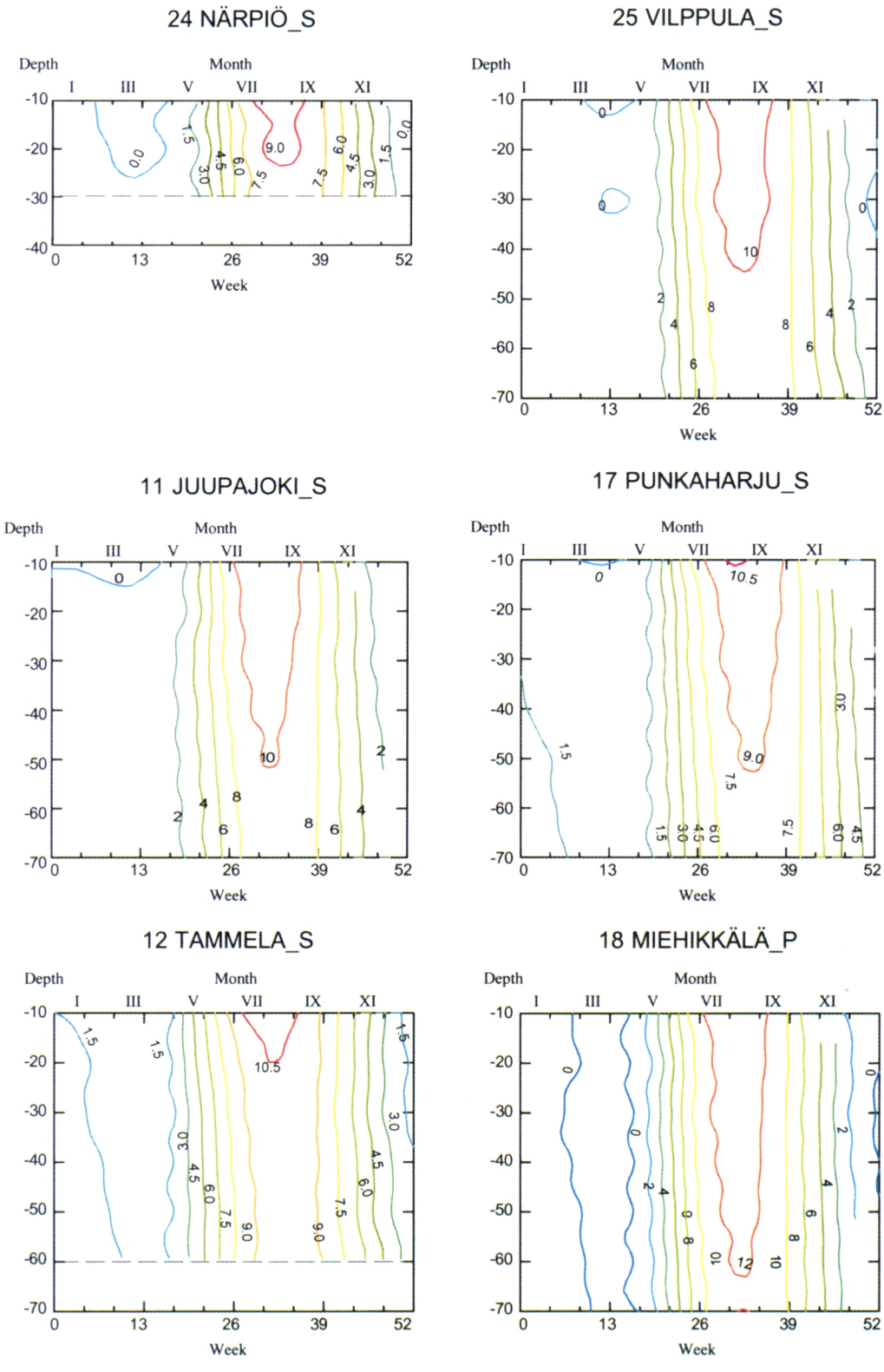

Figure 8b. Soil temperature measurements extend to the depth of 30 cm in Närpiö (No. 9) and to 60 cm in Tammela (No. 12).

(Huttunen & Soveri 1993). The topsoil normally freezes at a time when the mean air temperature has fallen to -5 °C (Solantie 1987). On the southern plot at Tammela_S (No. 12) subzero temperatures did not extend to a depth of 10 cm at all during winter 1997–98. An opposite example is Kivalo_S (No. 5), where the frozen-soil period lasted for approximately 31 weeks. Surprisingly, the corresponding period at the northernmost plot at Pallasjärvi_S (No. 3) was about 8 weeks shorter than that at Kivalo_S (No. 5) even though the winter index was higher at Pallasjärvi_S (No. 3) (Table 7). However, according to the precipitation measurements, the precipitation sum in winter 1997–98 (November–April) was approximately 40 % higher at Pallasjärvi_S (No. 3) than at Kivalo_S (No. 5), suggesting that the thicker snow cover protected the soil against subzero temperatures.

Our observations also clearly demonstrate the effect of soil characteristics and tree species on soil temperature. The soil under the Scots pine stands (No. 9 Ylikiiminki_P and No. 18 Miehikkälä_P) cooled down and warmed up more rapidly than under the spruce stands at the same latitude. Thus, both the maximum temperatures in summer are higher and the minimum temperatures in winter are lower under pine than under spruce. This is evidently a result of the higher thermal conductivity of coarse-textured soil and the lower interception of solar energy by the crown canopy in the pine stands.

At Uusikaarlepyy the soil temperature is being measured under a Norway spruce stand (Level II plot No. 23) and under an adjacent birch stand (Fig. 8a). The soil temperature under the birch stand was higher than that under the spruce stand throughout the year. The temperature difference reached a maximum of 3–5 °C during late May–June.

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Deposition

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Introduction

Deposition samples were collected throughout 1998 from 8 Scots pine and 8 Norway spruce stands (stand throughfall) and adjacent open areas (bulk deposition) (see Fig. 2, p. 12). The stand throughfall and bulk deposition samples were collected at 4-week intervals in winter and spring, and at 2-week intervals in summer and autumn. There were 20 systematically located precipitation collectors (∅ 20 cm, h 0.4 m) within the stand during the snowfree period, and 6 snow collectors (∅ 36 cm, h 1.8 m) during wintertime. The corresponding number of collectors for the adjacent open area was 3 and 2, respectively. The throughfall values for 1998 are compared in this report to the corresponding values for 1996 and 1997 (Lindroos et al. 1999).

Deposition in Scots pine stands during 1998

The amount of precipitation in the open areas adjacent to the Scots pine stands varied between 363–726 mm in 1998. The lowest precipitation was recorded on the plot (Sevettijärvi_P, No. 1) located in north-east Lapland close to the Norwegian border. Precipitation as stand throughfall varied between 328–634 mm (Fig. 9).

The acidity of stand throughfall was the highest in southern Finland. The lowest pH values were recorded on the plots in the southern parts of the country, and the pH increased on moving to the north. The mean pH of stand throughfall was lower than that of bulk precipitation. The amount of H^+ ions in stand throughfall was at a similar level or higher than that in bulk deposition (Fig. 9). The lower pH in stand throughfall compared to that of bulk deposition is related to the acidifying effect of organic substances leached from the tree canopies, as well as to the wash-off of dry deposition (Cronan & Reiners 1983). The sulphate load in stand throughfall was higher than that in bulk deposition, indicating that dry deposition was leached from the tree canopies. It is widely accepted that the increase in the sulphate load as rain water passes down through the forest canopy primarily represents the proportion of dry deposition (Lindberg & Lovett 1992). However, nutrient cycling between the trees and forest soil may also contribute to this phenomenon. There was a clear decreasing gradient in sulphate deposition running from south to north in both bulk deposition and stand throughfall (Fig. 9).

The N_{total}, NO_3 and NH_4 loads in stand throughfall and bulk deposition were the highest in southern Finland and decreased on moving to the north. The nitrogen load was lower in stand throughfall than in bulk deposition on all the plots, which indicates that nitrogen deposition is relatively low in Finland (Fig. 10). In central Europe and southern Scandinavia, where the nitrogen deposition is much higher, the amount of nitrogen in precipitation usually increases as it passes down through the canopy layer. The reason for the lower nitrogen load in stand throughfall than in bulk deposition in Finland is the uptake of nitrogen by the canopy layer (e.g. Lindroos et al. 2000).

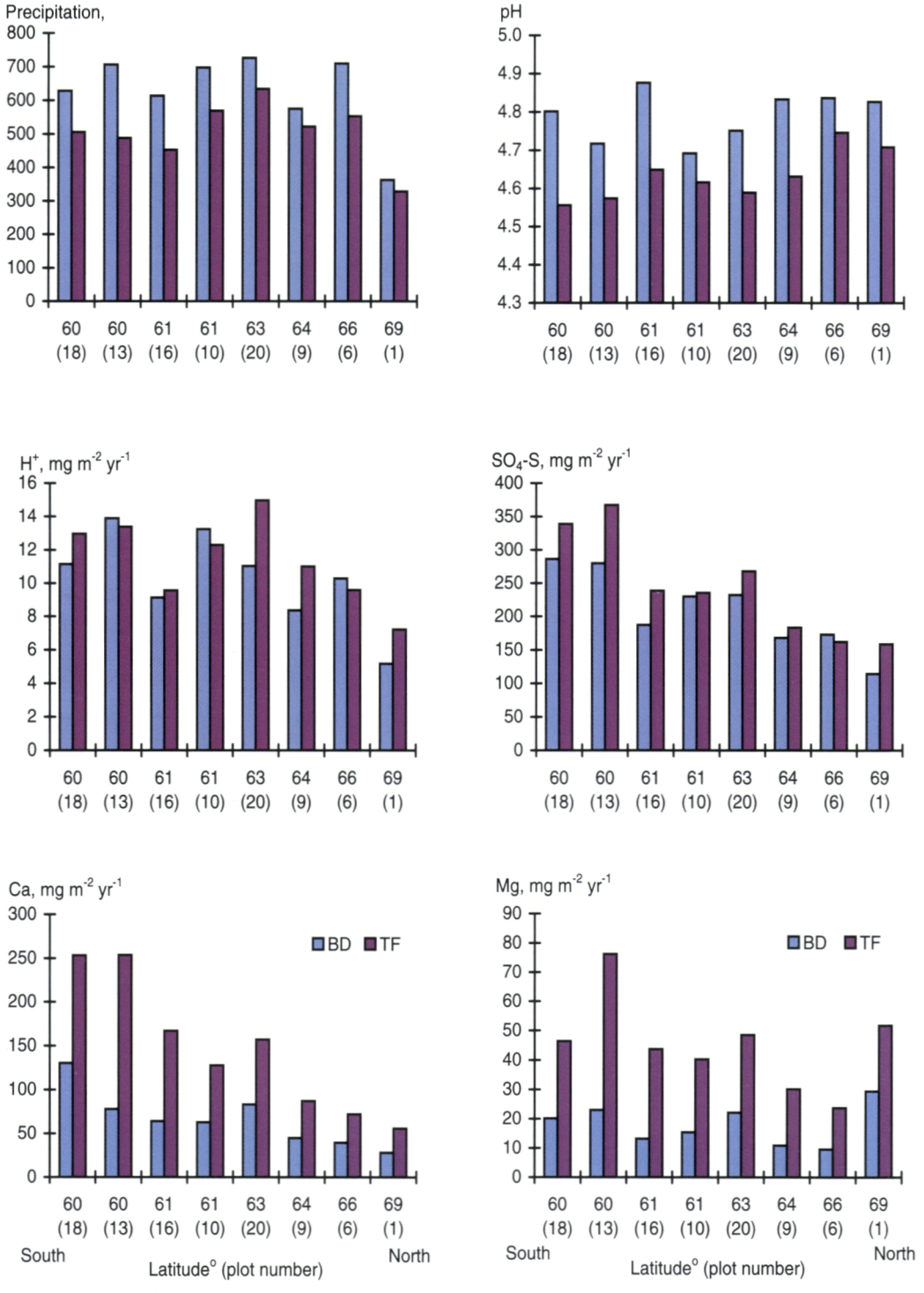

Figure 9. The amount of precipitation, mean pH and deposition of protons, sulphate, calcium and magnesium in bulk deposition (BD) and in stand throughfall (TF) during 1998 in 8 Scots pine stands (18 = Miehikkälä_P, 13 = Tammela_P, 16 = Punkaharju_P, 10 = Juupajoki_P, 20 = Lieksa_Pim, 9 = Ylikiiminki_P, 6 = Kivalo_P, 1 = Sevettijärvi_P).

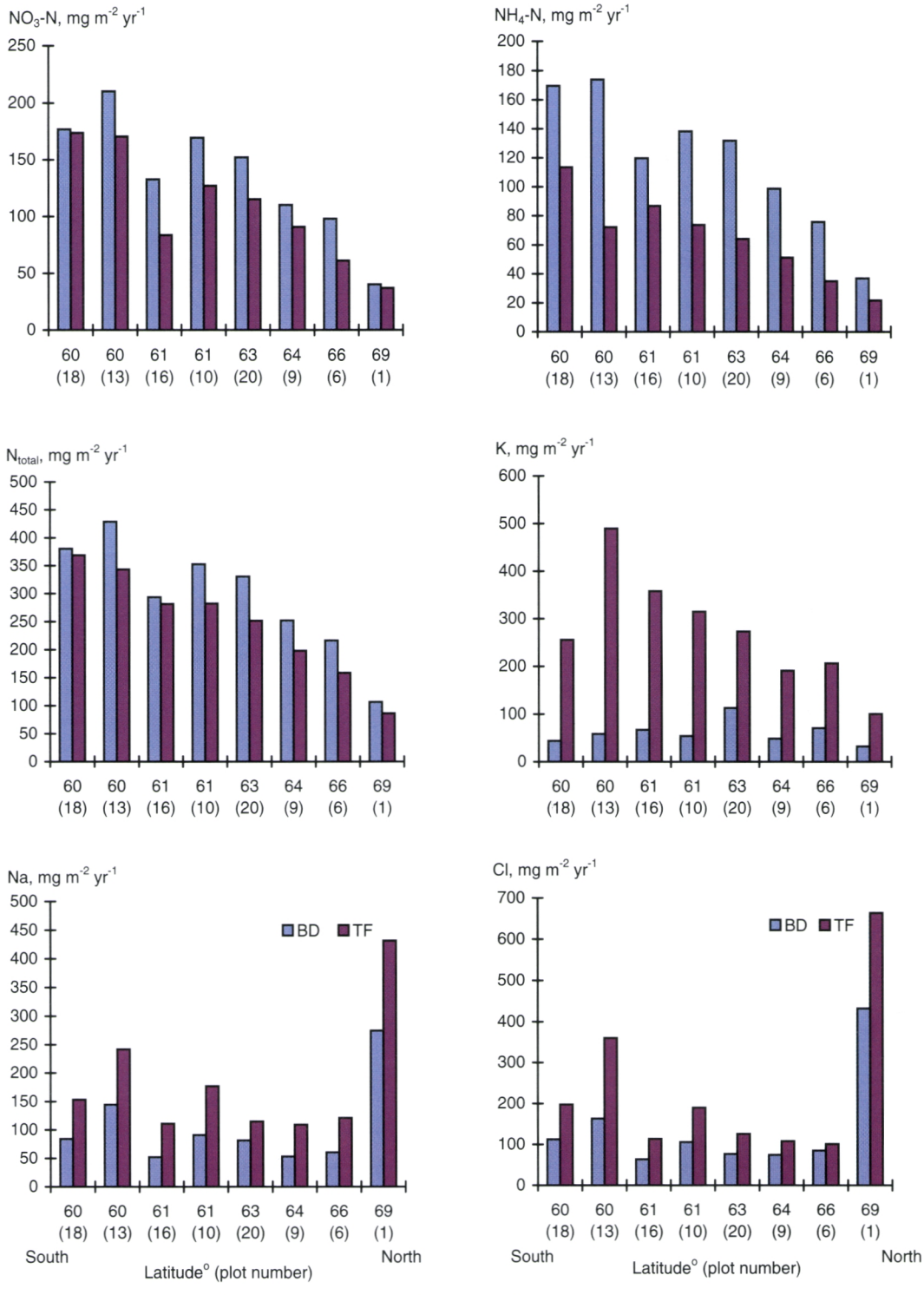

Figure 10. Deposition of nitrate, ammonium, total nitrogen, potassium, sodium and chloride in bulk deposition (BD) and in stand throughfall (TF) during 1998 in 8 Scots pine stands (see Fig. 9 for plot localities).

The Ca, Mg, K, Na and Cl loads in stand throughfall were higher than those in bulk deposition due to leaching and wash-off processes in the Scots pine canopies (Figs. 9 and 10). There was a clear decreasing S-N gradient in the bulk deposition of Ca, as well as of Mg when the northernmost plot (Sevettijärvi_P, No. 1) is excluded. There were also clear decreasing S-N gradients in stand throughfall for all the above ions. However, the vicinity of the Arctic Ocean was reflected as elevated Mg, Na and Cl loads in stand throughfall and bulk deposition on the northernmost plot (Sevettijärvi_P, No. 1).

Deposition in Norway spruce stands during 1998

The amount of precipitation in the open area varied in 1998 between 526–759 mm, and in stand throughfall between 327–722 mm (Fig. 11). There were no clear relationships between the mean pH in bulk deposition and in stand throughfall. The deposition of H^+ ions in stand throughfall was lower than that in bulk precipitation in all the stands. It has earlier been observed that spruce stands can have a buffering effect on deposition acidity in Finland (e.g. Lindroos & Derome 1998). In general, the H^+ ion load was highest in southern Finland. The pH values were exceptionally high, and the H^+ ion load correspondingly low, on the sample plot located on the west coast (Uusikaarlepyy_S, No. 23) (Fig. 11).

The effect of nutrient and organic matter leaching, as well as the wash-off of dry deposition accumulated in the spruce canopies, was reflected as elevated loads of SO_4, Ca, Mg, K, Na and Cl in stand throughfall compared to bulk deposition (Figs. 11 and 12). There were also clear decreasing S-N gradients for these components in both stand throughfall and bulk deposition.

Nitrogen (N_{tot}, NO_3, NH_4) deposition was the highest in the south, and decreased on moving to the north in stand throughfall and bulk deposition (Fig. 12). The lower nitrogen deposition load in stand throughfall compared to that in bulk deposition indicated nitrogen uptake by the crown canopy, as was also the case with the Scots pine plots. The one exception to the overall pattern was the spruce plot on the west coast (Uusikaarlepyy_S, No. 23), where local NH_3 emissions from agriculture have resulted in higher ammonium and total nitrogen deposition inside the stand (Fig. 12). These emissions have also resulted in the neutralisation of deposition acidity, as seen from the elevated pH values on this plot (Fig. 11).

Input of acidifying components to the forest floor from 1996 to 1998

In general, the input of acidifying compounds to the forest floor was greater in southern and central than in northern Finland during 1996–1998. On most of the plots, however, there was an increasing trend in the pH of stand throughfall from 1996 to 1998 (Figs. 13 and 14). There was also a strong decreasing SO_4 gradient in stand throughfall running from south to north in all three years. Sulphate deposition on the forest floor has decreased during the three-year period, especially on the plots in the southern and central parts of the country. This decrease cannot be explained by the variation in annual precipitation, but is connected with the decreased sulphate concentrations (Figs. 13 and 14). The sulphate load in stand throughfall is a relatively good indicator of the total (wet + dry) sulphate deposition from the atmosphere. The decrease in sulphate concentrations and total sulphate deposition have also undoubtedly at least partly decreased precipitation acidity during the three-year period. A decreasing trend in stand throughfall acidity and H^+ load, related to a decrease in sulphate concentrations and sulphate deposition, has been reported for the ICP-IM catchments in southern and central Finland for the period 1989–1997 (Ukonmaanaho et al. 1998, Lindroos et al. 2000). According to the results presented in this report, a similar trend was also evident for the period 1996–1998 on the ICP Forests Level II plots.

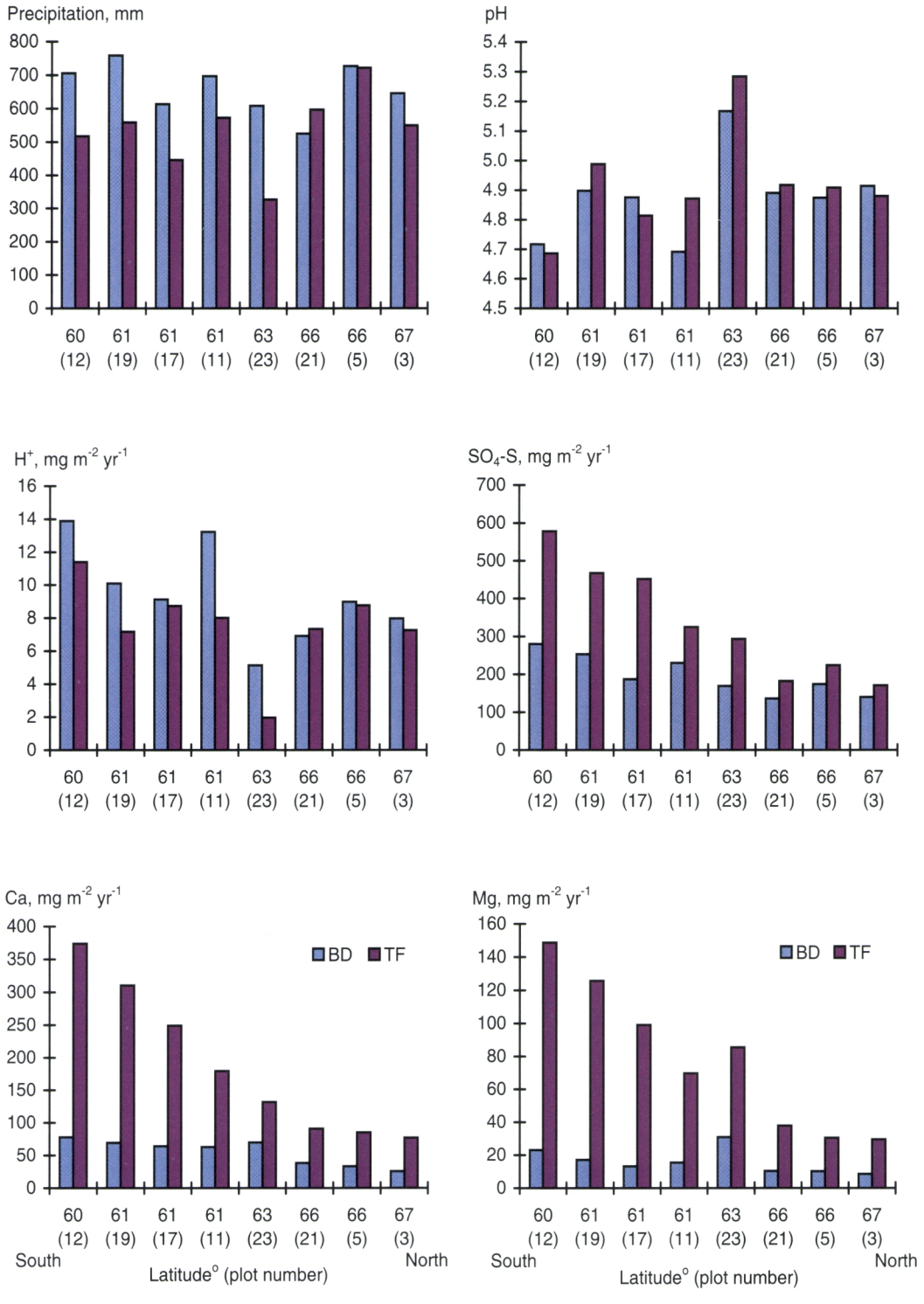

Figure 11. The amount of precipitation, mean pH and deposition of protons, sulphate, calcium and magnesium in bulk deposition (BD) and in stand throughfall (TF) during 1998 in 8 Norway spruce stands (12 = Tammela_S, 19 = Evo_Sim, 17 = Punkaharju_S, 11 = Juupajoki_S, 23 = Uusikaarlepyy_S, 21 = Oulanka_Sim, 5 = Kivalo_S, 3 = Pallasjärvi_S).

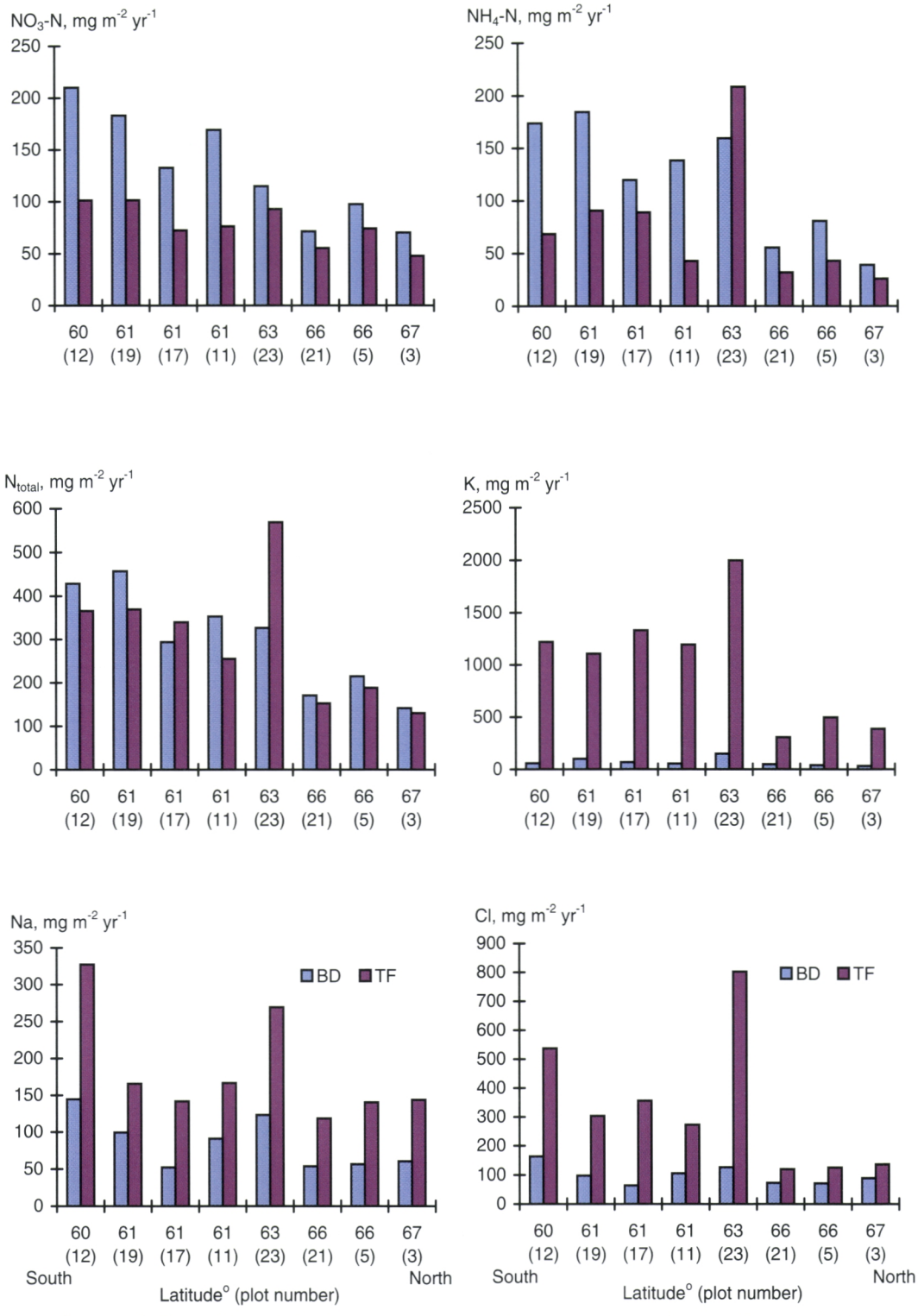

Figure 12. Deposition of nitrate, ammonium, total nitrogen, potassium, sodium and chloride in bulk deposition (BD) and in stand throughfall (TF) during 1998 in 8 Norway spruce stands (see Fig. 11 for plot localities).

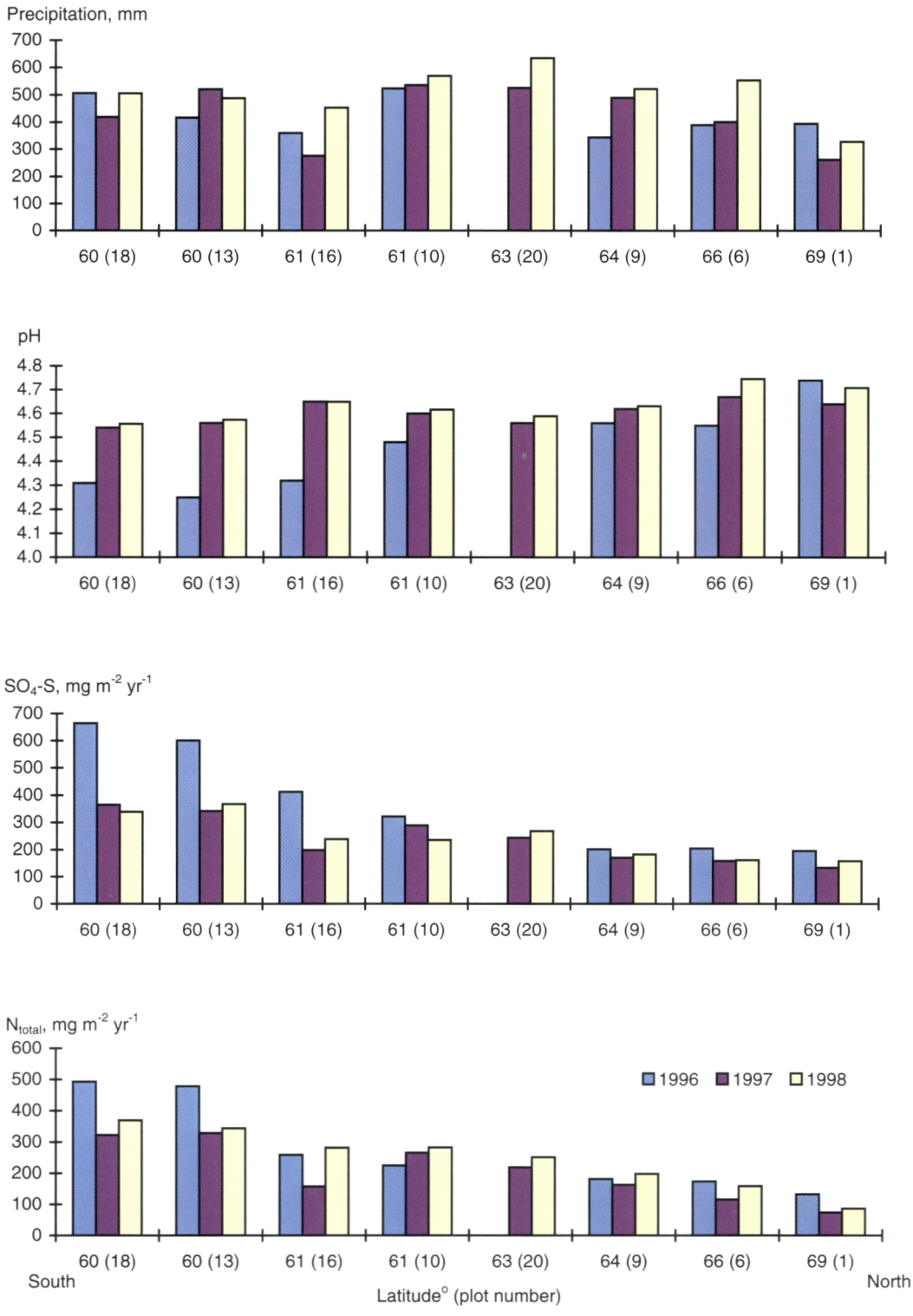

Figure 13. The amount of precipitation, mean pH and the deposition of sulphate and total nitrogen in stand throughfall in Scots pine stands during 1996–1998 (see Fig. 9 for plot localities).

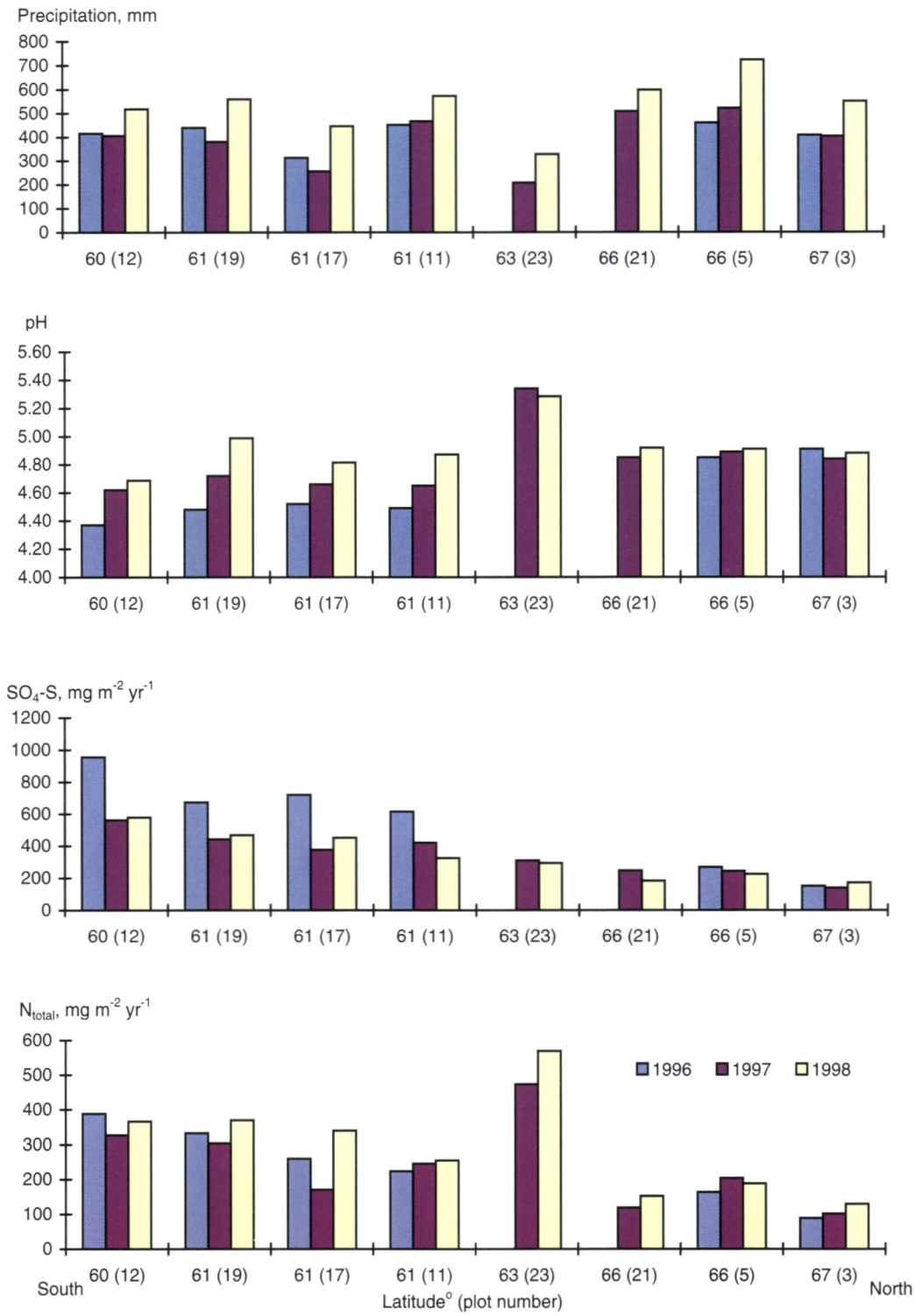

Figure 14. The amount of precipitation, mean pH and the deposition of sulphate and total nitrogen in stand throughfall in Norway spruce stands during 1996–1998 (see Fig. 11 for plot localities).

Total nitrogen deposition in stand throughfall also showed a decreasing S-N gradient throughout Finland in Scots pine and Norway spruce stands in 1996–1998 (Figs. 13 and 14). However, no clear time trends were detected during this relatively short monitoring period, even though the nitrogen load decreased strongly at the two southernmost Scots pine plots from 1996 to 1997–98.

Conclusions

The overall deposition pattern in bulk deposition and stand throughfall in 1998 was very similar to that measured in the previous years, indicating that sulphate and nitrogen deposition are the highest in southern Finland and decrease on moving to the north. Nitrogen-uptake processes in Scots pine and Norway spruce canopies play an important role in nitrogen fluxes inside the stand. The effect of nutrient and organic matter leaching, as well as the wash-off of dry deposition accumulated in the spruce and pine canopies, is clearly reflected as elevated loads of SO_4, Ca, Mg, K, Na and Cl in stand throughfall compared to the corresponding values in open areas.

Decreasing trends in stand throughfall acidity and in SO_4 concentrations and deposition loads were evident for the period 1996–1998, especially on the plots located in southern and central Finland. In contrast, no time trends in nitrogen deposition were detected during this relatively short monitoring period.

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Soil solution

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Introduction

The chemical composition of soil solution was monitored as a part of the Finnish ICP Forests (Level II) Programme on 12 sample plots located in commercially exploited forests in 1998 (see Fig. 2, p. 12). The results presented in this report represent percolation water collected in 6 Scots pine and 6 Norway spruce stands using gravity (zero tension) lysimeters. The chemical composition of percolation water in forest soil mainly reflects soil-formation processes, nutrient cycling, and the immediate effects of the deposition of acidifying compounds (Derome et al. 1999a). The aim of this study was to evaluate the acidification status in forest soil on the ICP/Forests Level II monitoring plots using percolation water quality as an indicator of acidification and buffering processes.

Material and methods

Percolation water was collected at 4-week-intervals during the snowfree period in 1998. Zero tension lysimeters (∅ 20 cm) were located at depths of 5, 20 and 40 cm from the ground surface. The installation and construction of the lysimeters have been described in detail in Derome et al. (1991). There were 5 lysimeters at each depth on the sample plots. The soil type on the plots was typically podsolic; most of the pine plots are located on sorted glacifluvial material, and the spruce plots on till soils. The samples were pre-treated and analysed according to the manual of the ICP Forests Programme. The soil solution parameters were pH, the Ca, Al and SO_4-S concentrations, and the molar Ca/Al ratio. The pH was measured on unfiltered samples. The samples were filtered through membrane filters (0.45 µm), and the filtrate preserved with concentrated HNO_3 prior to the determination of Ca and Al by ICP-AES. Sulphate was determined on unconserved samples by ion chromatography.

Results and discussion

Acidity

The buffering and neutralisation processes in forest soil, i.e. cation exchange and Al buffering and weathering (e.g. Schwertmann et al. 1987), normally result in a decrease in soil water acidity as it moves down through the soil. This phenomenon was clearly evident on the Scots pine and Norway spruce plots (apart from Miehikkälä_P, No. 18), the pH of the soil water increasing with soil depth (Fig. 15). There was a relatively clear south-north increasing trend in pH in the spruce stands, but not in the pine stands. The main reason for this was that the pH of soil water in the pine stands in southern Finland was, in general, higher than that in the spruce stands.

Aluminium

The total Al concentrations in soil water generally decreased with increasing depth in the soil in both the pine and spruce stands (Fig.

16), the mean values on most plots being well below the toxic Al concentration of around ca. 1.8 mg l^{-1} proposed by de Vries (1993). The mean total Al concentration on plot 17 (Punkaharju_S) (Fig. 16) was > 3.5 mg l^{-1} at a depth of 5 cm. However, a high proportion of the total Al in the uppermost layers of podzolic soil is in an organically complexed form (e.g. Lundström 1993), which is non-toxic to plants.

Sulphate

The mean sulphate concentrations in soil water increased on most of the plots on moving from a depth of 5 cm down to 40 cm (Fig. 17). The same phenomenon has been observed in previous years (Derome et al. 1999b). Evapotranspiration is the main cause of the increase in the sulphate concentrations because the amount of water percolating down through the soil decreases with increasing depth, the amount of sulphate remaining relatively constant. The highest sulphate concentrations occurred on the spruce plot (Punkaharju_S, No. 17) in southeast Finland, and the lowest on the pine plot (Juupajoki_P, No. 10) in central Finland and two of the plots (Kivalo_S, No. 5 and Kivalo_P, No. 6) in northern Finland. The sulphate concentrations at the northernmost plot (Sevettijärvi_P, No. 1) were high because the Arctic Ocean is located only ca. 70 km away, and there is a considerable input of marine-derived sulphate.

Molar Ca/Al ratio

The molar Ca/Al ratio is a widely used parameter in estimating soil solution acidification. The critical ratio value is usually considered to be 1.0 (e.g. de Vries 1993); plant roots and mycorrhizas may suffer damage at values below this critical level. The molar Ca/Al ratio in soil water at a depth of 40 cm was well above the critical value on all of the plots, and above the limit on most of the plots at a depth of 5 and 20 cm (Fig. 18). However, as the ratio values presented here are based on total Al concentrations (not monomeric Al^{3+}

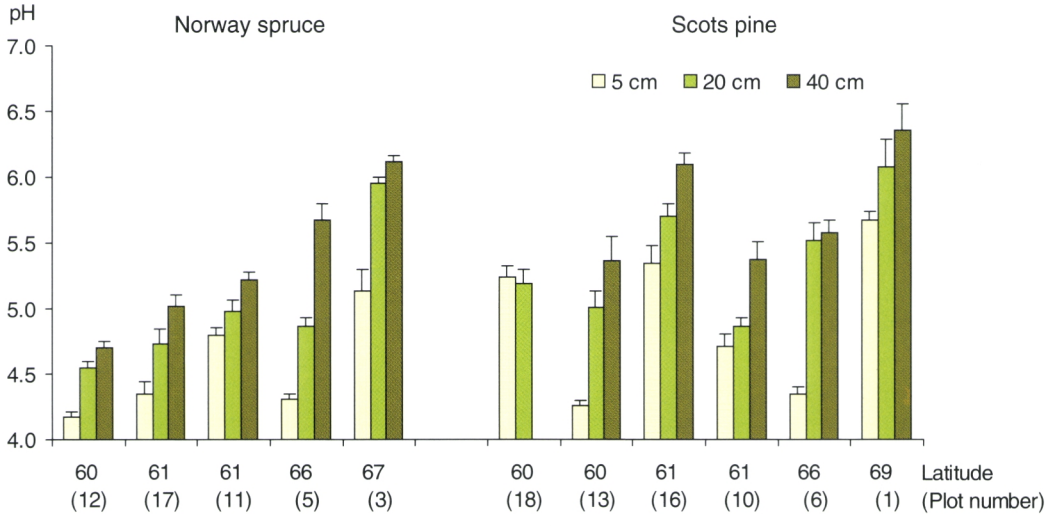

Figure 15. Mean pH in soil water collected at depths of 5, 20 and 40 cm during the snow-free season, 1998, on the spruce and pine plots. The bars indicate the standard error of the mean. Latitude refers to the location of the plots in Finland, and the number in parentheses to the plot number. 1 = Sevettijärvi_P, 3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 10 = Juupajoki_P, 11 = Juupajoki_S, 12 = Tammela_S, 13 = Tammela_P, 16 = Punkaharju_P, 17 = Punkaharju_S and 18 = Miehikkälä_P.

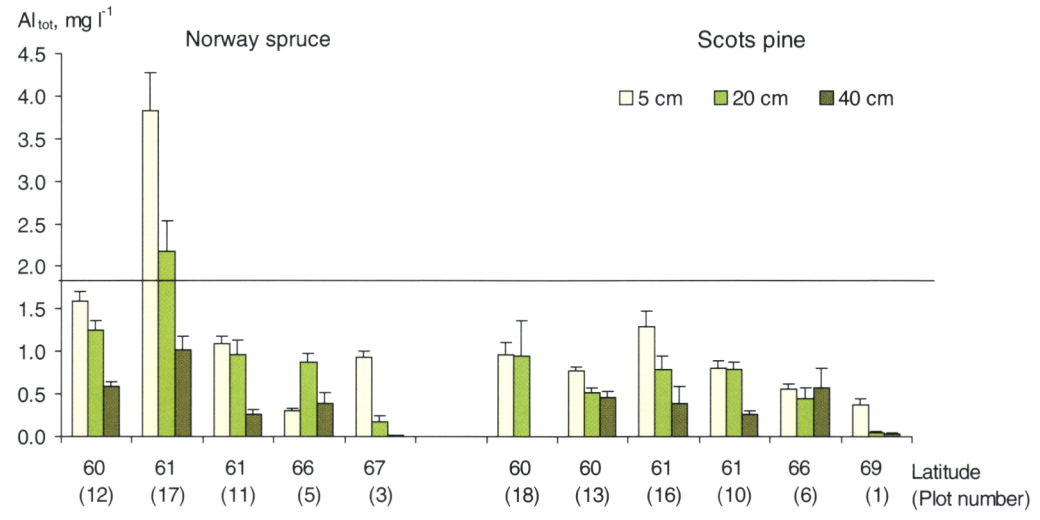

Figure 16. Mean total aluminium (A_{tot}) concentrations in soil water collected at depths of 5, 20 and 40 cm during the snow-free season, 1998, on the spruce and pine plots. The bars indicate the standard error of the mean. Latitude refers to the location of the plots in Finland, and the number in parentheses to the plot number (see Fig. 15 for plot localities).

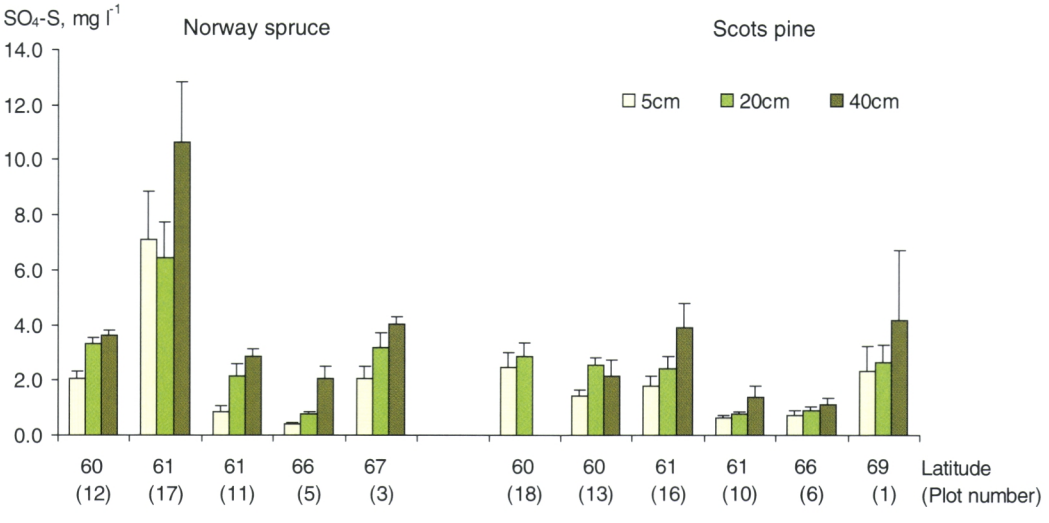

Figure 17. Mean sulphate concentrations in soil water collected at depths of 5, 20 and 40 cm during the snow-free season, 1998, on the spruce and pine plots. The bars indicate the standard error of the mean. Latitude refers to the location of the plots in Finland, and the number in parentheses to the plot number (see Fig. 15 for plot localities).

concentrations), low ratio values do not necessarily indicate the possibility of root damage in the uppermost soil layers on some of the plots.

Sulphate soil

The spruce plot at Uusikaarlepyy_S (No. 23) on the western coast of Finland differs from the other plots with respect to the age and origin of the soil. The relatively rapid rate of land uplift (ca. 90 cm/100 years) along the west coast means that soil formation processes on the site (altitude ca. 5 m a.s.l.) started only about 600-700 years ago after the site had risen above sea level (Björklund 1994). It is a so-called sulphate soil because the change from anaerobic to aerobic conditions following the gradual sinking of the ground water has resulted in the oxidation of sulphide, derived from the marine sediments, into sulphate (sulphuric acid). Sulphate soils typically have very low pH values, high Al and sulphate concentrations, as well as relatively abundant reserves of Ca, Mg and K (Björklund 1994). The results for soil water at depths of 5, 20 and 40 cm clearly reflect these soil formation processes (Table 8).

At this plot there was a clear decrease in pH and increase in the Al, Ca and SO_4-S concentrations with increasing depth. The Al

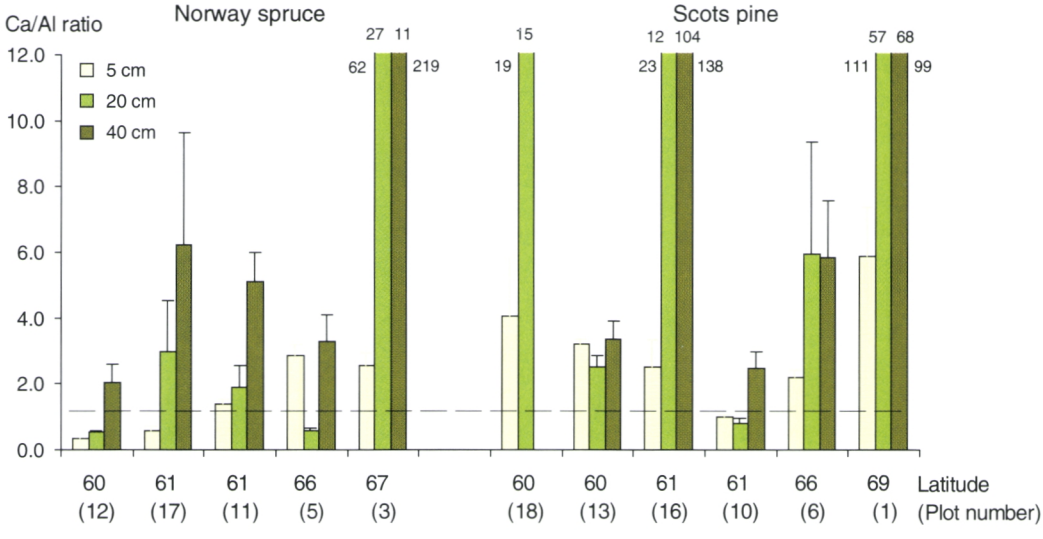

Figure 18. Mean molar Ca/Al ratio in soil water collected at depths of 5, 20 and 40 cm during the snow-free season, 1998, on the spruce and pine plots. The bars indicate the standard error of the mean. Latitude refers to the location of the plots in Finland, and the number in parentheses to the plot number (see Fig. 15 for plot localities).

Table 8. Mean pH, total Al, Ca and SO_4-S concentrations and the molar Ca/Al ratio in soil water collected at depths of 5, 20 and 40 cm at spruce plot No. 23 on the western coast of Finland. The standard error of the mean is given in parentheses.

Depth, cm	pH	Al_{tot} mg l^{-1}	Ca mg l^{-1}	SO_4-S mg l^{-1}	Ca/Al
5	4.14 (0.08)	4.6 (1.6)	3.1 (0.8)	11.4 (4.7)	0.69 (0.14)
20	3.76 (0.04)	57.0 (20.1)	25.0 (7.2)	155.5 (62.4)	0.44 (0.05)
40	3.81 (0.05)	77.7 (16.7)	33.3 (4.7)	200.1 (41.8)	0.41 (0.04)

concentrations at 20 and 40 cm depth were extremely high, and the molar Ca/Al ratio below the critical value at all depths. Despite these extreme values, the growth of the spruce stand is satisfactory and the trees are not suffering from needle loss (Derome et al. 2000).

Conclusions

The acidification parameters measured in the percolation water did not indicate, in general, excessive soil acidification in the pine and spruce stands. However, the spruce stand in the west coast was an interesting exception, since it is located on so called sulphate soil which is naturally strongly acidified. Soil acidification on this plot was reflected as low pH values in percolation water as well as high Al and sulphate concentrations and low Ca/Al molar ratios.

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4.2 Quality assurance and control of the deposition and soil solution samples

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Introduction

The laboratory of the Rovaniemi Research Station, Finnish Forest Research Institute, analyses all the deposition and soil solution samples from the 16 plots in the Finnish ICP Forests (Level II) monitoring network.

The staff of the laboratory consists of the head of the laboratory and seven laboratory technicians. A number of other laboratory technicians and pre- and post-graduate students are temporally employed. The station's researchers are also involved in method development, and in supervising the analysis work carried out for them in the laboratory.

The laboratory is not accredited. A quality system and manual are currently being prepared. Quality assurance is primarily implemented by 1) analysing control samples and monitoring the results using self-made software, 2) systematic internal quality control, and 3) annual participation in a number of international and national inter-laboratory ring tests. One of the laboratory technicians is responsible for quality assurance and data processing in the laboratory.

Control samples

A range of commercial and self-made control samples are used in most of the analyses carried out in the laboratory. A control chart (X control chart) is made for every control sample.

Internal quality control

Systematic internal quality control includes checking the departure time of samples from the field and their arrival at the laboratory, spot checks of the cleanliness of the laboratory-ware and purity of the distilled and ultra-pure water, as well as continuous control of the filtration of the water samples.

Inter-calibration

The laboratory has participated in three inter-calibration programmes for water samples. One of them is the international Aquacon-MedBas Project, organised by ISPRA, Italy. In 1998 we only received samples for sub-project 6 (Acid rain analysis), but earlier we also participated in sub-project 5 (Fresh water analysis). The Finnish Environment Agency each year organises a national inter-calibration series for six different types of analysis. The Lapland Regional Environment Centre arranges an international inter-calibration for laboratories working in Northern Finland, Norway and North-West Russia. Table 1 shows all the parameters analysed, the analytical methods and the number of samples per parameter/method.

In the Finnish ring tests, the performance of the participating laboratories was evaluated using z scores. The results were acceptable if they deviated from the theoretical concentration or the mean value of the data by less than twice the target value assigned for the total error.

Thus the result is acceptable (passes the z-score test) when $|z| < 2$, questionable (fails the z-score test) when $2 \leq |z| \leq 3$, and non-acceptable when $|z| > 3$ (Fig. 1).

Of the 188 laboratories that participated in the Aquacon ring test, 50 are involved in the ICP Forests program. z scores were not determined in this ring test. The results of the laboratories participating in the ICP Forests programme are shown in Table 2. The results have been divided into groups according to the proportion of results less than ±10 %, between 10 and 20 %, and greater than ±20 % of the expected values, as well the proportion of outliers.

Table 1. The total number of inter-calibration samples analysed in 1998.

Parameters	Method	Number of samples
pH, electrical conductivity		6
Chloride	IC	6
Sulphate, nitrate	IC	2
Ammonium, Ca, Mg, K, Na	IC	2
Ammonium	FIA	2
Nitrate	FIA	4
Nitrate + nitrite	FIA	3
Total N	FIA	7
Ca, Mg, Na, K	ICP-AES	4
Fe	ICP-AES	3
Al	ICP-AES	2
Cr	ICP-AES	1
DOC (NPOC)	Pyrolysis/ IR detection	7

IC = ion chromatography, FIA = flow injection analysis, ICP-AES = inductively coupled plasma atomic emission spectrometry, DOC = dissolved organic carbon, NPOC = non-purgeable organic carbon. The table does not include Ni, Cu and Pb because the results were below the detection limit of our analytical equipment. Some of the results for the Cr, Al and NH_4 analyses were also below the detection limit.

*Table 2. Distribution (%) of the results obtained by the ICP Forests laboratories for the two Aquacon inter-calibration samples (A and B) grouped according to the deviation from the expected value. The results for the Rovaniemi laboratory are indicated by *.*

Parameter	less than ±10 %		between 10 and 20 %		greater than 20 %		outliers	
	A %	B %	A %	B %	A %	B %	A %	B %
pH	79 (*)	90 (*)	6	4	4	0	10	6
Conductivity	74	85 (*)	20 (*)	11	0	2	7	2
Sulphate	88 (*)	80 (*)	6	14	0	0	6	6
Nitrate	69 (*)	84 (*)	19	14	2	0	10	2
Chloride	60 (*)	80 (*)	15	14	13	0	13	6
Calcium	42 (*)	90 (*)	27	2	21	0	10	8
Magnesium	33 (*)	90 (*)	51	4	10	0	6	6
Sodium	40	83 (*)	23	8	31 (*)	0	6	8
Potassium	56	65	19 (*)	21 (*)	19	21	6	0
Ammonium	78 (*)	78 (*)	10	14	4	4	8	4

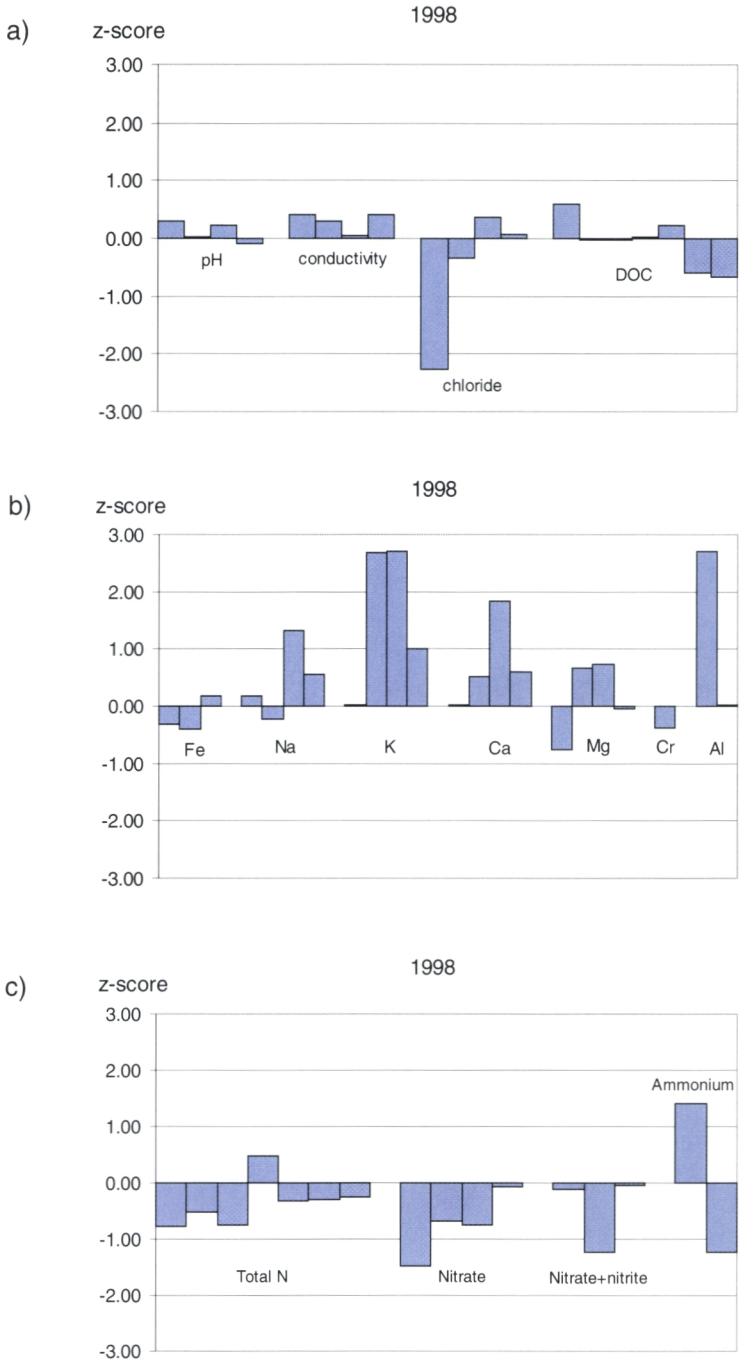

Figure 1. The z scores for a) pH, electrical conductivity, chloride and DOC, b) metals measured by ICP-AES, and c) nitrogen parameters measured by FIA.

Conclusions

During 1998 a total of 17 parameters was analysed on 79 inter-calibration samples using six different analytical methods. Most of the results were acceptable ($|z| < 2$), or the deviations from the expected values were less than ±10 %. The only problem has been in analysing potassium by either ICP-AES or ion chromatography. This problem has been eliminated by 1) validating the ion chromatographic methods for anions and cations, and 2) determining potassium by atomic absorption spectrometry (AAS) instead of ICP-AES, because the detection limit by AAS is lower than that by ICP-AES.

5 Results of pilot studies

5.1 LAI-2000 estimates as an indicator of forest vitality

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Background

Leaf area index (LAI, leaf area per unit ground area) is an important property quantity controlling the physical and biological processes of forests. However, the direct measurement of the LAI of coniferous forests is an insurmountable task in practice. Our knowledge of the variation in LAI and of the factors influencing it is more restricted than, for example, our knowledge of the factors influencing the variation in the rate of photosynthesis and the variation in nutrient concentrations. Due to the problems encountered in estimating LAI, it has been necessary to resort to subjective assessment of defoliation in studies focusing on forest vitality.

Much effort has been put into the development of indirect methods for measuring the LAI of forests stands. The method traditionally used to estimate the LAI of forests is based on the allometric relationships between leaf area and the cross sectional area of sapwood in the stem and/or branches (Shinozaki et al. 1964; Waring & Schlesinger 1985). However, because the relationships are species-specific and vary according to the site and climatic conditions, this method cannot be used as a general method for estimating LAI.

More promising indirect methods based on radiative techniques rely on the strong dependency between canopy structure and the gap fraction of the canopy (Lang 1986, Welles 1990). The gap fraction of a canopy is the fraction of view in a specific direction from beneath the canopy that is not blocked by foliage. It corresponds approximately to the transmittance of radiation in those wavelengths where scattering by foliage is small.

The inversion of gap fraction data to estimates of leaf area index is based on Beer's law as applied to leaf canopies with the assumption that the leaves are randomly distributed. This assumption is valid for agricultural crops, and the methods produce accurate estimates of LAI. The methods have proved to be so useful that several software and hardware packages are now commercially available. One, and perhaps the most popular of these, is the LAI-2000 Plant Canopy Analyzer (LAI-2000 Plant Canopy Analyzer 1992).

The structure of coniferous stands differs in three important respects from the homogeneous broad leaved agricultural crops for which the theory of inversion from canopy gap fraction to leaf area index was derived. First, because needles are not flat, the meaning of one sided leaf area is unclear. Second, the grouping of needles into shoots and branches invalidates the assumption of randomly located leaves. Because clumping increases the canopy gap fraction at a given leaf area, indirect methods (e.g. LAI-2000) give estimates of an effective

leaf area, that is smaller than the actual leaf area index (Chen et al. 1991, Chason et al. 1991, Smith et al. 1993). Third, in forest stands the stem and branch components may contribute significantly to the total plant area.

Gower and Norman (1991, see also Fassnacht et al. 1994) proposed that LAI-2000 gives an estimate of the shoot silhouette area index rather than LAI, and recommended that the instrument reading should be multiplied by a correction factor to account for the grouping of needles on shoots. The theoretical relationship between the correcton factor and the silhouette to total needle area ratio (STAR) is described by Stenberg et al. (1994), and in more detail by Stenberg (1995). Empirical studies with Scots pine (Stenberg et al. 1994, Smolander & Stenberg 1996) suggest that this correction technique may be successful in stands where the individual shoots constitute the most important clumping elements, and where the proportion of woody area is small.

Aims of the study

The general aim of the study was to evaluate whether the LAI-2000 would be a suitable tool for monitoring forest vitality. The evaluation was carried out in two separate studies. First, we assessed the accuracy of the leaf area index (LAI) and plant area index (PAI) measured by the LAI-2000 plant canopy analyser in a Norway spruce stands. In addition, earlier data sets from similar experiments made in two Scots pine stands were utilised. Second, the LAI-estimates measured in 20 ICP Forests (Level I and II) located in southern and central Finland were compared with visually determined defoliation indices.

Principle of the LAI-2000 plant canopy analyser

The LAI-2000 estimate is based on the assumption the canopy consists of (regions of) randomly distributed leaves or needles of convex shape, which are uniformly oriented with respect to the azimuth. The leaf area index on basis of the half of the total surface area basis (L = LAI/2) is therefore obtained as (Miller 1967, Lang 1991, Chen & Black 1992, Stenberg et al. 1994):

$$L = -2 \int_0^{\pi/2} \ln[T(\theta)] \cos\theta \sin\theta \, d\theta \qquad (1)$$

where $T(\theta)$ is the transmittance at zenith angle (θ).

The optical sensor of the LAI-2000 plant canopy analyzer (LAI-2000 Plant Canopy Analyzer 1992) comprises five detectors, arranged in concentric rings, which measure radiation (below 490 nm) from different

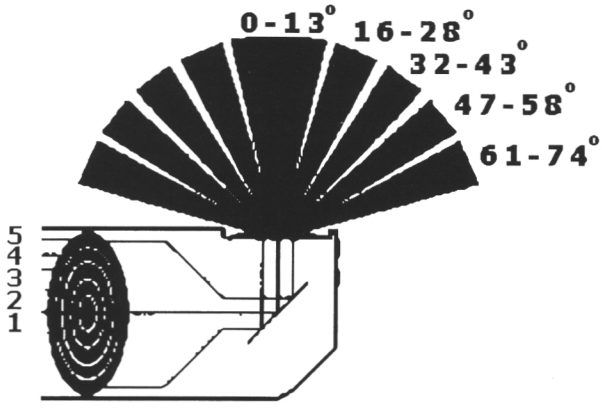

Figure 1. The principle of the optical sensor of LAI-2000.

sections of the sky (Fig. 1). Canopy transmittance for these different sections is computed as the ratio of the below-canopy to above-canopy readings for each detector ring, and the LAI-2000 estimate of leaf area index is calculated from these transmittance values as (see Eq. 1):

$$LAI-2000=-2\sum_{j=1}^{5}\frac{1}{n}\left[\sum_{i=1}^{n}\ln(tr(i,j))\right]\cos\theta_i w_j \quad (2)$$

where $tr(i,j)$ denotes the ratio of below- and above-canopy readings for detector ring (j) taken at location (i), θ_j is the zenith angle corresponding to ring (j), and w_j $(=sin\theta_j d\theta)$ is the weight attributed to ring (j).

In theory, if there were only leaves in the canopy, the LAI-2000 estimate would correspond to one half of the total leaf surface area index (LAI/2) (Eqs. 1 and 2). However, because the instrument sees not only the leaves, but also branches and stems, the LAI-2000 estimate includes the woody area, and logically should correspond more closely to one half of the total surface area index (PAI/2) of all the plant components. Disagreement between the LAI-2000 estimate and PAI/2 would indicate a non-random distribution of the foliage, e.g. caused by the clumping of needles on the shoots.

In this paper, all indices are expressed on a total surface area basis and, consequently, the LAI-2000 estimates have been multiplied by 2.

Material and methods

Stepwise decrease in LAI in a Norway spruce stand

The experiment was carried out between September 30 and November 5, 1997, and (the two last measurements) between May 10 and 18, 1998. Measurements were made in a circular plot with a 10 m radius, situated in a 25-year-old Norway spruce stand near the Suonenjoki Research Station (62°39' N, 27°05'E) in central Finland. The stand was established by planting at a spacing of 2 x 2 m (2370 living trees ha^{-1}) on an abandoned agricultural field. The mean height and diameter of the trees were 12.2 m and 13.4 cm, and the stand basal area was 33.4 m^2 ha^{-1}. Before starting the experiment, all dead branches below the living crown were removed from the trees on the plot and on a 10 m buffer zone.

Below canopy measurements were made with the LAI-2000 analyser at a height of 3.0 m above the ground. The 36 randomly located measurements points were marked inside a 5 x 5 m square in the centre of the plot (Fig 2). Above canopy measurements were made automatically every 15 s in an open field located 150 m from the plot. No restrictor was needed to prevent direct sunlight from reaching the sensor, because the measurements were made in the evening when the sun was less than 15° above the horizon.

After the first LAI-2000 measurement, the needle and branch areas were gradually reduced in steps, new LAI-2000 measurements being made after each reduction. The reduction was done in five steps by removing a branch (or branches) from each whorl of each tree on the plot and buffer zone as follows:

- reduction 1; one randomly selected branch was removed from each whorl,
- reduction 2; two randomly selected branches were removed from each whorl,
- reduction 3; two randomly selected branches were removed from each whorl,
- reduction 4; all the branches remaining in the main whorls were removed, 0.8 branches were left on the average
- reduction 5; all intermediate branches were removed
- (reduction 6; all stems were removed)

At each step, the branches removed from 20 randomly selected trees were collected in bags and transferred to cold storage (-15 °C) for further analysis. The total needle surface area (LAI) removed at each step was calculated from the needle dry weight (48 h at 80 °C) and specific needle area (SLA), which was determined on a whorl and age class basis for

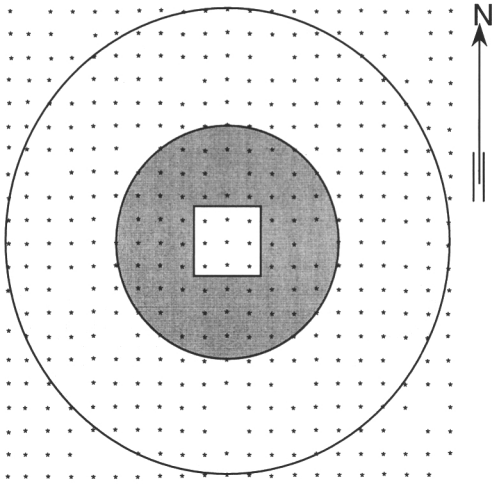

Figure 2. Location of the trees (*) and square (5 x 5 m) where LAI-2000 measurements were made. Grey circle (radius 10 m) indicates the area where the sample trees were located and the light grey circle indicates the 10 m buffer zone.

the 5 trees closest to the median tree using the following procedure.

The shoots of the sample branch were first separated into 4 age classes (C, C+1, C+2, and older). About 5 g of needles was randomly sampled from each of the four age classes. The main batch of shoots was dried for 48 h at 80 °C, and the needles separated from the shoots. The fresh needles taken for determining SLA were removed with a razor blade. The projected needle area of the needles was measured using a Kodak DCS-420 digital camera and the ColAn software package (Version 1.1, Colorsoft Oy, 1995). The pixel size in the image analysis was 0.1 x 0.1 mm. After measurements the needles were dried and weighed.

The total needle surface area of the needles was estimated as 3.6 times the projected needle area based on earlier results obtained with Norway spruce (Stenberg et al. 1999). The cross section of non shaded and shaded needles are shown in Fig. 3 and the SLA for different age classes by whorls in Fig. 4.

The total needle area removed at each step was calculated by multiplying the needle dry weight removed by the specific needle area. The needle dry weight removed from the stand was obtained by multiplying the mean needle dry weight of the 20 sample trees by the number of trees on the plot. SLA based on the 5 sample trees was determined as follows. The mean SLA of a sample branch from each whorl was obtained as the mean of the SLA of different needle age classes in the branch, weighted by the dry weight of the age class. The mean SLA of the whole tree was obtained as the mean of branch SLAs, weighted by the dry weight of needles in the corresponding whorl. The mean SLA of the canopy was obtained as the mean of the sample tree SLAs weighted by their needle dry weights.

Litterfall was collected during each harvesting period and was taken into account in the estimates of removed LAI.

The branch area index (BAI) removed at each step was estimated from photographically recorded projected areas of randomly selected branches from the sample trees in removals 1, 3 and 5, the intermediate branches. Branch area measurements were made for 15, 11 and 2 sample trees respectively. The total surface area of a branch was estimated as the projected area multiplied by π. Stem surface area was estimated from measurements of stem diameter at 1 m intervals.

Earlier experiments with Scots pine

The results from two experiments done with Scots pine are utilised in this report for comparison. In the first experiment (Smolander & Stenberg 1996) the needle and branch area of a Scots pine stand was reduced progressively to zero analogously to the experiment described above. In the second experiment with Scots pine, the plant area index was reduced progressively by removing randomly selected individual trees. In both experiments LAI-2000 and direct estimates of the leaf, branch and stem areas were determined in approximately the same way as in the Norway spruce experiment described above.



Figure 3. Cross sections of current year needles from the top, middle and lowest part of the canopy.

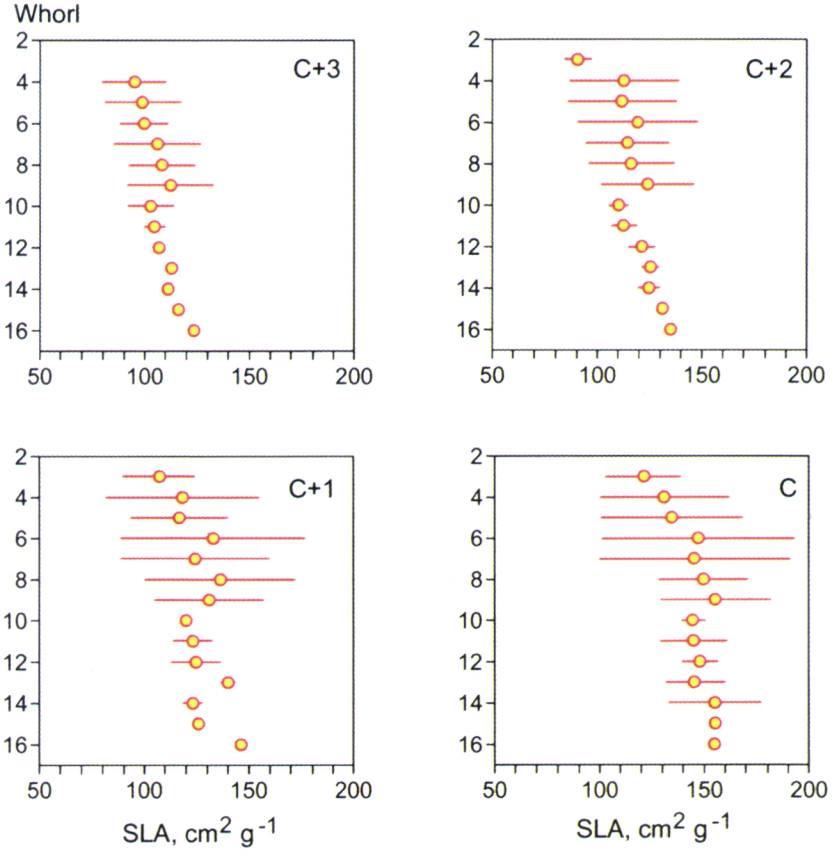

Figure 4. Mean and standard deviation of the specific needle area by whorls, numbered downwards from the top of the trees for different age classes. (Needle area = projected area of horizontally lying needles multiplied by 3.6)

LAI-2000 measurements on ICP Forests Level II plots

LAI-2000 estimates were made on 13 of the ICP Forests intensive monitoring (Level II) plots (Raitio 1999) between the 9th and 29th of September 1998. Six of the plots were pine stands and seven were spruce stands. In addition, 7 extensive monitoring (Level I) spruce sample plots were measured between the 6th and 8th of October 1998. The defoliation of the trees was evaluated during summer 1998 as a part of the standard monitoring procedure used to assess forest health (Raitio 1999). The plots are situated in southern and central Finland (Fig. 5).



Figure 5. Location of the intensive (Level II) and extensive monitoring (Level I) plots measured in this study.

When making the LAI-2000 measurements, a view restrictor of 90° or 180° (Level II) was used to hide the operator and to block out bright clouds close to the direction of the sun (Smolander & Stenberg, 1996, LAI-2000...). Measurements were not made when the sun was visible. Restrictors were placed on both sensors so that the same portion of sky was occluded in the above- and below-canopy readings. Readings from the lowest sensor ring (Fig. 1) were omitted in the analysis because the stands surrounding some of the plots were not uniform. This was especially the case with the Level I plots.

Measurements in the Level II stands were made in the middle of the subplot using a 5 x 5 m grid with 1 m intervals, resulting in 36 measurements per plot. A similar grid was used on the Level I plots, the grid being positioned so that the sensor opening could see only the trees on the plot. On the Level I plots 90°, 180°, 270° or 315° view restrictors were used. The measurements were repeated once to control the possible variation in light conditions. Most of the replicate measurements matched within 2 %. In the case of larger differences, the measurement in which the light conditions were more stable was used. The sensor was held at a height of one meter above ground level. The reference sensor was positioned at the nearest location with open sky. On some of the Level II plots it was possible to utilise the weather station tower located next to the plots. In other cases, the distance between the plot and the reference sensor varied from 100 m to 200 m, except for the Punkaharju plot where the maximum distance was 1.5 km.

Results and discussion

Accuracy of the LAI-2000 estimates

Before the removal of branches, the direct estimates of LAI and PAI in the spruce stand were 22.9 and 28.2, respectively (Fig. 6). These values were much higher than those obtained in the earlier investigated Scots pine stands (LAI 4.5 and 3.4; PAI 5.2 and 3.7). The

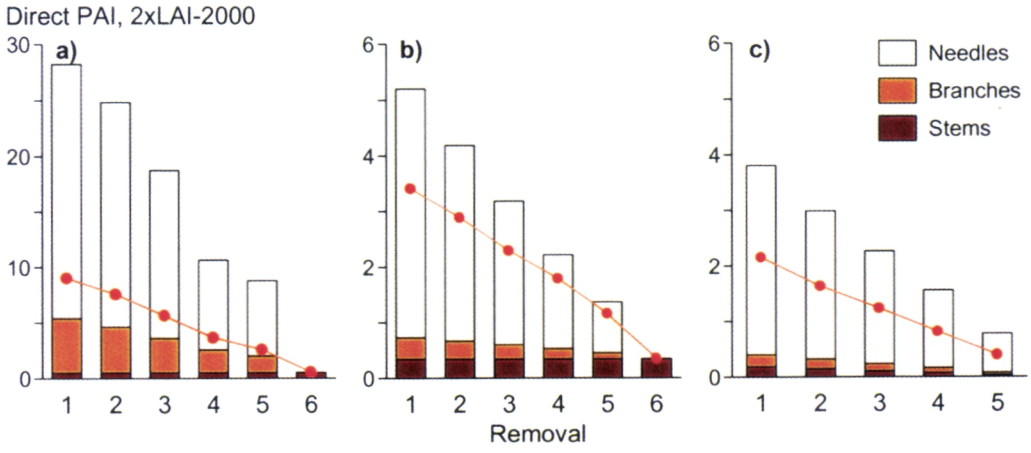

Figure 6. Effect of the stepwise removal of branches (or trees) on the components of PAI in the spruce experiment (a), and in the pine experiments where branches (b) and trees were removed (c).

proportion of LAI out of PAI was 81 % in the spruce stand, and 86 % and 90 % in the pine stands.

Before the removal of branches (or crowns), the LAI-2000 estimate was only 32 % of direct PAI for Norway spruce, and 66 % and 57 % for Scots pine, respectively. These results indicate that the distribution of needle area is more grouped in spruce than in pine stands. Grouping at the branch and crown level may be the reason because measured values of STAR have been of the same order of magnitude (ca 0.14) as for Scots pine (Oker-Blom & Smolander 1988, Smolander et al. 1994, Stenberg et al. 1999).

The response of LAI-2000 estimates to the gradual decrease of PAI and LAI in the three experiments are shown in Figs. 7 and 8, respectively. The relationship between LAI-2000 and direct PAI (LAI) was fairly linear and close in Scots pine, especially when whole trees were removed (Fig. 8c). When single branches were removed, there was a slight bending in the relationship (Fig. 8b). This is assumed to be caused by changes in the proportion of woody area out of PAI (Smolander and Stenberg 1996). In the Norway spruce experiment, the relationship between direct PAI and LAI-2000 was apparently linear, but much more scattered and biased than for Scots pine.

For monitoring forest vitality, the resolution of the method should be high enough, i.e. the method should also detect small changes in LAI. The decrease of direct PAI (ΔPAI) and direct LAI (ΔLAI) as a function of the decrease in the LAI-2000 estimate (ΔLAI-2000) is shown in Figs. 9 and 10, respectively.

In the experiment where the same number of trees was removed in each step, the between-step change in the LAI-2000 estimates (ΔLAI-2000) also remained relatively constant, but the removed LAI was underestimated by 36 % and PAI by 44 % (Figs. 9c and 10c). Underestimation of the change by the LAI-2000 also occurred in the experiment in which individual branches were removed, but it became smaller as the PAI decreased (Figs. 9b and 10b). In the spruce experiment, the relationship between ΔLAI-2000 and ΔPAI and ΔLAI was very biased especially when large amounts of foliage were removed (Figs. 9a and 10a).

The underestimate of LAI and PAI by the LAI-2000 was larger in the spruce stand than in the pine stands. This might be due to the grouping at branch and whorl level typical for spruce (Deblonde et al. 1994). While the underestimation by the LAI-2000 was large in all the experiments, the values were within the range reported in other studies (Stenberg 1996). However, it is difficult to explain the irregular

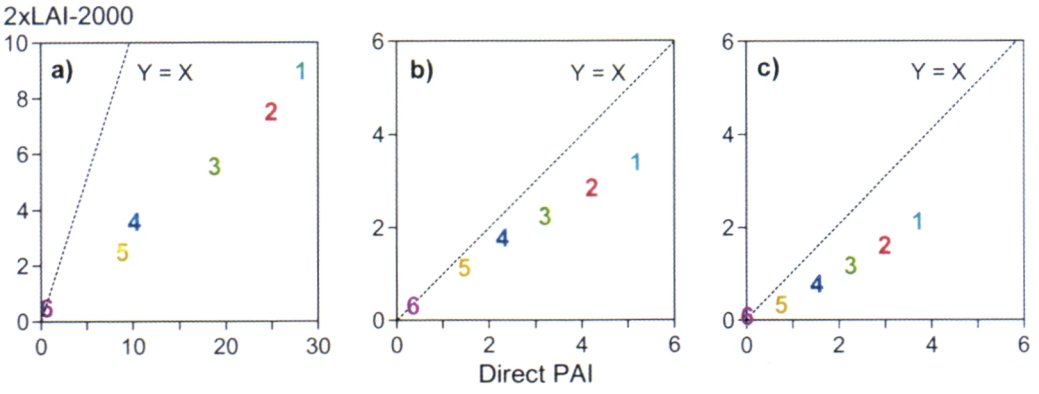

Figure 7. Relationship between 2xLAI-2000 and direct PAI in the spruce experiment (a), and in the pine experiments where branches (b) and trees were removed (c). Numbers refers to the removal.

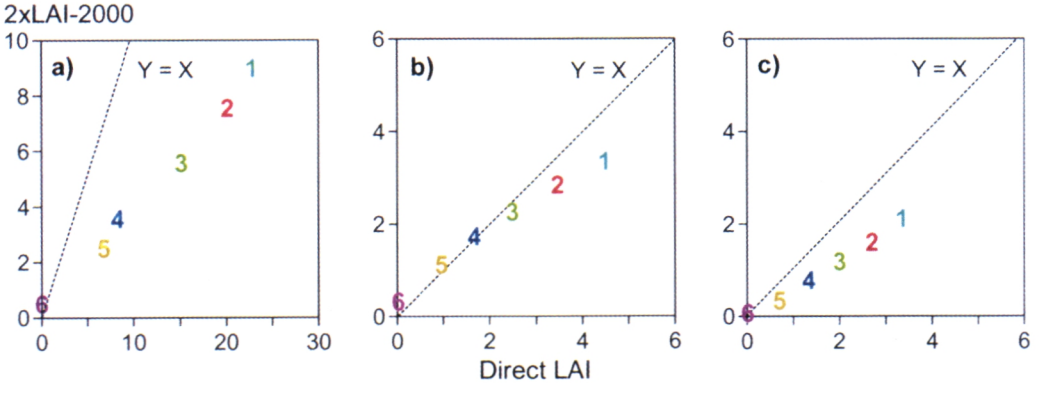

Figure 8. Relationship between 2xLAI-2000 and direct LAI in the spruce experiment (a), and in the pine experiments where branches (b) and trees were removed (c).

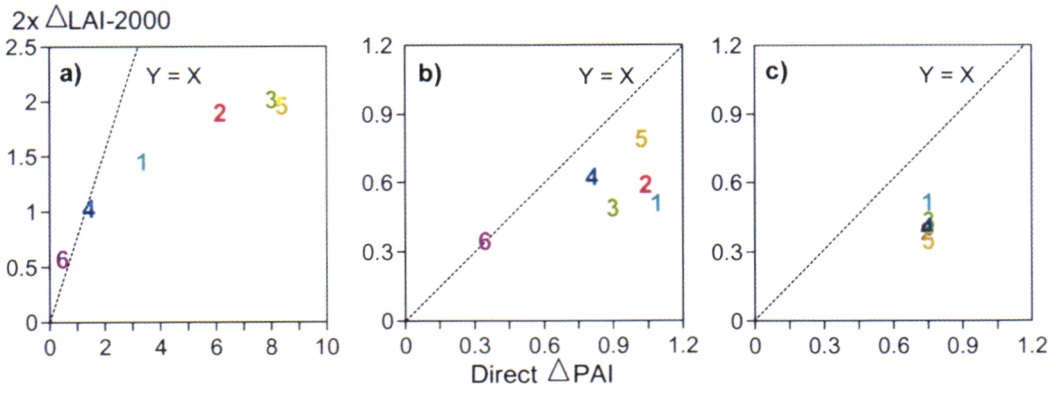

Figure 9. Relationship between the change in 2xLAI-2000 and the change in direct PAI in the spruce experiment (a), and in the pine experiments where branches (b) and trees were removed (c).

response of the LAI-2000 to the decrease of PAI and LAI in the spruce experiment. While the areas removed in different steps varied greatly, the change in the LAI-2000 estimates was much less variable. This discrepancy cannot be explained by possible errors in determining the direct LAI, caused by, e.g. biased sampling and different conversion procedures. Neither can it be explained by the uncertain accuracy of the LAI-2000 estimates in the spruce experiment, caused by the fact that the measurements were made late in the autumn (in poor light).

Correlation between LAI-2000 estimates and visual defoliation indices

Defoliation degree determined visually by the Finnish ICP Forests Programme are shown as function of LAI-2000 based estimates in Fig. 11a. The correlation between LAI-2000 and the defoliation degree was 0.72 for pine and 0.60 for spruce (Fig. 11a). When the effect of stand density was taken account, by dividing the LAI-2000 estimates by the stand basal area, similar correlations were obtained, 0.75 for pine and 0.45 for spruce (Fig. 11b). The sapwood basal area would be a better denominator than stand basal area, but estimates of stand sapwood area were not available in this study.

Conclusions

According to these experiments, a fairly close linear relationship exists between "true" LAI and the LAI-2000 estimate in Scots pine stands. However, the slope of the linear relationship is less than one, i.e., the LAI-2000 systematically underestimates LAI. As far as change recognition is concerned, this means that the change detected by the LAI-2000 is fairly accurate on a percentual basis, but the actual amount of change is underestimated.

The underestimation of LAI (PAI) by the LAI-2000 in the Norway spruce stand was much larger than that in the Scots pine stands, and the relationship between directly measured and estimated LAI was very scattered. A higher degree of grouping (e.g. at branch, whorl, and crown level) in spruce than in pine stands may explain the larger underestimation (Smith et al. 1993). Systematical underestimation could be adjusted, e.g. by applying a (species- and site-specific) correction factor. This does not pose any problem when the main aim is to detect the rate of change, not the absolute change. However, as a result of scattering, estimates of change by the LAI-2000 did not work even on a percentual basis.

The correlation between visually determined defoliation and the LAI-2000 estimates were low, especially when stand

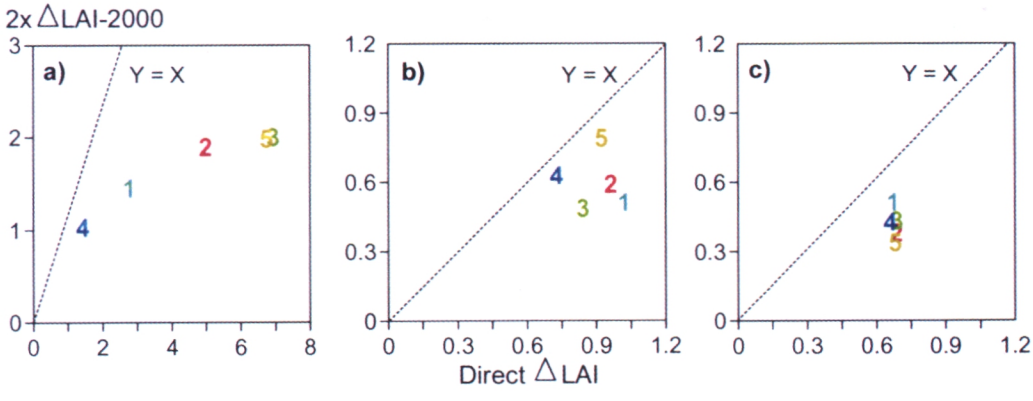

Figure 10. Relationship between the change in 2xLAI-2000 and the change in direct LAI in the spruce experiment (a), and in the pine experiments where branches (b) and trees were removed (c).

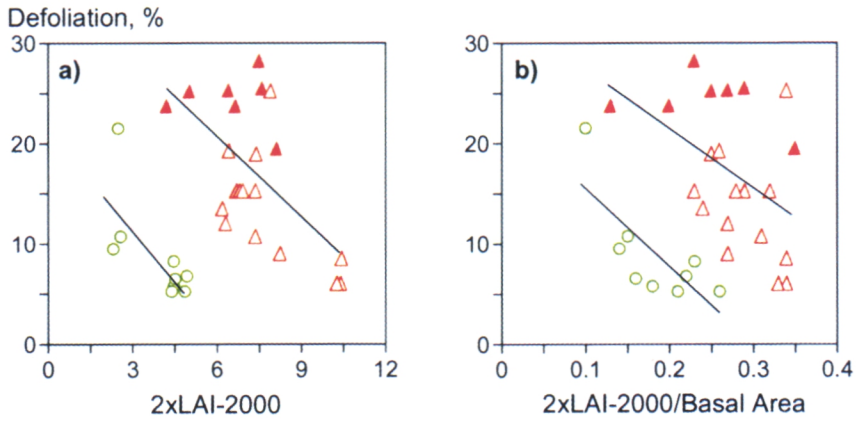

Figure 11. Relationship between LAI-2000 estimates and visually determined defoliation degree (%) (a) in Level II (open symbols) and Level I (closed symbols) stands. LAI-2000 estimates divided by stand basal area are shown in (b). Circles refer to Scots pine and triangles to Norway spruce.

density was taken into account by dividing the LAI-2000 estimate by stand basal area. The data did not support the use of LAI-2000 estimates as an indicator of forest condition without more detailed studies. Because LAI-2000 estimates are based on physical measurement of canopy transmission, they are theoretically more sound than visually determined defoliation (crown transparency). In pine stands, the LAI-2000 evidently measures relative changes in LAI fairly accurately. However, understanding the response of LAI-2000 to changes in the LAI of Norway spruce stands needs more detailed analysis of the grouping of foliage at higher levels of hierarchy. In addition to methodological development, monitoring a number of plots (e.g. Level II stands) would produce an interesting time series about the variation in LAI. This information would be useful in interpreting visual observations of tree condition as well as other measurements for describing the state of forest ecosystem.

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5.2 Comparison of sampling methods for crown condition surveys

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Introduction

Since 1986 the Finnish Forest Research Institute has annually surveyed crown condition in background areas in Finland (Forest Condition in Europe ...). During 1986–1994 these crown condition inventories were based on the systematic grid of fixed area sample plots laid down by the Finnish National Forest Inventory (NFI). The number of trees per sample plot has varied from 2 to 38, and the average number of trees on the sample plots has been 11. The variation in tree number on the sample plots reflects the variation in the density of the stands, and takes into account forest succession.

The Commission regulations (EC no: 1696/87, 926/93 and 1398/95) set a minimum limit for the number of sample trees per plot. According to the Commission regulation (EC no:1398/95), the minimum number of sample trees per plot is 20 in southern and 10 in northern Finland. In order to fulfil this regulation the area of most of the circular sample plots was increased for the1995 crown condition inventory. As a consequence, the size of the plots varies and is dependent on the stand density.

The aim of this study is to compare the statistical properties of the estimate of crown condition in three sampling methods. The main emphasis is on the sample mean of the defoliation degree, but some remarks are also made about the sample mean of discoloration degree. In the first sampling method the area of the circular plots is 300 m^2, as was the case in the Finnish inventories during 1986–1994. In the second method the area of the circular plots is at least 300 m^2 and the number of trees on each plot at least 20. This corresponds to the Finnish inventories carried out in southern Finland since 1995. In the third method the sample plots are the four-point cross cluster grid described in the ICP Forests manual (Manual on methodologies ...). In this method there are 24 trees on each plot and the size of the plot depends on the stand density. The centre points of the plots are selected by systematic sampling and are the same in all three methods.

Material and methods

Data set and the sampling methods

For this comparison study on sampling methods, a subsample of 30 plots in Southern Finland was selected from the 394 systematically distributed permanent sample plots used in the annual crown inventory (Level I) and established during 1985–1986 in connection with 8th NFI. The plots selected for the subsample were plots where it was physically possible to implement all the three sampling arrangements in the same stand.

The field work was carried out by three experienced observers. All the data sets for the methodological comparison were collected at

the same time as the annual crown condition inventory in 1995. The selection criteria and tree vitality assessment method were the same as those used in the annual forest crown condition inventory in Finland. Trees in the dominating crown layer with a diameter at breast height of at least 4.5 cm were inspected. Defoliation and discoloration were estimated from the upper half of the living crown of spruce, and from the upper 2/3 of the living crown of pine and broadleaved trees.

In the first sampling method (method 1) the radius of the circular plot was 9.77 m and the area 300 m^2. In this method the crown condition (defoliation and discoloration) was assessed on all the trees fulfilling the selection criteria and growing inside the plot. In the second sampling method (method 2) the area of the circular plots was at least 300 m^2. If the number of trees on a plot of 300 m^2 was less than 20, new trees fulfilling the selection criteria and closest to the centre point of the plot were added to the sample until the number of trees on the plot was 20. As a result of this, the size of the plots varied according to the stand density.

The third sampling method (method 3) was based on the four-point cross cluster grid procedures described in the ICP Forests manual (Manual on methodologies ...). In sampling method 3, a 4-point cluster grid, with four subplots oriented along the main compass directions at a distance of 25 m from the centre point of the sample plot, was superimposed on the 30 plots at the same time as the annual crown condition survey was carried out. On each subplot the 6 trees nearest to the subplot centre and fulfilling the same criteria as the trees in method 1 and 2 were selected for the sample.

Statistical analysis

Expected values of the sample means

In all three sampling methods the number and locations of the centre points of the sample plots were the same, but the method used for selecting the trees around the centre of the plots was different. The average number of trees per plot was the smallest in method 1 and the largest in method 3. The number of plots including at least one tree of a specific tree species is also the smallest in method 1 and the largest in method 3. The greater the number of trees on a plot within mixed forest, the higher is the probability that at least one tree of a minority species will be included in the sample. Table 1 shows the number of sample plots, the mean and standard deviation of the number of trees per plot, mean defoliation and mean discoloration by tree species and sampling methods in the test data.

In method 1 all the trees within the circular plots are selected. When the location of the plot grid is random, all the trees in the population will have the same sampling probability and the sample mean of the trees will be an approximately unbiased estimate of the mean value of the trees in the population. The sample size is random and therefore the estimate is not unbiased.

In method 3 the six trees closest to the midpoint of the sub plots are selected, and hence the sampling probability of a tree depends on the distance between the tree and the neighbouring trees. The larger the free space around a tree, the higher is the sampling probability of the tree. The exact probabilities are not known and can only be computed if the location of all the trees is known. The arithmetic mean of all the sample trees is an unbiased estimate of the weighted mean of the trees of the population, where the weights are equal to the unknown sampling probabilities. The difference between the expected values of sample means in the two sampling methods is mainly caused by the differences in the weights of the plot means. Each sample plot represents an area defined by the grid of sample plots. In method 3 the expected value of the sample mean is approximately equal to the weighted mean of the arithmetic means of the areas, the weight of an area being proportional to the size of the area. This mean value is here called the mean value weighted by the size. The mean value of the trees in the population is the weighted mean of the mean values of the areas, the weight of an area being proportional to the number of

Table 1. The number of sample plots, mean number of trees on a plot, standard deviation of the number of trees on a plot, mean defoliation and mean discoloration in the test data.

Species Sampling method	m = number of plots with $n_i > 0$	$\overline{n}$ = mean of n_i, i = 1,2,3,...,m	$\sigma_{\overline{n}}$ = standard dev. of n_i	$\overline{y}_f$ = mean defoliation	$\overline{y}_c$ = mean discoloration
Pine					
Method 1	21	14.1	7.7	10.2	0.1
Method 2	23	15.7	8.1	10.2	0.1
Method 3	25	15.2	9.1	10.4	0.5
Spruce					
Method 1	18	7.2	6.0	16.6	3.1
Method 2	19	11.3	8.0	19.4	3.1
Method 3	20	13.4	8.3	18.0	3.5
Broadleaves					
Method 1	10	4.8	4.5	11.7	0.4
Method 2	11	5.4	4.2	12.3	0.3
Method 3	17	4.2	2.9	10.8	0.7
All species					
Method 1	30	15.8	6.4	12.1	1.0
Method 2	30	21.1	2.5	13.5	1.1
Method 3	30	24.0	0.0	13.3	1.6

trees in the area. This mean value is here called the mean value weighted by the number of trees.

Method 2 is a combination of methods 1 and 3. In the test data the number of trees per plot was constant (= 20) on 80 % of the plots, and the expected value of the arithmetic mean of the sample is approximately equal to the mean value weighted by the size, as is the case in method 3.

Method 1 provides an estimate of both the mean value weighted by the number of trees and the mean value weighted by the size. Both mean values also can be estimated in the case of method 2 if we know which of the sample trees lie inside the plots of fixed radius. In the case of method 3, the mean value weighted by the number of trees cannot be estimated if the distances between the sample trees are not known.

The correlation between the defoliation degree and the stand density was negative, and hence the mean value weighted by the number of trees was smaller than the mean value weighted by the size. This was also true in the case of the discoloration degree.

The arithmetic sample mean of the mean defoliation degree of the plots is 13.5 % in method 1, 13.6 % in method 2 and 13.3 % in method 3. The differences between the sampling methods are small and the difference between methods 1 and 3 is 0.2 % units. In Table 1 the mean of the defoliation degree of all the sample trees is 12.1 % in method 1, 13.5 % in method 2 and 13.3 % in method 3. The difference between sampling methods 1 and 3 in this case is 1.2 % units. The mean value of the plot means and the mean value of the trees are the same in method 3, and almost the same in method 2.

In the estimates of the proportional number of trees belonging to a fixed defoliation class k, the value of the target variable y_i is 1 if tree i belongs to class k and y_i is otherwise 0. The sample mean of the observations can be used as the estimate of the proportional size of defoliation class k in the population, but the expected value of the sample mean depends on the sampling method in the same way as in the case of the mean defoliation degree described above.

The effect of the randomness of the sample size

In all three sampling methods, the sample size of each tree species is random and this has an effect on the expected value of the sample mean. The effect depends on the number of plots and on the correlation between the number of trees on a plot and the mean value of the plot. The greater the absolute value of the correlation, the larger is the effect and, conversely, the greater the number of plots, the smaller is the effect. The upper limit of the effect is given by the formula developed for simple random sampling: $\sigma \frac{\sigma_{\bar{n}}}{\bar{n}}$, where σ is the standard deviation of the sample mean and $\sigma_{\bar{n}}$ is the standard deviation of the number of trees on a plot and $\sigma_{\bar{n}} = \frac{\sigma_n}{\sqrt{m}}$ (Cochran, p. 162). As an example of the mean value of broadleaves trees, in method 1 the ratio $\frac{\sigma_{\bar{n}}}{\bar{n}} = \frac{4.5}{4.8\sqrt{m}}$ (Table 1). If m = 10, $\frac{\sigma_{\bar{n}}}{\bar{n}}$ = 0.29 and if m = 100, $\frac{\sigma_{\bar{n}}}{\bar{n}}$ = 0.09, thus indicating that the effect is negligible compared to the standard error of the estimate if the number of plots is not small.

Variances of the sample means

The sample mean can be written in the form

$$(1) \qquad \bar{y} = \frac{\sum_{i=1}^{m} n_i \bar{y}_i}{\sum_{i=1}^{m} n_i},$$

where y is the defoliation degree (or discoloration degree) of a tree, n_i = the number of trees of a given species or species group on sample plot i, m = the number of sample plots for which $n_i > 0$, and $\bar{y}_i = (1/n_i)\sum_{j=1}^{n_i} y_{ij}$ is the mean value of y on plot i.

We assume that the y-value generating process is a random one, and that $y_{ij} = \mu_i + \varepsilon_{ij}$, where μ_i is the mean value of the process around the midpoint of sample plot i, expectation $E(\varepsilon_{ij}) = 0$ and variance $V(\varepsilon_{ij}) = \sigma_i^2$. The estimate (1) can be written in the form

$$(2) \qquad \bar{y} = \frac{\sum_{i=1}^{m} n_i \mu_i}{\sum_{i=1}^{m} n_i} + \frac{\sum_{i=1}^{m} n_i \bar{\varepsilon}_i}{\sum_{i=1}^{m} n_i}.$$

The error variance is $V(\bar{y}) = E_1(V_2(\bar{y})) + V_1(E_2(\bar{y}))$, where E_2 and V_2 are the conditional mean and the conditional variance of the y-value generating process given the sample plots, and E_1 and V_1 are the mean and variance over the sample plot selection.

The conditional expectation is $E_2(\bar{y}) = \frac{\sum_{i=1}^{m} n_i \mu_i}{\sum_{i=1}^{m} n_i} = \frac{1}{m\bar{n}} \sum_i n_i \mu_i$, where

$\bar{n} = (1/m)\sum_i n_i$ is the mean number of trees on a plot. Because the distances between the plots are large compared to the size of the plots, we can safely assume that the deviations ε_{ij} from the plot means are uncorrelated if the trees are not on the same plot. The conditional variance is then

$$V_2(\bar{y}) = 1/(m\bar{n})^2 \sum_i n_i^2 Var(\bar{\varepsilon}_i)$$

$$= \frac{1}{m\bar{n}} \frac{1}{m} \sum_i \frac{n_i^2}{\bar{n}} Var(\bar{\varepsilon}_i).$$

The variance

$$\mathrm{Var}(\bar{\varepsilon}_i) = \frac{\sigma_i^2}{n_i} + \frac{\sigma_i^2}{n_i^2} \sum_j^{n_i} \sum_{k \neq j}^{n_i} r(\varepsilon_{ij}, \varepsilon_{ik}),$$

where $r(e_{ij},e_{ik})$ is the coefficient of correlation between deviations ε_{ij} and ε_{ik}, $j \neq k$. The correlations considered were the within-plot spatial correlation of the defoliation degree (and the discoloration degree) separately for pine, spruce and broadleaves. No distance-dependent structure was found and we assume that there is no within-plot correlation. The conditional variance V_2 is then

$$V_2(\bar{y}) = 1/(m\bar{n})^2 \sum_i n_i^2 \sigma_i^2 / n_i = 1/(m\bar{n})\, V_w,$$

where $V_w = 1/m \sum_i \left(\frac{n_i}{\bar{n}}\right) \sigma_i^2$ is the weighted average of the within-plot variances. The estimator of both the conditional variance $V_2(\bar{y})$ and its expectation $E_1(V_2(\bar{y}))$ is

$$\hat{V}_2(\bar{y}) = \frac{1}{m\bar{n}} \hat{V}_w^2 = \frac{1}{m\bar{n}} \frac{1}{m} \sum_i \frac{n_i}{\bar{n}} s_i^2, \quad \text{where}$$

$$s_i^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2.$$

The values of V_w depend on the sampling method through the weights $n_i/\bar{n}$. The expected effect of the weights on the value of V_w depends on the correlation between the number of trees n_i and the within-plot variance σ_i^2. The mean values and the variances of defoliation and discoloration increases as the average age of the trees on a plot increases, and the correlation between n_i and σ_i^2 is negative in methods 1 and 2. Table 2 shows the effect of weighting in the test data. In Table 2 the estimates $\hat{\sigma}_w = \sqrt{\hat{V}_w}$ for pine, spruce and broadleaves were computed by estimating the variances s_i^2, i = 1,2,3,...,m, of each tree species by using all the trees of the species in the data regardless of the sampling method.

The estimates of the variance due to the sample plot selection $V_1(E_2(\bar{y}))$ are not unbiased because the sample plots have been selected by systematic sampling. The expression developed for simple random sampling is, however, suitable for comparisons of these sampling methods. The expression is (Cochran 1977)

$$V_1 = Var\left(\frac{\sum_i n_i \mu_i}{m\bar{n}}\right)$$

$$= \frac{1}{m\bar{n}^2} \frac{\sum_i n_i^2 (\mu_i - \mu)^2}{m-1} = (1/m)\, V_b, \text{ where}$$

$$V_b = \frac{1}{m-1} \sum_i \left(\frac{n_i}{\bar{n}}\right)^2 (\mu_i - \mu)^2 \text{ is}$$

the between-plot variance and m is the mean value of the population. The between-plot variance V_b depends on the sampling method only through the weights $(n_i/\bar{n})^2$. The estimators of the variances V_1 and V_b are

$$\hat{V}_1 = (1/m)\hat{V}_b \text{ and}$$

$$\hat{V}_b = \frac{1}{m-1} \sum_i \left(\frac{n_i}{\bar{n}}\right)^2 (\bar{y}_i - \bar{y})^2 .$$

Table 2 shows the values of $\hat{\sigma}_b = \sqrt{\hat{V}_b}$ for pine, spruce and broadleaves and different sampling methods in the test data.

In Table 2 the differences between sampling methods are negligible. The variance V_1 depends both on the between-plot variance and on the number of plots. The total number of plots is the same in each sampling method, but the number of plots including trees of a specific tree species depends on the sampling method. In the test data, pine is the predominant tree species on most of the plots that have pines, and the differences between the sampling methods are rather small (m = 21 in method 1 and m = 25 in method 3). Broadleaves are minority species on all the plots of the test data

Table 2. Estimates of the square roots of the within-plot variance and the between-plot variance of pine, spruce and broadleaves for the three sampling methods.

Species Sampling method	Defoliation Within plots $\hat{\sigma}_w$	Between plots $\hat{\sigma}_b$	Discoloration Within plots $\hat{\sigma}_w$	Between plots $\hat{\sigma}_b$
Pine				
Method 1	7.1	5.2	3.5	0.6
Method 2	7.4	5.2	3.4	0.7
Method 3	7.5	6.2	3.7	0.9
Spruce				
Method 1	9.2	10.6	3.8	2.3
Method 2	9.5	9.8	3.9	2.2
Method 3	9.3	9.5	4.8	3.3
Broadleaves				
Method 1	8.7	9.6	1.5	1.0
Method 2	8.3	9.0	1.5	1.0
Method 3	8.0	9.7	1.7	1.2

and the differences between the sampling methods are larger (m = 10 in method 1 and m = 17 in method 3). The differences between the sampling methods are greatest in the estimates of broadleaves.

A convenient formula for the standard error of the estimate $\bar{y}$ is

$$\hat{\sigma} = \sqrt{\hat{V}} = \sqrt{\frac{1}{m}\left(\hat{V}_b + \frac{\hat{V}_w}{\bar{n}}\right)}.$$

In method 1 the values of V_b V_w and $\bar{n}$ are e.g. $V_b = 9.6^2$, $V_w = 8.7^2$ and $\bar{n} = 4.8$ for the defoliation of broadleaves. On the national level the number of broadleave plots is about 200. We can approximate the differences between the methods by using m = 150 for sampling method 1 and m = 250 for method 3. For the number of plots m = 150, standard error $\hat{\sigma}$ = 0.85, for m = 200 $\hat{\sigma}$ = 0.73 and for m = 250 $\hat{\sigma}$ = 0.66, which indicates that the standard error of the large area estimates of the broadleaves is small, and 0.2 % units smaller in method 3 than in method 1. The precision of method 2 lies between the other two.

The variance of the mean of the plot

The arithmetic mean $\bar{y}_i$ of plot i is an estimate of the local mean value μ_i. The variance $\bar{y}_i$ is σ_i^2/n_i. Except for very small and very large values of μ_i the coefficient of variation $CV_i = \sigma_i/\mu_i$ is approximately independent of μ_i. For the defoliation degree $CV_i \approx 0.6$ and the coefficient of variation of $\bar{y}_i$ is $CV_{\bar{y}_i} \approx 0.6/\sqrt{n_i}$. For n_i = 1,10,20 and 24 the values of $0.6/\sqrt{n_i}$ are 0.6, 0.19, 0.13 and 0.12, which shows that the random error of the local estimate of a tree species can be large in all three methods, and that the difference between method 2 (total number of trees on a plot is at least 20) and method 3 (total number of trees on a plot is 24) is small.

Summary and conclusions

In method 1 the sampling probabilities of all the trees in the population are known. The arithmetic mean of the sample trees is an approximately unbiased estimate of the arithmetic mean of the trees in the population. In method 3 the sampling probabilities of the trees are not known. The expected value of the arithmetic mean of the sample trees is a weighted mean of the trees in the population, the weight of a tree being proportional to the free space around the tree, and thus the trees of a sparse stand have more weight than the trees of a dense stand. The weights can be computed only if the spatial locations of all the trees are known. The difference between the arithmetic mean and the weighted mean of the trees depends mainly on the distribution of densities of the stands and on the correlation between the mean value and the density of the trees in the stand. This correlation is negative and hence the arithmetic mean is smaller than the weighted mean. In the test data the estimate of the difference in the defoliation degree of all the trees was about 1 % unit.

The grid of possible plot means in systematic sampling defines the areas that each sample plot represents. The mean of the population weighted by the sampling probabilities is approximately equal to the weighted mean of the mean values of the areas, the weight of an area being proportional to the size of the area. The arithmetic mean of the population is equal to the weighted mean of the areas, the weight of an area being proportional to the number of trees on the area. In methods 1 and 2 both the weighted means can be estimated. In method 3 there is no unbiased estimate for the mean weighted by the number of trees.

The differences between the expected values of the arithmetic sample means in the different sampling methods are mainly caused by the differences in the weights of the plot means. In method 1 the weight of a plot mean is proportional to the number of trees on the plot. If all the tree species are taken into account, method 3 gives the same weight to all the plot means and method 2 gives almost the same weight to all the plot means. Therefore the expected value of the sample mean in method 2 is close to the expected value in method 3. In method 1, the weight of the plot mean in the sample mean of one tree species is also proportional to the number of trees of the specific species on the plot. In method 3 the weight is proportional to the proportional number of the trees of the tree species. Here again method 2 is close to method 3.

The sampling variances of large area estimates are small in all three sampling methods and the differences between the methods are negligible. The total number of trees on a plot can be small in method 1 and hence the estimate of a local value of the defoliation degree can be poor. In mixed stands the local estimates of one tree species can be poor in all three sampling methods. The average number of sample trees on a plot is greater in method 3 than in method 2. The sampling variance of the local estimate is proportional to the inverse of the sample size and the difference in precision between the sample size, of 20 trees on a plot and 24 trees on a plot is small.

In conclusion, the estimates of the mean defoliation degree over a large area given by all three methods are approximately equally precise. Only methods 1 and 2 provide approximately unbiased estimates of the mean defoliation degree of the trees of the population. The sample mean in methods 2 and 3 is, on the average, rather similar and overestimates the mean value of the population. The bias is, however, small if all the other sources of error in the survey are taken into account. In sparse stands the total number of trees on a plot is small in method 1 and the precision of the estimate of the local defoliation degree is poor. This problem was avoided in methods 2 and 3. The precision of the plot mean in a sparse stand is best in method 3 and almost equally good in method 2. In dense stands the sampling variances of the plot means are close to each other in all three sampling methods.

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5.3 Development and evaluation of methods for determining deposition in the form of snow within the stand on the Finnish intensive (Level II) continuous observation plot network

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Background

The long winter period in the Nordic countries especially means that a relatively high proportion of the precipitation comes in the form of snow. There are a number of technical and logistical problems involved in the collection of snow samples. Under these conditions, errors in the amount of precipitation can have a considerable effect on annual estimates of the deposition of pollutants. The major sources of error are listed in the following.

Evaporation losses (primarily bulk precipitation)

Reflected radiation from the snow cover on cloud-free days in late winter can result in the evaporation of water from the snow collectors. This can occur 1) when the snow in the collector melts and water is lost as water vapour through the large, open collector surface, or 2) as a result of the direct loss of water from the snow samples through sublimation. This may also be a problem in stands of low density. The losses are presumably restricted to water, the other components in precipitation being retained in the collectors. Annual estimates of the amount of precipitation will be underestimated, but deposition values should not be significantly affected.

Incomplete snowfall collection (primarily bulk precipitation)

Effect of wind at exposed sites

Snow samplers located in wide, exposed areas, will not collect representative snow samples during periods with relatively high wind velocities. This problem can be partly eliminated through careful siting of the collectors.

Formation of snow/ice caps on the collectors

Snow readily accumulates on top of the snow collectors, even if the rim of the collector is kept as narrow as possible. The formation of rime (layers of ice and snow on exposed surfaces) is also a serious problem under certain conditions. The caps which form on the collectors can be relatively high and they can easily be blown off in strong wind. This means that a varying proportion of the snow is not actually collected. In some areas the thickness of the snow cover can be well over 1 m, and there is a danger that the snow collectors will become buried.

Representability (primarily snow sampling within the stand)

Number of snow collectors within the stand

Snow sampling inside the stand is currently being performed in Finland using 6 snow collectors systematically located on the observation plot. The number of corresponding rainfall samplers is 20. The reason for the smaller number of snow samplers is a logistical problem since all the snow in the samplers has to be transported to the laboratory, where it is melted and a composite sample prepared. A preliminary trial indicated that the minimum number of snow samplers required to obtain a representative sample of snowfall within a spruce stand was about 8, and in a pine stand about 12. There was also considerable variation between collection periods.

Snow collector surface area

The size of the aperture of precipitation collectors is known to have an effect on sampling efficiency; the smaller the aperture size the greater the sampling error. The height of the collectors may also have an effect. The error involved in snow sampling will undoubtedly be much greater than that for rainfall sampling owing to the fact that snowflakes are more susceptible to air turbulence.

Preliminary results

Representability of the snow sampling

Experimental design

The part of the pilot study concerned with assessing the representability of the snow samples is being carried out on all 16 Level II monitoring plots where deposition is being collected (see Fig. 2, p. 12). 20 snow collectors (Fig. 1) were erected on each plot at the same systematic sampling points as the rainfall collectors. The 20 samplers were collected and weighed in the field at all the plots on two occasions (March, April) during winter 1998/99, according to the normal sampling procedure. This is being repeated on two occasions (February, March) on the 16 plots during the winter 1999/2000, and continued at 4-week intervals on 4 of the plots up until the winter is completely over. All the samples were transported to the laboratory of the Rovaniemi Research Station for pre-treatment. The chemical analyses were carried out in the same laboratory.

Sample pre-treatment and chemical analyses

After arriving at the laboratory the samples were weighed. The bags containing the snow samples were placed in large, acid-washed plastic containers and left to stand overnight in a cool room to thaw. 500 ml of water (sub-sample) was taken from each of the 6 melted snow samples that are normally used for determining deposition. These sub-samples were combined, in proportion to the total volume (weight) of the individual 6 samples, ready for filtration and analysis. 1000 ml of water (samples) was taken from each of the 20 melted snow samples, and pre-treated and analysed separately.

All the sub-samples (6) and samples (20) were filtered through a 0.45 µm membrane filter using a peristaltic pump (positive pressure). Prior to filtering, the filters were rinsed with 200 ml of ultra-pure water in order to remove any carbon-containing particles or fibres. Ultra-pure nitric acid (65 %) was added (0.25 ml/100 ml) to the samples prior to the determination of S_{tot}, Ca, Mg and Na by ICP/AES, and K by AAS. NO_3^-, SO_4^{2-} and Cl^- were determined by IC, NH_4^+ and N_{tot} by FIA, and DOC on a TOC analyser.

Calculations

The amount of precipitation (mm), average pH and amounts of S_{tot}, Ca, Mg, K, Na, NH_4^+-N, N_{tot}-N, NO_3^--N, SO_4^{2-}-S, Cl^- and DOC per m^2 for one 4-week period (February/March) were calculated using the following combinations:

1. Using the amount of water and concentrations for the 6 combined sub-samples as is normally done in the deposition monitoring. Denoted as 6 * 6 in the figures.
2. Using the amount of water in 10 of the individual snow samplers (every second sampler) and the concentrations in 5 of the snow samplers (every fourth sampler). Denoted as 5 * 10 in the figures.
3. Using the amount of water in the 20 individual snow samplers (every sampler) and the concentrations in 5 of the snow samplers (every fourth sampler). Denoted as 5 * 20 in the figures.
4. Using the amount of water in the 20 individual snow samplers (every sampler) and the concentrations in the 20 snow samplers (every sampler). Denoted as 20 * 20 in the figures. These are used as the reference values in the analysis.

Volume-weighted concentration values were used.

The total surface area of the different number of collectors and proportion of the surface area of the plot (30 x 30 m) are given in the following.

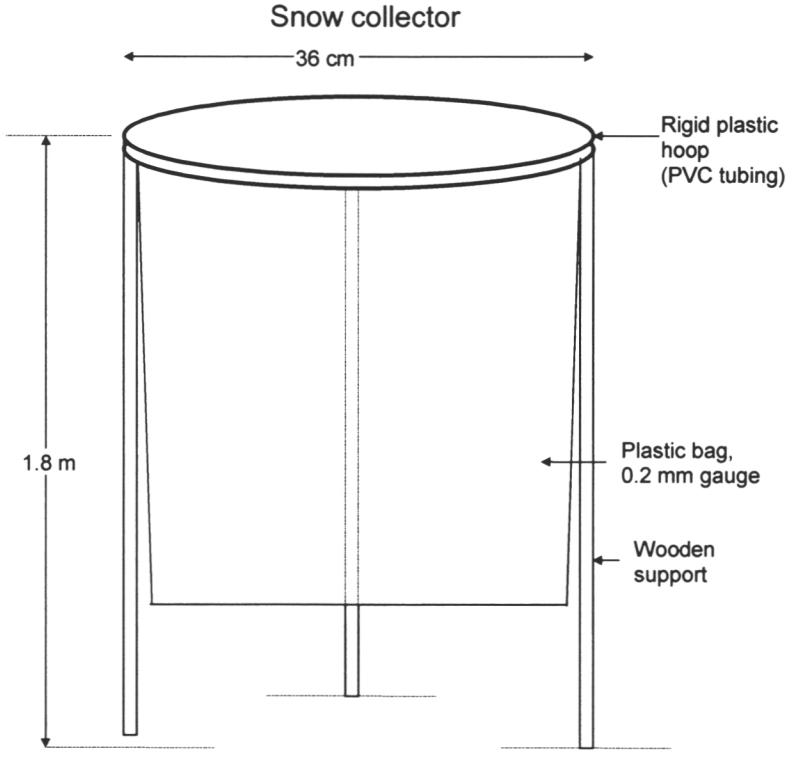

Figure 1. The plastic bag for collecting snowfall fits tightly over the plastic hoop. The bag is held in place by plastic clips (not shown) that are pressed down over the bag/hoop. The hoop is attached to the three wooden legs by means of plastic holders (not shown) screwed onto the top of the wooden supports.

Number of collectors	Total surface area, m^2	Proportion of plot area, %
5	0.51	0.0006
6	0.61	0.0007
10	1.02	0.0011
20	2.04	0.0023

In order to reduce the number of figures, the preliminary results presented here are for 4 plots – 2 Norway spruce and 2 Scots pine stands. One of the spruce stands had high inter-sampler variation (SD +/- 9.5 mm) in the amount of snow, and the other three stands had relatively small variation (SD +/- 2.3, 2.3, 2.7 mm).

Amount of precipitation (as snow)

Decreasing the number of collectors (20, 10 or 5) did not markedly decrease the accuracy of the estimate of the amount of precipitation (Fig. 2). However the set of 6 collectors normally used in determining deposition gave a very poor estimate on the spruce plot in northern Finland (Pallasjärvi_S, No. 3), the value being 24 % less than the reference. Two of the 6 collectors on the plot are located very close to spruce trees. The branches on the trees growing at this site extend almost down to the butt of the stem, and the shielding effect on these two collectors is considerable.

Weighing the snow collectors in the field using spring scales appeared to be an extremely accurate procedure (Fig. 3), despite the poor lighting and otherwise extreme conditions. This reflects the high competence of the field workers. The precision pocket scales (Pesola Scales, AAS-Service) are intended for fishermen, the weight being read from a scale marked on the vertical body of the device. Two sizes were used: 2.5 kg (scale division 0.02 kg) and 10 kg (scale division 0.05 kg). The samples were weighed in the laboratory using a digital plate balance (Ohaus, 50 kg, scale division 20 g).

The amount of precipitation measured in the stand (20 collectors) was very different from that measured in the open area (2 collectors) for one 4-week period (February/March).

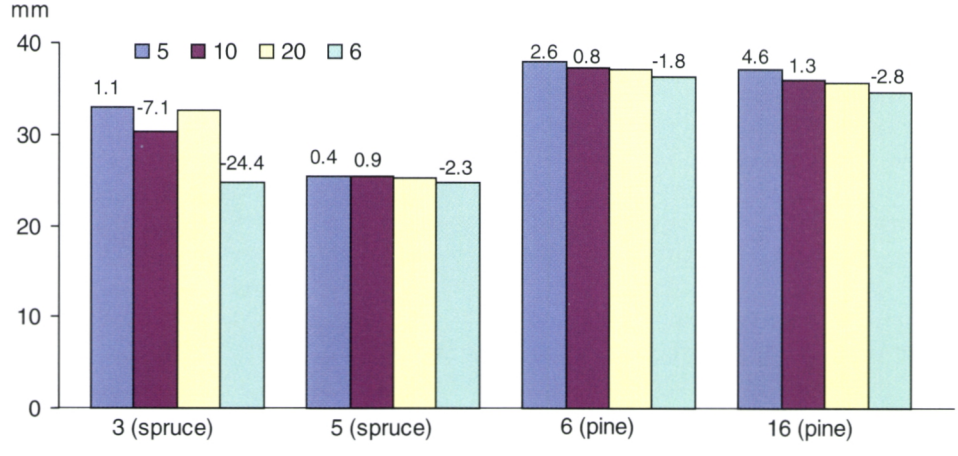

Figure 2. The amount of stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6). The value for 20 collectors has been used as the reference value. The difference (%) between the reference value and the value obtained with different numbers of collectors is marked above the columns. 6 collectors have normally been used in throughfall monitoring in Finland. The 4-week collection period was in February/March 1999.

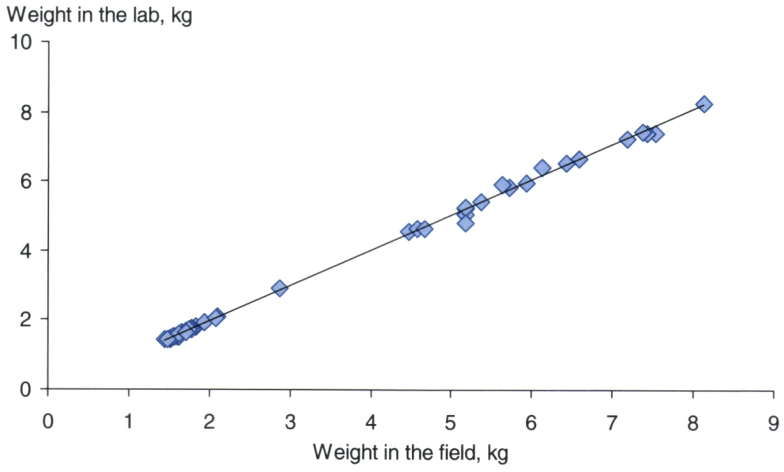

Figure 3. Correspondence between snow samples weighed in the field using spring balances (max. 2.5 and 10 kg) and the same samples weighed in the laboratory using a plate balance (max. 50 kg). The observations were made by two field workers on two different plots.

Plot	Precipitation, mm		Increase/decrease
	Open area	Inside the stand	Inside stand
3	34.9	32.7	- 6.3 %
5	28.0	25.3	- 9.6 %
6	27.3	37.1	+ 35.9 %
16	54.9	35.6	- 35.2 %

The amounts of precipitation measured in the stand and in the open are not, as such, directly comparable, because not all the snow falling on the stand passes immediately into the collectors. A varying proportion of this snow is retained temporarily by the tree crowns, and falls to the ground at a later date (e.g. if the temperature rises above 0 °C, during windy periods etc.). Some of the snow in the tree crowns will also be lost through evaporation (especially on sunny days during late winter). The occurrence of rime (ice crystals formed on surfaces directly from moisture in the air) increases the amount of precipitation inside the stand. Rime formation on the collectors in open areas is minimal compared to the amount accumulating in tree crowns. For these reasons, comparison of the amount of precipitation in the open and in the stand is only meaningful when the budgets are calculated for the whole winter.

pH and DOC

As pH is a measure of the hydrogen ion concentration, the amount of snow collected is not expected to have any effect on the average pH. This was the case on the four plots (Fig. 4).

Although there is minimum chemical interaction between the crown and snow if the air temperature during the collection period remains below 0 °C, the snow samples always contain varying amounts of dry deposition that has earlier accumulated in the tree crowns, as well as tree litter. Spruce and pine stands differ considerably in the pattern of e.g. needle shedding. Pine needles are mainly shed in the autumn, while spruce needles are shed throughout the year. The proportion of needle litter in spruce stands is especially high during the winter due to the tearing effect of the snow accumulating in the crowns. The spatial variation in litterfall within individual stands is known to be high, and there is also

considerable variation between and within tree species. Increasing the number of snow collectors from 5*10 to 5*20 only slightly decreased the deviation in DOC from the reference value (Fig. 5), and it is apparent that obtaining an accurate estimate of DOC presupposes that analyses are carried out on more than 5 snow samples/plot. The high variation in the DOC values was also increased by the fact that additional organic matter was undoubtedly extracted from the litter during and immediately after the snow-thawing stage in the laboratory. There was a considerable time lag (up to 12 hours) between the start of thawing and the filtering stage.

Nitrogen

The N_{tot}, NH_4^+ and NO_3^- values obtained with 5*10 or 5*20 snow samples differed by less than 9 % from the reference values, and increasing the number from 5*10 to 5*20 only marginally improved the results on most of the plots (Fig. 6). The results given by the combination normally used in measuring deposition (6*6) differed considerably from the reference values on all the plots.

Sulphur

The S_{tot} and SO_4^{2-} values obtained with 5*10 or 5*20 snow samples differed by less than 4 % from the reference values on three of the plots, and increasing the number from 5*10 to 5*20 had little effect on the results (Fig. 7). The results for plot 3 were not as satisfactory. As was the case for nitrogen, the results given by the combination normally used in measuring deposition (6*6) differed considerably from the reference values on most of the plots.

Base cations (Ca, Mg, K)

There was considerable variation between the values for Ca, Mg and K, as well as between the plots, with 5*10 or 5*20 snow samples compared to the reference values (Fig. 8). In the case of Ca and Mg, the difference on three of the plots (excluding Plot 3) was within tolerable limits (< 10 %). For K, on the other hand, the difference was extremely high; over 50 % on the two spruce plots. The results for Ca, Mg and K given by the combination normally used in measuring deposition (6*6) also differed considerably from the reference values on the two spruce plots.

Sodium and chloride

The difference in the amount of Na (5*10, 5*20) compared to the reference value was below 6 % on all four plots (Fig. 9). The variation in the amount of Cl^-, on the other hand, was much higher.

Preliminary conclusions

1. The spatial variation in the amount of precipitation (as snow) within stands appears to be relatively high, and depends on the tree species, stand density and structure of the crown canopy (not studied here, but generally accepted).

2. The pH of the snow is independent of the amount of precipitation, and hence of the number of collectors used.

3. The number of collectors required to obtain accurate estimates of the deposition load of cations, anions, total N and S and DOC varies according to the individual components. Spatial variation in the deposition of K, Mg and DOC is extremely high, presumably due to the high spatial variation in litterfall.

4. The procedure used in melting the snow samples in the laboratory needs to be further developed in order to minimise the leaching of K, Mg and DOC from the solid material (needle and other litter) unavoidably present while the snow samples are being melted.

5. The weighing of snow samples in the field, and the transport of a smaller number (e.g. 5) of snow samples to the laboratory for chemical analysis appears to be a promising

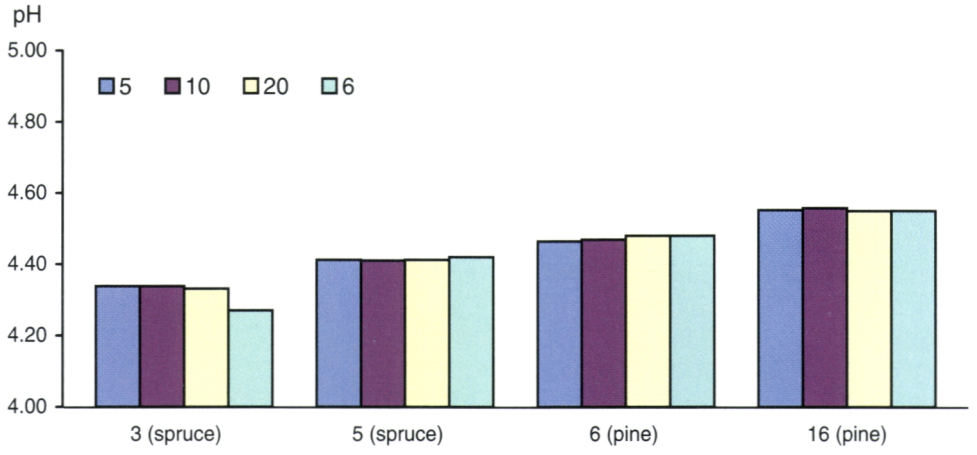

Figure 4. The average pH of stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6).

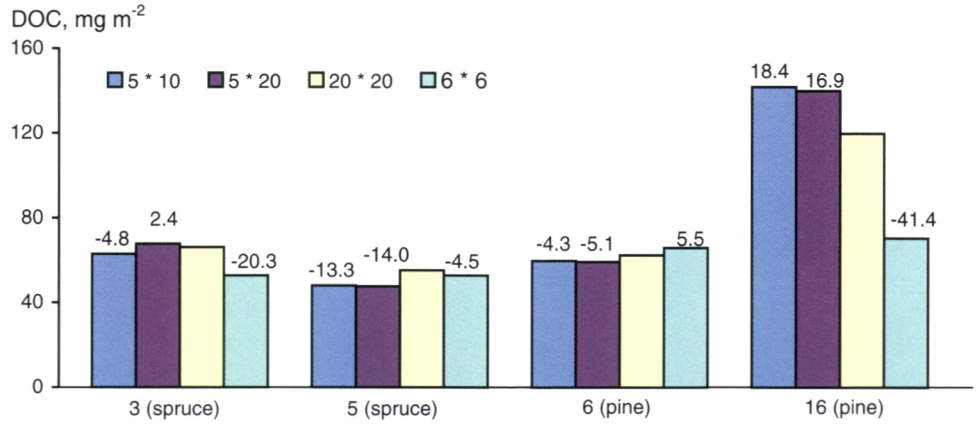

Figure 5. The deposition load of DOC in stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6). The value for 20 collectors has been used as the reference value. The difference (%) between the reference value and the values obtained wth different numbers of collectors is marked above the columns. 6 collectors have normally been used in throughfall monitoring in Finland. The 4-week collection period was in February/March 1999.
*5 * 10 = concentration from 5 collectors, amount of precipitation from 10 collectors.*
*5 * 20 = concentration from 5 collectors, amount of precipitation from 20 collectors.*
*20 * 20 = concentration from 20 collectors, amount of precipitation from 20 collectors.*
*6 * 6 = concentration from 6 collectors, amount of precipitation from 6 collectors.*

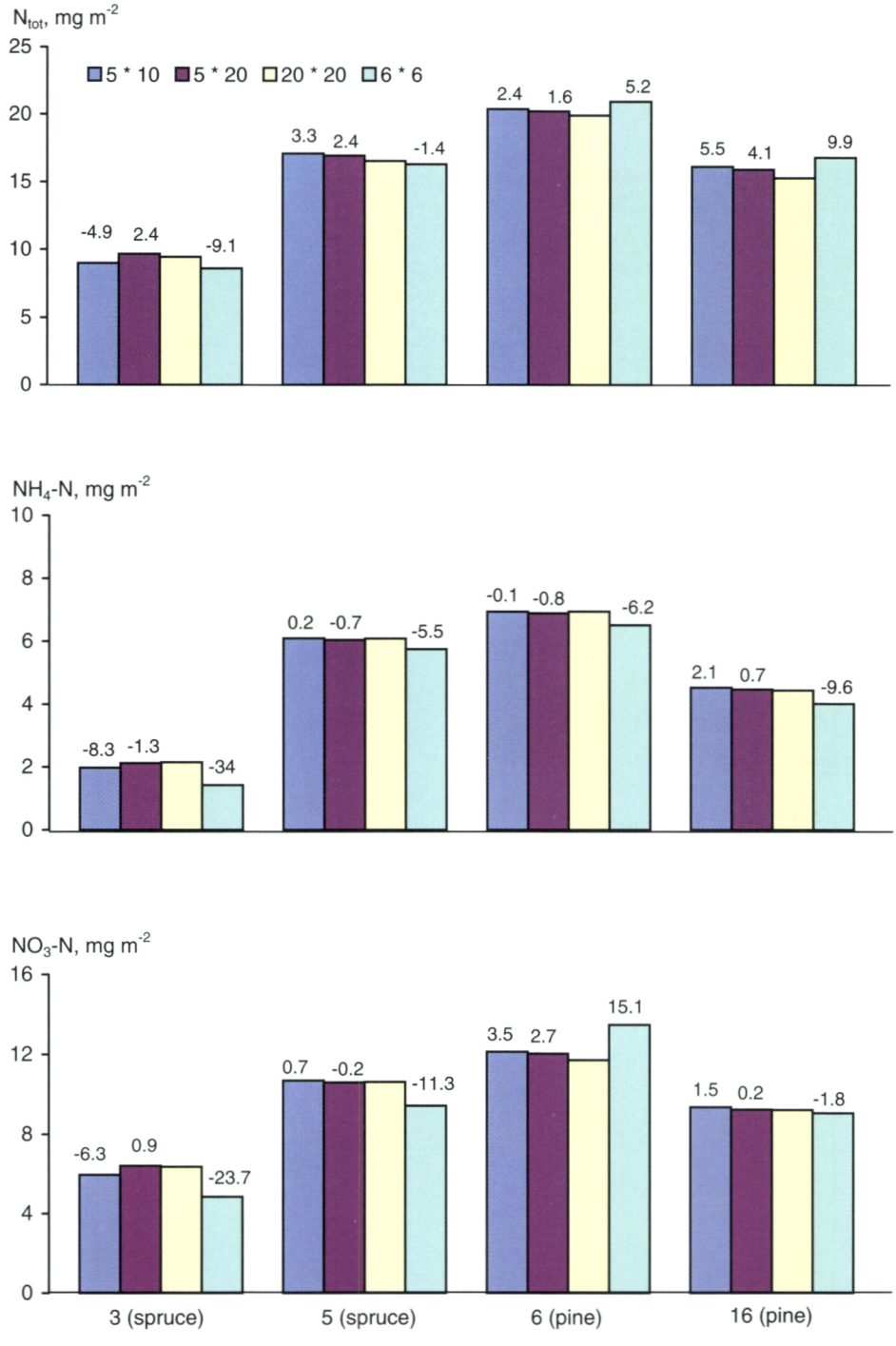

Figure 6. The deposition load of Ntot, NH_4^+ and NO_3^- in stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6).

means of increasing sample representability, and reducing the work load and costs of field work.

6. The minimum number of samplers needed to obtain a reliable estimate of the deposition load will probably have to be determined for each plot separately.

7. Although a systematic layout should be used with respect to the position of the collectors, selection of the snow samples to be taken for chemical analysis could be restricted to those collectors known to give precipitation amounts and deposition values close to the average for the plot. However, this presupposes the chemical analysis of snow from all the snow collectors on the plots at regular intervals (e.g. every two years). Furthermore, changes in the structure of the crown canopy over time will undoubtedly change the spatial variation in precipitation and the deposition load within the stand.

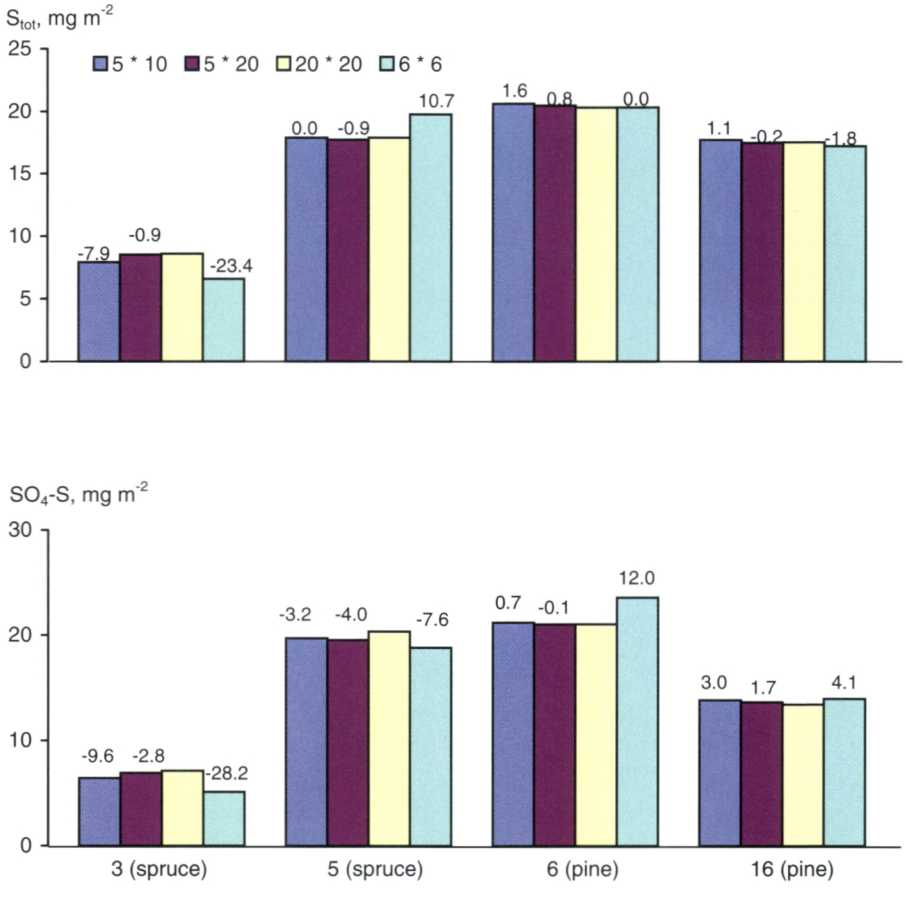

Figure 7. The deposition load of S_{tot} and SO_4^{2-} in stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6).

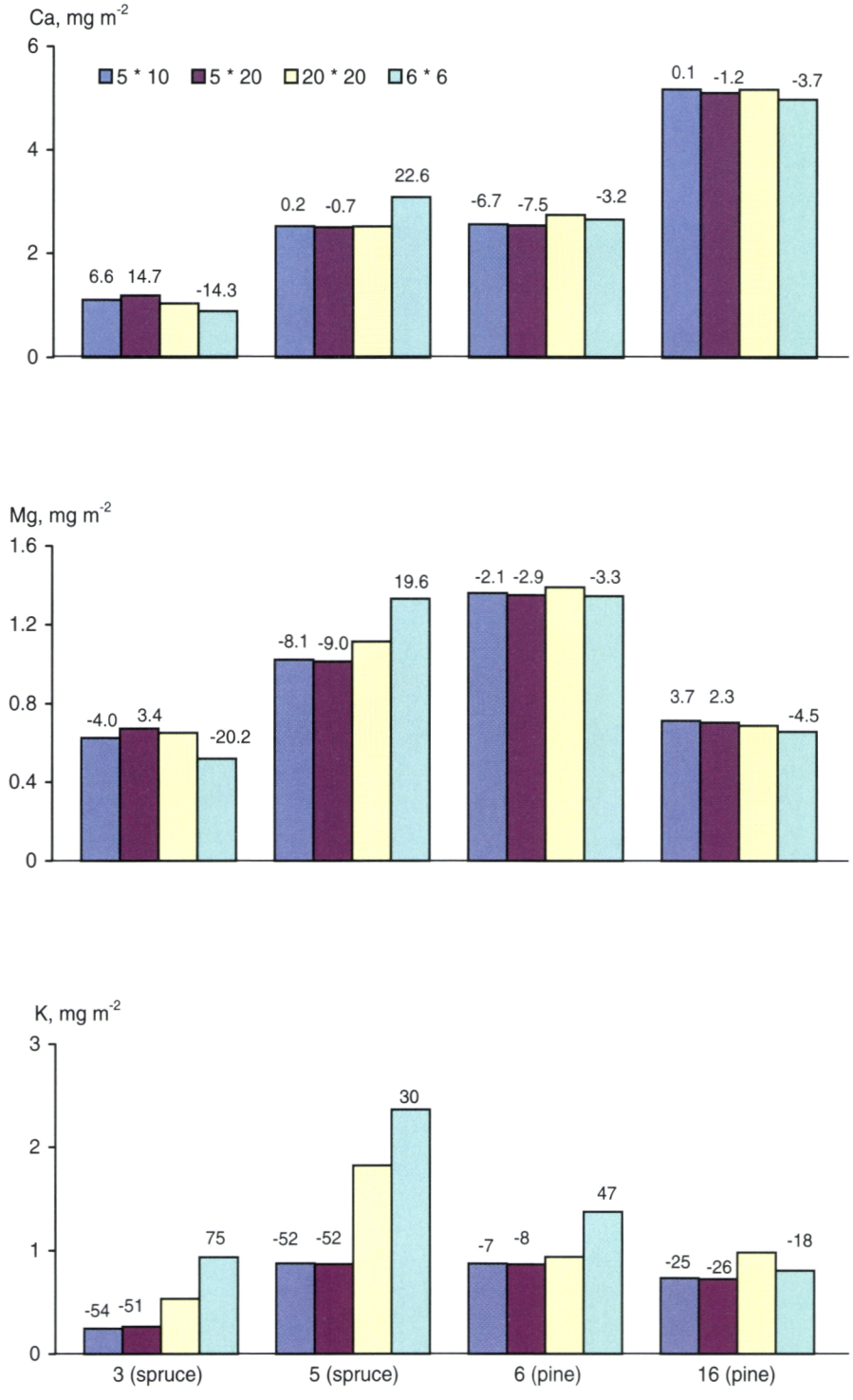

Figure 8. The deposition load of Ca, Mg and K in stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6).

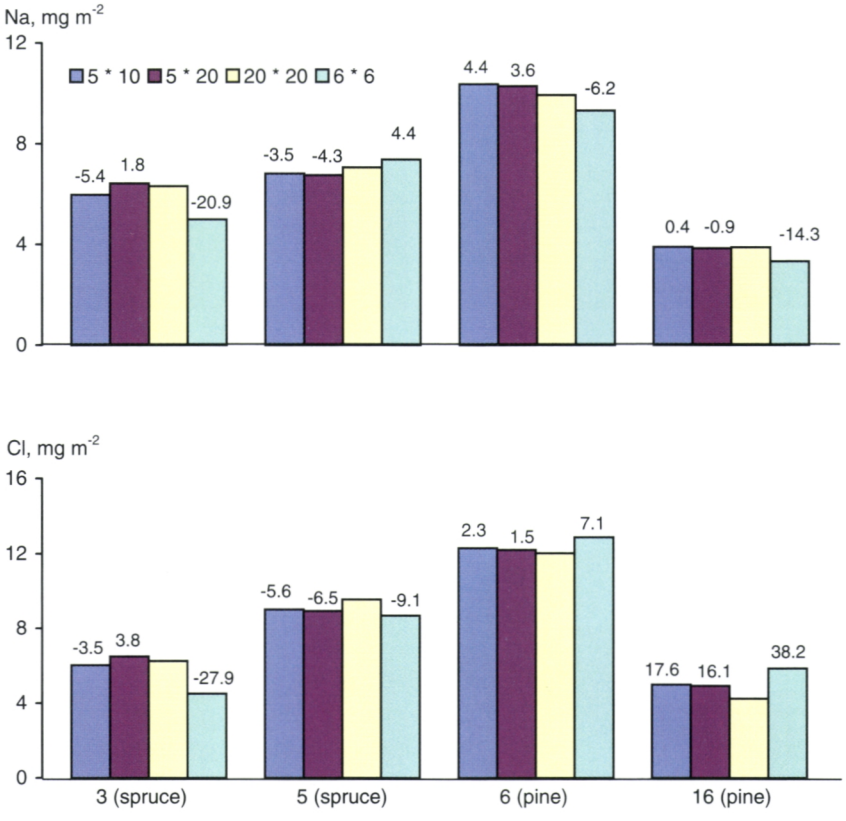

Figure 9. The deposition load of Na and Cl- in stand throughfall (as snow) on four sample plots (3 = Pallasjärvi_S, 5 = Kivalo_S, 6 = Kivalo_P, 16 = Punkaharju_P) calculated using different numbers of snow collectors (5, 10, 20 or 6).

5.4 Telemetric data transmission from the field to the office

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Background

The carrying out of non-stop weather, soil and tree-stand monitoring is an essential part of the measurements made in the ICP Forests Level II monitoring. The intensive monitoring of the daily growth of trees in Finland is carried out using girth bands. The first prototype of a girth band, measuring diameter changes in an accuracy of 0.03 mm, was ready for field-testing in 1993. During the first summer the data were recorded manually.

Automatic data loggers were installed in 1994, mainly for economic reasons. In 1995 bands were tested in connection with data collection at weather stations on the Finnish Level II monitoring network. When using data loggers, the measurement data has to be transferred to portable computers at intervals of about 1–2 months (Fig. 1).

The main technical problems in using girth bands to monitor the circumference of trees at intervals of one hour are associated with thunderstorms and browsing animals, which tend to chew the plastic cables installed in the forest. Checking that the devices are functioning properly therefore requires weekly visits to the experimental plots. Owing to the fact, that Finland, sparsely populated, and the labour costs and especially travel-related costs are high, performing this work "manually" usually means relatively long intervals between data retrieval visits.

In order to reduce the proportion of manual work and to guarantee disturbance-free functioning of the equipment, data collected in the field should ideally be transmitted immediately to the researcher's computer. This is where state-of-the-art data communication technology comes in. The setup used in transferring the data from field to the office is as follows:

The data collected in the forest are transmitted from the measurement points along wires or by wireless technology (radio) to the data loggers, which, in turn, send the data via a radio transmitter to a link station, located no more than 100 km away. The data are then transferred via a transmitter built into the telephone link station to the research institute's mainframe computer (Fig. 2). Sufficient transmission capacity, an appropriate data transmission speed, and the testing and correcting of transmission errors are the basic prerequisites of this data transmission network.

Aims of the study

Our objective was to construct a reliable data collecting system for the real-time transfer of growth and meteorological data (collected in the forest at 1-hour intervals using girth bands) directly to a mainframe computer located in an office facility. The development project comprises the designing and construction of the electronic hardware, the development of software for data transmission and error checking, and the setting up of a set of working prototype equipment.

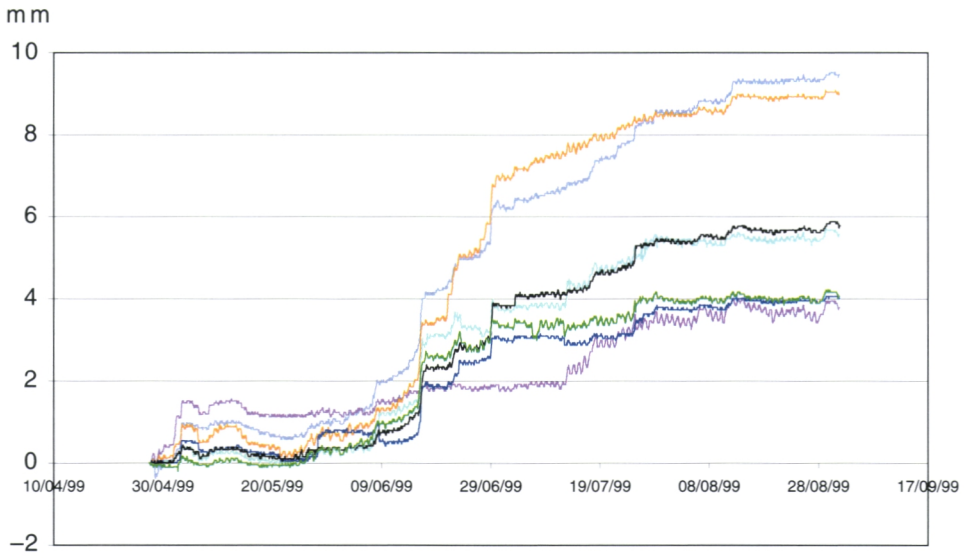

Figure 1. Example of the typical results of girth band measurements.

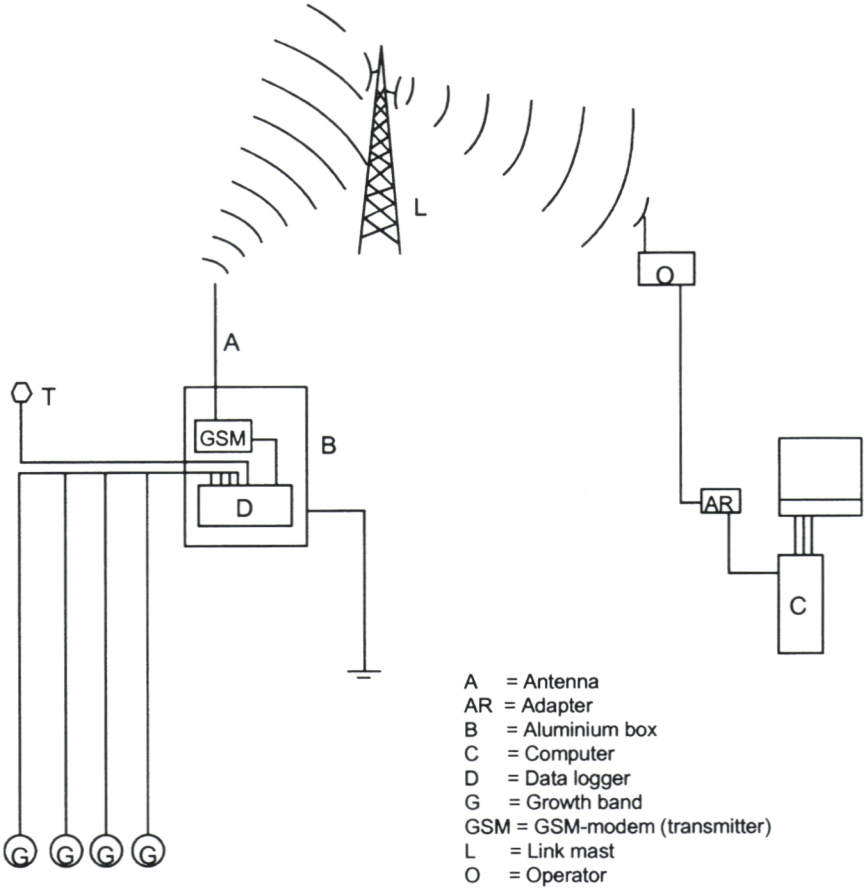

Figure 2. Schematic presentation of the data transfer system.

Structure of the data transfer system

Regardless of the communication system used, a wireless data transfer system always utilises a transmitter, receiver, and techniques for transferring the data to the transmitter, ready for transmission to the receiver.

Output power and energy consumption of the system are key points.The transferred data is also have to be as error-free as possible. The output power of the transmitter has to be large enough to ensure that the signal also reaches the nearest link station during unfavourable weather conditions. An output power of one watt is adequate for a distance of approximately 10 km. However, the range is dependent on the frequency band used, the properties of the antenna and the local topography.

The rate of data transfer is also subject to users choice. Large amounts of data (e.g. graphic material) require a higher transfer rate. However, a high rate also means an increased risk of errors.

In Finland permissions for transmitting radio traffic are granted by the Ministry of Transport and Communications. Typical carrier frequency bands used in telemetric data transfer vary between 150–1100 MHz. The GSM-technique uses the range 900 MHz or 1100 MHz.

Development of the equipment

The first trials concerning the transmission of data from the forest to the office were made using a Mobidex transmission network running at a frequency of 150 MHz. The reason for this was the network's good coverage, which also extended into the remotest parts of Finland. When a transmission output of about 20 W is used, data can be sent to link stations up to 70 km away.

In the preliminary study, the data were collected in a data logger manufactured by Campbell. A software package (PNET) was developed for collecting, testing and transmitting the data. An experimental plot near to the town of Uusikaarlepyy, located on the western coast of Finland, was chosen for the trial.

The detectors that were used in the testing phase were girth bands, developed at the Finnish Forest Research Institute, and thermometers. Both of these produce analog output data. The bands were mounted on spruce trunks. The forest stand also had a 16 m mast, which was used for meteorological measurements. The telemetric system was erected close to the mast. The system was located inside an aluminium instrument box to provide protection against moisture as well as against electric shocks caused by lightning (Fig 3). The system was also grounded. A small solar panel was used to provide electricity.

The testing was started in autumn 1997. After some initial problems with the transmitters' aerials and the solar panels, reliable functioning was achieved in summer 1998. The data (Fig. 1) clearly shows the beginning and cessation of growth, as well as sharp increases in stem diameter, usually due to heavy rain.

In 1998, it was decided to develop the equipment using the GSM data transmission network. The advantages offered by GSM compared to Mobidex include smaller size, low power consumption, considerably faster data transmission, and lower price.

The GSM-based equipment was installed in forest at sites near to Oulu and Rovaniemi, the latter right on the Arctic Circle. The functioning of the equipment has been tested and both experimental plots have provided faultless measurement data on an hourly basis since July, 1999. The functioning of the devices will also be tested in the winter (with temperatures dropping to -50 °C).

Costs of the equipment and conclusions

The following is a rough comparison of the prices of the Mobidex and GSM equipment (in Euros):

	Mobidex	GSM
Receiver/transmitter at link station	3000	1000
Receiver/transmitter at experimental plot	1000	300

In addition to data transmission, both systems include 12-channel data loggers, temperature and precipitation measurement instruments, and 8–10 girth bands per experimental plot. The total price of these measurement devices is about EUR 3000.

Telemetric data transmission from the forest to the office has proved to be a fully functioning method. The costs of the equipment can be offset against the saving in travel costs already during the first summer. Non-stop monitoring also reveals any malfunctions in the equipment, which, in turn guarantees the continuity of measurement data availability during the growing season. At the moment, this telemetric data transmission system is in "production use" at three remote sites in northern Finland.

For the time being, data from the individual girth bands is transferred to data logger via cables. Wireless data transfer is only used for sending the data from the data logger to the office. Cables has proved to be rather vulnerable to problems caused by small animals like voles. Therefore in the next phase we intend to test methods for transferring data from individual sensors to a data logger by wireless data transfer.

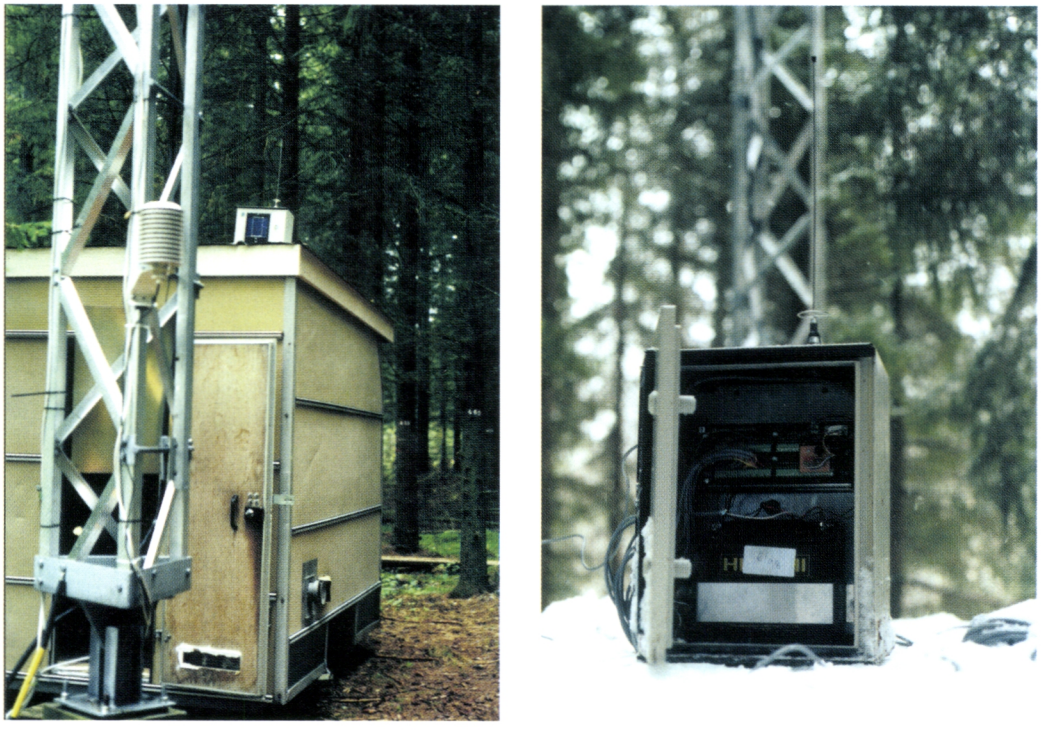

Figure 3. a) Campbell data logger and the transmitter on the roof with 16 m high aluminium mast next to the cabin, b) Data logger/ transmitter near, and a 15 Ah battery.

5.5 Monitoring of diseases caused by *Heterobasidion annosum* and *Peridermium pini* in Norway spruce and Scots pine stands by airborne imaging spectrometry (AISA)

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Introduction

Background and objectives

Heterobasidion annosum (Fr.) Bref. has been considered as one the most dangerous and economically most significant pathogens in coniferous forests in Finland and the other Nordic countries (Bendz-Hellgren et al. 1998). The importance of this pathogen may increase in the future due to the global warming caused by the greenhouse effect, as well as to the changes in cutting practices. Earlier, cuttings mainly took place during the winter, but nowadays they are carried out throughout the year. Both climate warming and the changing cutting practices increase the risk of stump infection, which is the most common route through which diseases spread in managed forests (Rishbeth 1951b, Rishbeth 1951a, Kallio 1970).

Increasing concern is also caused by the spread of the resin top disease in young Scots pine (*Pinus sylvestris*) stands. The disease is caused by *Peridermium pini* (Pers.) Lev. and *Cronartium flaccidium* (Alb. & Schw.), and occurs in both cultivated and naturally regenerated stands. The proportion of infected trees increases as a stand gets older. The exact spreading mechanism, as well as the significance of the disease in young stands, is not known. In any case, resin top disease is one of the most serious diseases in coniferous forests in North Finland especially.

Research has been carried out to intensify the use of remote sensing in forest damage monitoring. The European Commission has, together with the Finnish Forest Research Institute, financed the project *Airborne Imaging Spectrometer (AISA) in Forest Inventory and Forest Health Monitoring* (Project no. 95.60.SF.007.0: Remote, Sensing/ 27.VII.1995.) The purpose of this project was to test the applicability of airborne imaging spectrometers in forest damage monitoring. Forest inventory methods using the AISA instrument have also been developed in other research projects financed by the Technology Development Centre of Finland (for examples, see Mäkisara & Tomppo 1996, Mäkisara et al. 1997).

Finland's forest resources have been

surveyed in the national forest inventories (NFI) since 1921. So far, eight inventories have been completed, and the 9th NFI began in 1996. A multi-source inventory system was developed during the eighth inventory (1986–1994). In addition to ground measurements, the system uses satellite images and digital map data (Tomppo 1991, Tomppo 1993). The multi-source inventory produces both statistical data and digital thematic maps for the computation units. Compared to the inventory methods that employ only sampling and field measurements, the multi-source inventory provides much more detailed information about forests with very low additional cost.

The Finnish NFI produces information about forest resources, forest biodiversity and forest health, including damage caused *by Heterobasidion annosum, Peridermium pini* (Pers.) Lev. and *Cronartium flaccidium*. The inventory proceeds region by region, one rotation taking 5–10 years. Field data are collected on field plots and in the surrounding stands. However, thorough inventory of stand-level damage is not always possible, especially in the early stages of damage. Satellite images and digital map data are utilised, in addition to field data, in the multi-source part of the inventory. However, the resolution of current satellite images is not high enough to detect small areas of forest damage.

Forest damage was recorded in the 8th NFI and its update (1989–1994) over 8.30 million hectares (41 % of the total forestry land). Damage decreasing stand quality was found on 4.45 million ha, which is 22 % of the forestry land. Total damage was observed on 37 000 ha, severe damage on 640 000 ha, and observable damage on 3.47 million ha (Table 1).

Examples of fungal species are scleroderris canker *Gremmeniella abietina* (Lagerb.), resin-top disease *Cronartium flaccidium* (Alb. & Schw.) & *Peridermium pini* ((Pers.) Lev.), and a range of rot fungi including annosus root-rot *Heterobasidion annosum* ((Fr.) Bref.) and *Armillaria* (Fr:Fr.) species. They reduced stand quality over an area of 1.44 million ha (7.2 % of the forest land).

Moose and other damaging animals decreased stand quality on 340 000 ha (1.7 % of forest land). Wind, snow and other abiotic damaging agents reduced stand quality on 1.06 million ha (5.3 %). The other major damaging agents which had reduced stand quality were: unrecognised damaging agents 850 000 ha (4.2 %), competition between trees 340 000 ha (1.7 %), human activities, including harvesting damage 110 000 ha (0.6 %).

The report of the Airborne Imaging Spectrometer (AISA) in Forest Inventory and Forest Health Monitoring project was completed and sent to the European Commission in 1998 (Tomppo et al. 1998), and the summary is presented in Tomppo et al. (1999). The damaging agents selected for the study were a) air pollution damage on Scots pine around the Cu-Ni smelter at Harjavalta, SW Finland, b) the pine bark bug, *Aradus cinnamomeus* (Panzer) on young Scots pine, c) defoliation of Scots pine caused by the European pine sawfly, *Neodiprion sertifer* (Geoffr.), and d) all forms of damage found in a test area in southern Finland in order to test the use of AISA images in large-scale forest inventories. The estimation of needle biomass was also tested. The study demonstrated that airborne remote sensing based on the AISA instrument does have a potential in forest health monitoring, and that Landsat TM images are powerful tools in identifying damage over large areas. The proportion of correctly classified observations in the test material in the Harjavalta area, for instance, varied between 85–95 %, and Landsat TM gave even better results. The studied damage areas were mostly small-scale ones that also contained some undamaged patches, whereas the areas (except for Harjavalta) corresponded to normal Finnish forests. There were problems in finding slight cases of damage, especially when only a small proportion of the trees were affected by damage. The needle biomass estimation showed that the biomass could be assessed even more accurately, at least on the pixel level, than the tree stem volume.

The aim of this study was to continue the development of methods for monitoring forest

Table 1. Forest damaging agents and their severity according to the 8th NFI and its update (1989–1994).

	1000 hectares													
	Degree of damage													
Damaging	Light		Observable		Severe		Total		Multiple damage		No damage		Total	
Agent	area	%	area	%	area	%	area	%	area	%	area	%	area	%
Unrecognised	852	4.3	755	3.8	90	0.4	4	0.0	.	.	.	.	1700	8.5
Wind	198	1.0	171	0.9	40	0.2	7	0.0	.	.	.	.	416	2.1
Snow	255	1.3	404	2.0	77	0.4	2	0.0	.	.	.	.	738	3.7
Other abiotic	220	1.1	277	1.4	73	0.4	8	0.0	.	.	.	.	579	2.9
Competition	181	0.9	107	0.5	7	0.0	.	.	.	.	.	.	295	1.5
Human activities	150	0.8	102	0.5	10	0.1	.	.	.	.	.	.	262	1.3
Moose	242	1.2	234	1.2	45	0.2	4	0.0	.	.	.	.	524	2.6
Other animals	117	0.6	52	0.3	6	0.0	1	0.0	.	.	.	.	176	0.9
Resin top disease	277	1.4	163	0.8	28	0.1	.	.	.	.	.	.	468	2.3
Scleroderris canker	740	3.7	216	1.1	22	0.1	2	0.0	.	.	.	.	981	4.9
Rot fungi	165	0.8	494	2.5	136	0.7	5	0.0	.	.	.	.	800	4.0
Other fungi	380	1.9	299	1.5	69	0.3	2	0.0	.	.	.	.	751	3.8
Multiple damage									302	1.5			302	1.5
No damage											11728	58.6	11728	58.6
Total	3858	19.3	3467	17.3	638	3.2	3.7	0.2	302	1.5	11728	58.6	20030	100.0

damage with an imaging spectrometer. The emphasis was placed on damage caused by the economically significant pathogens *Heterobasidion annosum* root rot on spruce and pine, and resin top disease caused by *Peridermium pini* (Pers.) Lev. and *Cronartium flaccidium*. The specific aims were:

1. To analyse the spectral properties of the canopies of trees affected by the pathogenic fungi *H. annosum* and *P. pini*, and to compare the spectral properties of these trees to those of healthy trees and to those growing under other major stress factors.

2. To develop image analysis methods for detecting trees infected by *H. annosum* and *P. pini* at early stages of the diseases.

3. To develop methods for integrating airborne disease monitoring as a part of the present multi-source NFI.

Heterobasidion annosum and *Peridermium pini* as damaging agents

Heterobasidion annosum

There are three intersterility groups (S, P and F) of *Heterobasidion annosum* in Europe. The S intersterility group of *H. annosum*, also known as *Heterobasidion parviporum* Niemelä & Korhonen, causes butt rot mainly on Norway spruce (*Picea abies*) in southern Finland (Korhonen 1978, Niemelä & Korhonen 1998). The P intersterility group of *H. annosum*, also called *Heterobasidion annosum* (Fr.) Bref. sensu stricto, specialises on Scots pine (*Pinus sylvestris*) and other *Pinus* species (Korhonen 1978, Niemelä & Korhonen 1998). It is most abundant in southeastern Finland (Laine 1976). The F intersterility group of *H. annosum*, also called *Heterobasidion abietinum* Niemelä & Korhonen, infects species of *Abies* with their distribution centre in the Mediterranean countries (Capretti et al. 1990, Niemelä & Korhonen 1998).

The decay caused by the S intersterility group may reach a height of more than ten metres without any external symptoms appearing in a living spruce (Tamminen 1985, Greig 1998). The symptoms, which indicate possible butt rot, include crown density, crown colour, resin exudation and butt swelling. The disease, however, cannot be distinguished with certainty by visual assessment (Greig 1998). A study conducted in Sweden indicated that personnel trained in forestry were only slightly more successful in assessing the incidence of butt rot in single trees compared with a randomly selected reference group (Vollbrecht & Agestam 1995). Observations of possible stem injuries and increment/age cores taken at a height of 1.3 meters, are utilised in the NFI to detect rot defects. Only 55–58 % of infected trees have been detected in this way (Tamminen 1985, Korhonen 1989).

The P intersterility group infects roots and the stem base, causing growth losses and mortality on pine (Laine 1976, Kurkela et al. 1978). In advanced stages of the infection, pine exhibits crown symptoms such as chlorotic and sparse foliage. In an infected pine stand, diseased trees typically occur in expanding centres, which include stunted, dead and fallen trees in various stages of decay (Laine 1976, Korhonen 1978).

During the 6th and 7th NFIs, supplementary studies have been conducted to determine the frequency of rot in southern Finland. In the eastern coastal regions of southern Finland and in the western archipelago, the proportion of decayed trees out of the total volume has been 20–30 % (Kallio & Tamminen 1974, Tamminen 1985). In other parts of southern and south-western Finland, the proportion of decayed spruces out of the total volume has been 8.6–18.5 % (Tamminen 1985).

H. annosum causes indirect and direct economic losses as a result of reduced quality and volume of timber and retarded growth of the diseased trees. The increased number of dead and windthrown trees results in increasing costs of sanitary measures, an increasing amount of decay in the next tree generation due to the presence of infected stumps and root

contacts, as well as shorter rotation periods (Bendz-Hellgren et al. 1998). The annual economic losses in Finland caused *by H. annosum* in *P. abies* and *P. sylvestris* are estimated to be 200 million FIM (35 million ECU) (Bendz-Hellgren et al. 1998).

Peridermium pini

Resin top disease caused by *Peridermium pini* (Pers.) Lev. and *Cronartium flaccidium* (Alb. Schw.) is common on Scots pine *(Pinus sylvestris)* throughout Fennoscandia. *P. pini* is an autoecious and *C. flaccidium* a host-alternating species. Despite this, however, they are genetically very closely related (Hantula et al. 1998). The main alternate hosts *of C. flaccidium* in Finland are *Vincetoxicum spp., Paeonia spp., Pedicularis palustris* and *Melampyrum spp.*, of which *Melampyrum spp.* is considered to be the most important (Kaitera et al. 1999).

In the 8th NFI and its update, 2.3 % (468 000 ha) of the forest land was affected by resin top disease. In a study conducted in connection with the 7th NFI in northern Finland, 2.5 % of 12 738 pines on 3700 sample plots were infected (Kaitera & Jalkanen 1995). The proportion of trees infected increased along with stand age: from 1.2–1.9 % in young stands to 4.5 % of the stands approaching final cutting (Kaitera & Jalkanen 1995). If stands are poorly managed the number of trees infected increases. The average proportion of infected pines typically reaches 3 % when more than 30 years have elapsed since the last thinning (Kaitera & Jalkanen 1995). In a study, conducted in northern Finland, the stem lesions caused by resin top disease reduced the saw timber volume by 34.3 % and the dead tops by 21.8 % (Kaitera et al. 1994). In an earlier study, 26 % of the Scots pines in the study areas were infected. The volume losses resulting from dead standing trees in the study areas were not included in the study. In some extreme cases, 80 % of the trees in old pine stands have been infected by *P. pini* (Kurkela 1994).

Materials and methods

The AISA Spectrometer

The Finnish Forest Research Institute (Metla) purchased an airborne imaging spectrometer (AISA, Airborne Imaging Spectrometer for Applications) in 1995. The instrument acquired was the first so-called pre-series AISA spectrometer delivered by the company Karelsilva. The AISA spectrometers are currently manufactured by Spectral Imaging, Ltd. (Specim) in Finland.

AISA is a low-cost imaging spectrometer that was designed from the very start for both research and operational work. It uses a CCD sensor matrix with 384 columns and 286 rows. The CCD sensor and the optical system limit the wavelength range, which for Metla's AISA is 450–870 nm. The row dimension of the CCD array is used for the spectral sampling, resulting in a basic spectral channel width of 1.6 nm. Up to five basic channels can be summed within the detector to make channels with a width of up to 8.0 nm. The columns of the CCD matrix are used to sample 384 adjacent spatial locations across the flight track. The field of view of the instrument is 21 degrees, resulting in a pixel width (IFOV) of one milliradian. An altitude of 1600 metres was used when collecting data for this study, resulting in a pixel width of 1.6 metres.

The tape recorder of the AISA can store 375 000 16-bit spectral samples per second. This is not enough to store all of the data available from the CCD. The instrument is programmable so that the user can select what information is stored on tape. In the spatial mode, all spatial pixels are stored but only at selected wavelengths. Five basic channels can be summed up within the CCD to form wider spectral channels and to increase the radiometric resolution. A spectral mode and a mixed mode are also available. In the spectral mode the complete 286 channel spectra are stored, but only at selected spatial locations. The mixed mode combines characteristics of the spatial and spectral modes.

The spatial data collection mode was used in this study. Two different spectral channel configurations were used, one consisting of 30 channels (Table 2, Fig. 1) and one consisting of 28 channels (Table 3).

The pixel dimension along the flight track is determined by the aircraft speed and the exposure time for each raw data row. For example, the nominal aircraft speed used in collecting the data for this study was 100 knots (about 51 m/s). The exposure time was 34 ms (28 channel configuration) or 37 ms (30 channel configuration), resulting in raw data pixel lengths of 1.73 or 1.90 metres.

When imaging a target site, the aircraft typically flies along a number of adjacent lines over the site and the image strips have to be combined into one geocoded image before use. The raw data numbers must also be converted into physical units, and the differences between the CCD cell characteristics must be corrected. This is done at Metla using software based on the GEOVIS system developed at VTT (Mäkisara et al. 1994b, Mäkisara et al. 1994a) and enhanced at Metla. The geometric processing uses all the navigation data available from the flight in order to make an initial approximation of the final image (differential GPS (DGPS) and angular velocity data are used at Metla). The geometric correction is then interactively refined by the operator until the required accuracy is obtained. A numerical map has been used as a reference in this refinement. The geometric processing can also use a digital terrain model (DTM). A DTM with a 25 metre pixel size was used in this study.

The radiometric correction performed on the data does not include any atmospheric correction. It transforms the raw data into units of *radiance as "seen" by the instrument.* Atmospheric correction was not necessary for the experiments in this study. Each experiment used only one image, and the atmospheric correction within the image would have been the same at all locations.

Table 2. The spectral channel configuration with 30 channels (Mäkisara et al. 1997).

Nbr	Centre	Width	Nbr	Centre	Width	Nbr	Centre	Width	Nbr	Centre	Width
1	470.1	7.3	9	599.8	7.3	17	710.5	4.6	25	803.2	4.6
2	487.6	7.3	10	623.1	7.3	18	725.7	7.6	26	818.4	4.6
3	505.1	7.3	11	646.7	7.6	19	733.3	4.6	27	844.2	4.6
4	522.6	7.3	12	668.0	7.6	20	742.4	4.6	28	853.3	4.6
5	541.5	7.3	13	675.6	7.6	21	750.0	4.6	29	860.9	4.6
6	550.2	7.3	14	686.2	4.6	22	775.8	4.6	30	865.4	4.6
7	564.8	7.3	15	696.8	4.6	23	784.9	4.6			
8	579.4	7.3	16	701.4	4.6	24	794.1	4.6			

Table 3. The spectral channel configuration with 28 channels (used in the Mäntsälä test area).

Nbr	Centre	Width	Nbr	Centre	Width	Nbr	Centre	Width	Nbr	Centre	Width
1	470.1	7.3	9	623.1	7.3	17	733.6	4.6	25	829.3	4.6
2	496.3	7.3	10	642.4	7.6	18	724.9	7.6	26	844.5	4.6
3	512.4	7.3	11	668.3	7.6	19	750.3	4.6	27	861.2	4.6
4	541.5	7.3	12	678.9	7.6	20	776.1	4.6	28	871.8	4.6
5	550.3	7.3	13	697.1	4.6	21	785.2	4.6			
6	564.8	7.3	14	701.7	4.6	22	794.3	4.6			
7	579.4	7.3	15	710.8	4.6	23	801.9	4.6			
8	599.8	7.3	16	727.5	4.6	24	817.2	4.6			

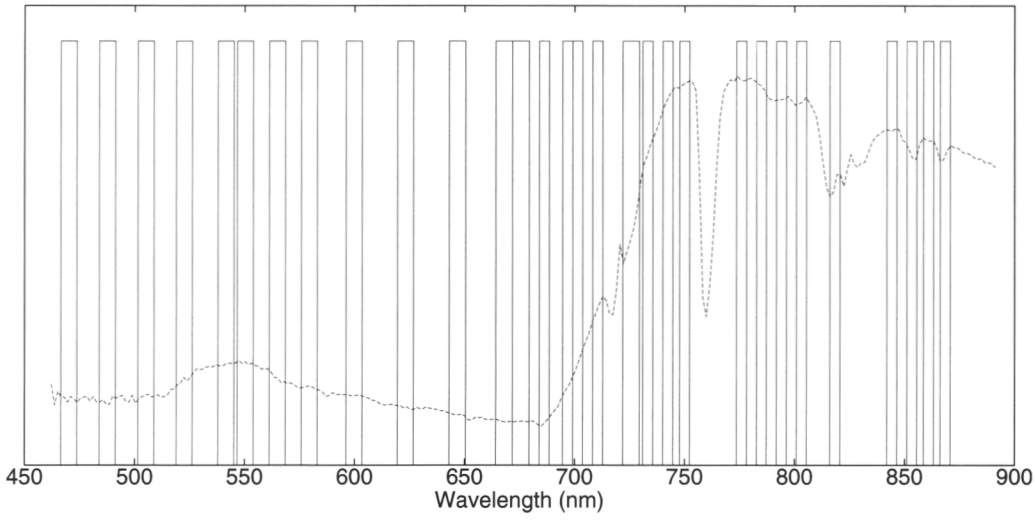


Figure 1. The spectral channel configuration with 30 channels together with a spectrum from vegetation (Mäkisara et al. 1997).

Heterobasidion annosum root rot on spruce

Ground Measurements

Four test areas were chosen in the study for analysing the spectral properties of Norway spruce affected by *H. annosum* (Table 4). The areas were located in Vantaa, Pornainen and Mäntsälä (Fig. 2).

All the test areas consisted of mature spruce-dominated stands, some of them with an admixture of broadleaved trees (mainly birch or aspen) and Scots pine. The measured stand level variables were similar to those of the NFI.

Two types of training areas, "infected" and "healthy", were selected at each test site. The training areas were subjectively chosen from those parts of the test areas where there were high (infected) and low (healthy) infection rates. As large homogeneous areas as possible were selected. The test areas were geo-referenced with a hand-held compass and a measuring tape using control points that were clearly visible on the AISA image. The estimated uncertainty of the ground control points compared to the image was in most cases 1–5 metres (2–3 pixels).

Infection by *H. annosum* was examined on the stump surfaces after the areas had been cut. The stumps of each tree in the training areas were recorded. A wood sample was taken aseptically with an increment borer from every spruce stump with visible signs of decay. The wood samples were placed on 2 % malt agar medium in Petri dishes in the laboratory. After 5–10 days' incubation, the plates were examined for growth of *H. annosum*. Based on the results of mating tests (Korhonen 1978), all the *H. annosum* strains isolated from the spruce stumps proved to belong to the S intersterility group.

Two infected areas and one healthy area were selected in the Ruotsinkylä test area. The proportions of infected trees were 85 % and 92 % in the infected training areas, and 15 % in the healthy reference area (Table 5). The size of the training areas in terms of 1.6 x 1.6 m pixels are given in Table 5.

Table 4. The test areas and their sizes.

Name	Municipality	Area (ha)
Ruotsinkylä	Vantaa	3.8
Seutula, Riipilä	Vantaa	8.2
Pornainen, Askola	Pornainen	2.8
Mäntsälä	Mäntsälä	3.0

Three infected and three healthy reference training areas were selected in the Seutula test area. The infection rate was 69–86 % of the stems in the infected training areas, and 3–24 % of the stems in the healthy areas (Table 6). The size of the areas varied from 140.8 m^2 to 256 m^2.

Three infected and two healthy training areas were selected in the Pornainen test area. The proportions of infected trees were 73–94 % in the infected training areas, and 0–6 % in the healthy areas (Table 7).

One infected area and two healthy areas were selected in the Mäntsälä test area. The infection rate of the infected training area was 86 % of the trees (Table 8), and in the healthy areas 6–11% of the trees.

Image Data

All the test areas except the Mäntsälä area were imaged on July 22, 1996. A channel configuration of 30 spectral channels (Table 2) was used in these areas. The Mäntsälä test area was imaged on July 1, 1997, using a channel configuration of 28 channels (see Table 3). The pixel size in the geocoded images was 1.6 x 1.6 m.

The spectral features of the training areas were extracted after radiometric and geometric correction of the image data. Spectral clustering was used before image analysis in order to identify tree pixels with various degrees of shading. This was done to minimise the influence of the varying canopy structures and stand densities. The ISODATA utility (ERDAS, 1997) with ten classes was applied. Field measurements from the training areas were assigned to spectral classes. The spectral means of these classes were analysed (Fig. 3).

The number of classes including spruce pixels of various degree of shading was 2–4 depending on the image and test area. Two or three classes were selected for analysis.

The classes were selected by a) visually comparing the AISA image and the overlay image created by ISODATA classification algorithm, b) studying the mean spectra of the classes, and c) studying the scatter plots with ISODATA classes in order to reveal possible overlapping of the classes. The main principle was to compare the scatter plots (with standard deviations of 1.0 and 2.0) and to exclude classes containing both tree and non-tree pixels.

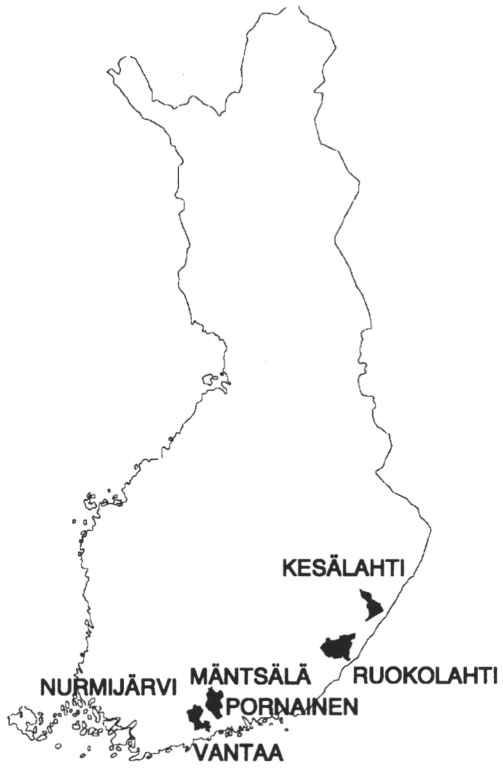


Figure 2. The municipalities in which the test areas of the study were situated.

The pixels with various degrees of shading were analysed both separately and together. The mean spectra, standard deviations and the normalised mean spectra of the infected and healthy training areas were compared. Normalisation was performed by dividing each channel of the mean spectrum s of either an infected or healthy area by the average of the values in the channel in question in the infected and healthy training spectra:

$$s_{i,normalised} = \frac{s_i}{(\bar{r}_i - \bar{i}_i)/2} \qquad (1)$$

where r_i is the mean spectrum of the healthy areas and i_i the mean spectrum of the infected

Table 5. Characteristics of the infected training areas and healthy reference areas in Ruotsinkylä.

Training area	Pixels	Area (100m^2)	Infected spruces (%)	Non-infected spruces (%)	Birch/pine (%)	Stems, total
1. Infected	131	3.35	92	8	-	25
2. Infected	295	7.55	85	15	-	55
3. Healthy	168	4.30	15	82	3/0	33

Table 6. Characteristics of the infected training areas and healthy reference areas in Seutula, Riipilä.

Training area	Pixels	Area (100m^2)	Infected spruces (%)	Non-infected spruces (%)	Birch/pine (%)	Stems, total
1. Infected	160	4.10	69	31	-	26
2. Infected	88	2.25	86	14	-	21
3. Infected	128	3.28	84	10	6/0	31
4. Healthy	147	3.76	3	97	-	24
5. Healthy	112	2.87	24	76	-	37
6. Healthy	147	3.76	21	79	-	32

Table 7. Characteristics of the infected training areas and healthy reference areas in Pornainen, Askola.

Training area	Pixels	Area (100m^2)	Infected spruces (%)	Non-infected spruces (%)	Birch/pine (%)	Stems, total
2. Infected	166	4.25	94	4	-	24
3. Infected	99	2.53	92	6	-	12
5. Infected	240	6.14	73	22	4/0	45
1. Healthy	134	3.43	-	100	-	27
4. Healthy	209	5.35	6	94	-	32

Table 8. Characteristics of the infected training areas and healthy reference areas in Mäntsälä.

Training area	Pixels	Area (100m^2)	Infected spruces (%)	Non-infected spruces (%)	Birch/pine (%)	Stems, total
3. Infected	228	5.84	86	14	-	42
1. Healthy	61	1.56	11	67	0/22	9
2. Healthy	77	1.97	6	82	0/12	17

areas. Normalisation was also carried out by dividing the mean spectra by a selected channel or function of channels. However, these procedures did not provide much new information.

Heterobasidion annosum root rot on pine

Ground Measurements

The Ruokolahti test area was chosen for analysing the spectral properties of Scots pine canopies affected by *H. annosum* root rot (Fig. 2). The test area was the largest in this research project, and contained several Heterobasidion-infected stands of different development class. However, due to the shadows of clouds over some parts of the area (see Section 2.3.2), the field work had to be restricted to the cloud-free parts of the area.

The main criterion in choosing the training areas was to find homogeneous, pure pine stands with as high a rate of *H. annosum* infection as possible. The training areas in the sunny parts of the AISA image consist of two mature pine stands in which the infection was defined in two different ways. In training areas 1), 2) and 3) (Table 9) the infection was identified from the star-shaped resin formations on the stump surfaces after felling of the stand. The infection rate in the "infected'' training areas was 56–75 % of the stems, and in the "healthy'' area 18 % of the stems.

In training areas 4) and 5), infection was determined on the standing trees (Table 9). No infected trees occurred in training area 5), and was therefore selected as a healthy area. Training area 4) contained a group of trees killed or defoliated by *H. annosum*. The infection rate was 26 % of the stems. Infection was identified by visual inspection and the external appearance of the pines. 78 % of all the infected trees were dead, and the rest heavily defoliated. No borings or pure culture isolations were made. The "infected'' and healthy areas in these two mature stands were combined in order to obtain as large training areas as possible.

The training areas in the shadowy parts of the Ruokolahti test area were selected from one stand. Two infected training areas were established around groups of trees that were dying or already dead. The healthy part of the same stand acted as the reference area. The infection rates in the "infected'' training areas were 34 and 78 % of the stems (Table 10), and in the healthy area 2 % of the stems.

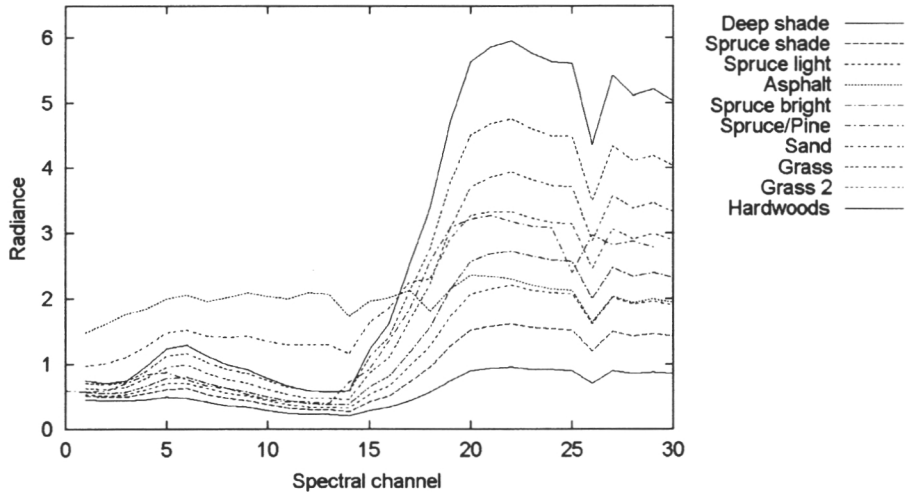


Figure 3. The spectral means of the 10 ISODATA classes at Ruotsinkylä.

Table 9. Characteristics of the infected training areas and healthy reference areas in sunny (cloud free) parts of the image at Ruokolahti.

Training area	Pixels	Area (100 m²)	Infected pines (%)	Non-infected pines (%)	Birch/pine (%)	Stems, total
1. Infected	54	1.38	75	25	-	8
2. Infected	145	3.71	56	44	-	16
4. Infected	189	4.84	26	71	3/0	35
3. Healthy	167	4.28	18	82	-	17
5. Healthy	111	2.84	0	100	-	15

Table 10. Characteristics of the infected training areas and healthy reference areas in shadowy parts of the image at Ruokolahti.

Training area	Pixels	Area (100 m²)	Infected pines (%)	Non-infected pines (%)	Birch/pine (%)	Stems, total
1. Infected	219	5.61	34	57	9/0	56
3. Infected	57	1.46	78	22	-	9
2. Healthy	270	6.91	2	90	8/0	48

Image data

The Ruokolahti test area was imaged on July 24, 1996. During the imaging flight, clouds started to gather near the test area and the cloud shadows extended into the test area. The actual coverage of the shadows was determined during image rectification. The channel configuration with 30 channels was used (Table 2). The pixel size in the geocoded images was 1.6 x 1.6 m.

Methods for reducing the effect of shadows on the AISA images have been developed and tested in another Metla research project "Airborne Imaging Spectrometer (AISA) in Forest Inventory and Forest Health Monitoring'', also financed by the European Commission. The results obtained with these methods were not acceptable and another approach was chosen. The Ruokolahti image was classified into 10 classes using the ISODATA utility (ERDAS 1997). The number of iterations was 15.

The 10 classes were further divided into two parts using visual interpretation of the image and prior knowledge of the region. Classes 1–4 were mainly located in the sunny parts of the area, and at least part of classes 3–10 in the shadowed parts. Classes 3 and 4 were included in both categories in order to be able to handle correctly the heterogeneous regions at the borders of the shadowed regions. These regions were mixed, with the deepest shadows inside the canopies of the sunny parts of the image. However, the training areas of both the sunny and shadowy parts of the image were located in the homogeneous parts of the image where the illumination was constant. This overlap of classes was therefore not considered to cause any problems.

The sunny and shadowy parts of the image were further classified with ISODATA. The number of classes was set to 10 and the number of iterations to 15. The results of these two classifications were assigned to spectral classes using visual interpretation of the AISA image, prior knowledge of the region, and field measurements from the training areas.

The pine pixels belonging to the classes of further interest were extracted from the original AISA image. The spectral means, standard deviations and various normalisations of the infected and healthy training areas were studied.

The normalisation in Equation (1) also proved to be best in this case.

Based on preliminary tests, only the directly illuminated parts of the test area were selected for further analysis. Non-parametric discriminant analysis with the Mahalanobis distance was used as discriminant criterion to classify the observations of the infected and healthy training areas. The squared Mahalanobis distance between two observation vectors x and y is given by

$$D_t^2 = (x-y)' C^{-1} (x-y) \qquad (2)$$

where C is the covariance matrix of the spectral vectors.

The estimate of the posterior probability of observation x belonging to class j is

$$p(j|x) = m_j(x)\,p(j) / \sum_k m_k(x)\,p(k) \qquad (3)$$

where $m_k(x)$ is the proportion of (training) observations in class k, which are the nearest neighbours of x (SAS Institute Inc., 1989). Equal prior probabilities $p(j)$ were used. The experiment was performed as cross-validation.

Peridermium pini

Ground Measurements

Three test areas in southern and south-eastern Finland were selected for analysis of the spectral properties of Scots pine infected by *P. pini*. One test area was in Nurmijärvi and the two others, Rasti 1 and Rasti 2, were located in Kesälahti (Fig. 2).

Five other test areas infected by *C. flaccidium* in northern Finland were originally intended to be used, but they were rejected on the basis of the results of the "Airborne Imaging spectrometer (AISA) in Forest Inventory and Forest Health Monitoring'' project. Stands with a similar, young growing stock and a sparse canopy structure did not show any promise in distinguishing forest damages with the AISA spectrometer.

The Nurmijärvi test area consisted of mature pine stands from which the *P. pini*-infected trees were not removed in the thinnings. This area well represents mature pine stands in South Finland with heavy infection by *P. pini*. The damage in the stand is mainly evident as a) dead trees, b) trees with the top of the crown dead, and c) cankers in the trees. The damage can be considered old damage, because it has remained in the stand for years. The resistant, healthy trees can be distinguished from infected ones rather easily. The infection rate in the "infected'' training areas was 30–68 % of the stems, with an average infection rate of 40 %. There was no infection in the healthy areas.

The Kesälahti test areas, Rasti 1 and Rasti 2, were both young Scots pine thinning stands with a fresh infection of *P. pini*. In Rasti 1, the training areas were located and measured in mid June when the current year's infection of the branches was not yet visible in the canopies. The symptoms of the infected parts of the stand were mainly a) dead trees, b) top of crown dead, c) cankers and only a few branches killed the previous year. In the Rasti 1 test area, there were three "infected'' training areas and two "healthy'' areas. The infection rate in the "infected'' training areas was 34–56 % of the stems, with an average infection rate of 47 %. The infection rate in both healthy areas was 13 % of the stems.

The training areas in the Rasti 2 area were located and measured in mid July. At this time, orange-yellow aecidial pustules of *P. pini* had already matured, and were no longer visible at the time of the field work. However, a fresh infection of the tops of the branches was clearly visible as browning. This affected the damage appearance classification to the extent that the most common damage class was "dead/dying branches'', the tree being classified as such when browning was observable in several branches. Dead trees, dead crown tops and cankers caused by the fungus were in a minority, but kept in mind as the training areas were chosen in this test area. The infection rate in the "infected'' training areas was 38–56 % of the stems, with an average infection of 45 % of the stems. The infection in the healthy areas was 3 % of the stems.

Image Data

The Nurmijärvi, Solttila, test area was imaged on July 22, 1996 and the Kesälahti test areas on July 24, 1996. The channel configuration with 30 spectral channels (Table 2) was used. The pixel size in the geocoded images was 1.6 x 1.6 m.

The spectral features of the training areas were extracted after preprocessing the image data. The spectral means of the training areas, as well as standard deviations and normalisations of the spectral means, were calculated. As expected, ground reflectance was found to have an effect on the spectral features of the canopies of young thinning stands in the Kesälahti test areas. The same methodology as that used with *H. annosum* was applied to minimize the influence of varying canopy structures and stand densities in Nurmijärvi and Kesälahti. The division of the canopies into different shade classes was also applied.

The ISODATA utility (ERDAS 1997) was used to pre-classify the AISA image of each test area globally into 10 classes. The number of iterations was set to 15. The result of classification was assigned to spectral classes using visual interpretation of the AISA images, as well as prior knowledge of the test areas and field measurements of the located training areas.

The pine pixel classes were selected for further study by a) visually comparing the AISA image and ISODATA classification, b) studying the mean spectra of the classes and, c) studying the scatter plots with an overlay of the classes, in order to reveal possible overlap of the classes. The effect of incompletely closed canopies became apparent when the spectra of the mature pine stand in Nurmijärvi and the young thinning stands in Kesälahti were compared. Especially in Rasti 1 and Rasti 2 test areas, the scatterplots revealed pixels containing both trees and ground.

Three shade classes of pine pixels were extracted from the Rasti 1 AISA image, and four classes from the Rasti 2 image. Four shade classes were extracted from the AISA image from Nurmijärvi.

The spectral means, standard deviations and various normalisations of the mean spectra for infected and healthy training areas were calculated. The normalisation used was (1). Non-parametric discriminant analysis and the Mahalanobis distance were used to determine the discriminant criterion in order to classify the observations of infected and healthy training areas (equations (2) and (3)). Cross-validation was applied.

Results

Heterobasidion annosum root rot on spruce

The possible effects of *H. annosum* root and butt rot on the spectral characteristics of Norway spruce were analysed. The distributions of the infected and healthy training areas were examined first. The purpose of this was to determine whether the infected and healthy areas could be identified in a simple manner without stratifying the pixels into tree pixels (with different shading classes) and ground pixels. However, we found that tree pixels and ground pixels have to be separated, and tree pixels further divided into different classes according to the degree of shading.

Two classifications were used for the tree pixels: either the two classes "shade'' and "light'', or the three classes "shade'', "light'' and "brightness''. Tree pixels were also analysed separately, but this did not produce any new information about the radiances of the healthy and the infected areas.

The mean spectra of the infected training areas in Ruotsinkylä and Seutula were at a higher level in the visible region than those of the healthy areas. The greatest differences in the normalised mean spectra occurred in the visible region, and the differences were smaller in the near-infrared region. However, the standard deviations were much larger than the differences in each channel.

The mean spectra and the normalised mean spectra in the Pornainen and Mäntsälä test areas were different from those in Ruotsinkylä and

Seutula. In the visible region, the differences between the mean spectra of the infected and healthy training areas were very small. Neither were there any major differences in the near-infrared region. The normalisations showed that the spectral regions where the greatest differences occurred were in completely different regions of the spectra. These results indicate that further analysis with larger data sets is required in order to be able to distinguish the signs of *H. annosum* infection from the stand-wise variation in reflectance from the canopies.

Especially in the Pornainen test area, differences were expected as a result of the distinct difference in the rate of infection between ''infected'' and "healthy'' training areas. Comparison of the spectra and normalised spectra of the infected and healthy training areas showed that the differences in the channel-wise means were small compared to the channel-wise standard deviations. It was not possible to classify the image into infected and healthy pixels. It was concluded that *H. annosum* root rot on spruce does not affect the tree vitality in such way that it would be visible in the spectrum of the trees as determined by the AISA spectrometer.

Heterobasidion annosum root rot on pine

The possible effects of *H. annosum* on the spectral characteristics of Scots pine were analysed in the Ruokolahti test area. The training areas were located separately in the sunny and shadowed parts of the image. Unsupervised classification of the image was performed in two phases using the ISODATA algorithm. The first phase divided the image of the test area into two classes, with some overlap. The resulting classes were further classified separately in the second phase. The final goal was to classify the tree pixels into different shade classes (shading caused by trees) in both the sunny and shaded parts of the image.

The distinction between infected and healthy training areas was clear in the sunny parts of the Ruokolahti image, whereas in the shaded parts of the image the mean spectra of the infected and healthy training areas were almost equal. The normalised means and standard deviation of these training areas supported the conclusion that the differences in spectra between infected and healthy trees were small.

The mean spectra of the trees of the infected training areas in the sunny parts of the image were at a lower level at all wavelengths. The clearest distinction between the infected and healthy training areas occurred in the visible region, especially in the red region.

The overall differences between the radiances of infected and healthy trees gave some hope for the reliable detection of infected trees. Non-parametric discriminant analysis with Mahalanobis distance was applied. Each observation was classified correctly in the training phase. The results of the cross-validation classification were successful (Table 11). Almost 83 % of the observations in the healthy areas were correctly classified. The rate of correctly classified observations of infected training areas was 91 %.

Peridermium pini

The possible effects of *P. pini* on the spectral characteristics of Scots pine were analysed in a similar manner as the effects of *Heterobasidion annosum* on spruce and pine. The mean spectra, normalised mean spectra, and standard deviations of the radiance values of infected and healthy training areas were calculated for tree pixels.

The mean spectra of the infected training areas were at a higher level in the visible region than those of the healthy areas in every test area (Fig. 4). The normalised mean spectra showed that the greatest differences between the infected and healthy areas occurred in the red light region. However, the differences varied to some extent between the test areas. They were slightly higher in the blue region than in the green region. No clear distinction could be found between the infected and healthy areas

Table 11. Error rate estimates from the cross-validation classification of the infected and healthy training areas (equal priors).

	Healthy	Infected	Total
Ruokolahti (sunny part)	0.1707	0.0871	0.1289
Nurmijärvi	0.2837	0.0645	0.1741
Kesälahti, Rasti 1	0.1000	0.0333	0.0667
Kesälahti, Rasti 2	0.1296	0.0389	0.0843

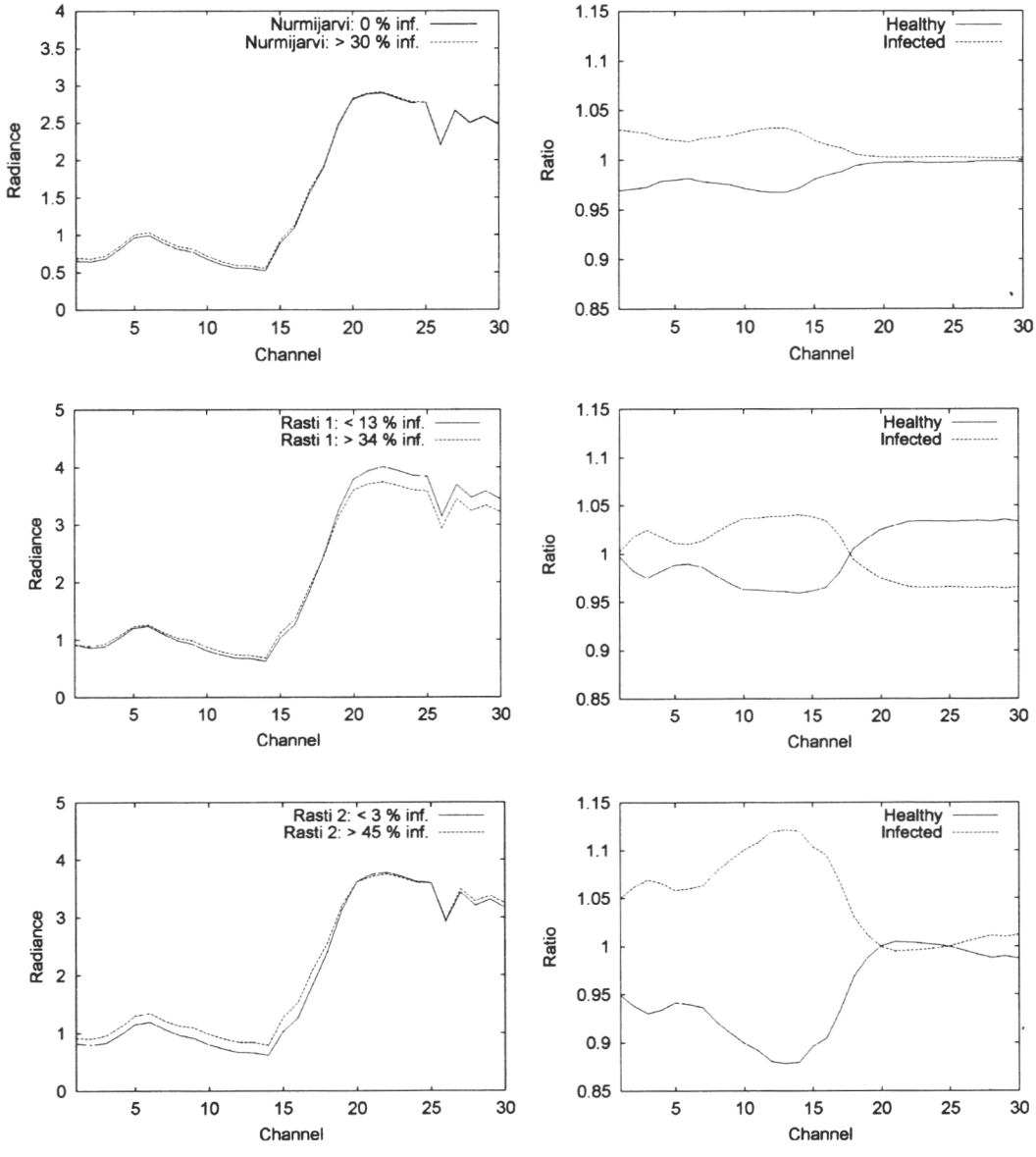


Figure 4. Mean spectra of the infected and healthy training areas (left) and the normalisation of the means (right): Nurmijärvi, Rasti 1 and Rasti 2.

in the near-infrared region. The channel-wise differences between the infected and healthy areas were, in terms of the standard deviations, rather small in each test area (Fig. 5). The higher radiance values of the infected trees in the visible region indicated that infected and healthy trees could be separated on the basis of AISA data.

Non-parametric discriminant analysis with Mahalanobis distance and cross-validation criteria was applied to classify all the training area pixels. Each observation was classified correctly in the training phase. In the Nurmijärvi test area, 72 % of the healthy observations and 94 % of the infected observations were correctly classified (Table 11). In the Rasti 1 test area, 90 % of the healthy observations and 97 % of the infected observations were correctly classified (Table 11). In the Rasti 2 test area, 87 % of the healthy observations and 96 % of the infected observations were classified correctly (Table 11).

Conclusions

The possibilities of detecting decreased tree vitality and damage caused *by Heterobasidion annosum* on Norway spruce *Picea abies* (L.) Karst. and Scots pine *Pinus sylvestris* L., as well as *P. pini* on Scots pine, by means of airborne spectrometer data were studied. The aim was to analyse whether it would be possible to integrate airborne monitoring of these diseases as part of the current satellite-image aided Finnish national forest inventory. Field measurements of the inventory already produce information about the extent and severity of the most important damaging agents. The goal was to improve the possibilities of recognising early damage symptoms, and to develop cost-efficient methods for surveying susceptible areas. The methods could probably also be applied outside Finland.

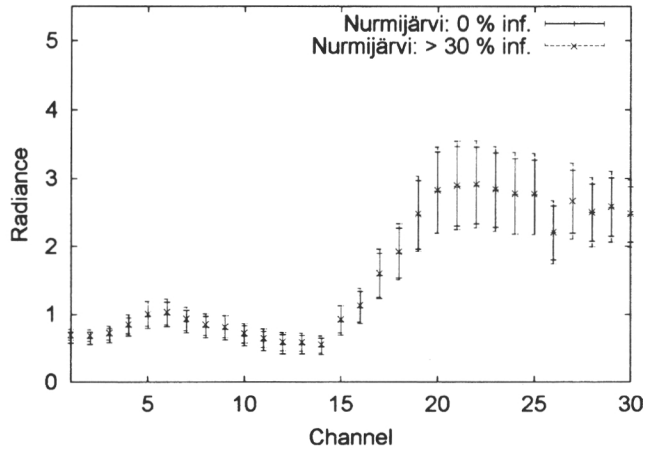
Four test areas with *Heterobasidion annosum* on Norway spruce, one with *Heterobasidion annosum* on Scots pine, and three with *P. pini* on Scots pine were used. The test areas were further subdivided into infected and healthy areas based on field measurements. Threshold values were used for the proportions of infected trees. Each test area was imaged once, most of the areas in 1996 and one in 1997. The test area for *Heterobasidion annosum* on Scots pine was partly covered by cloud during the imaging. Earlier studies with an AISA spectrometer were utilised in selecting the imaging configuration and image channels, as well as in geometrical rectification and preprocessing of the data.

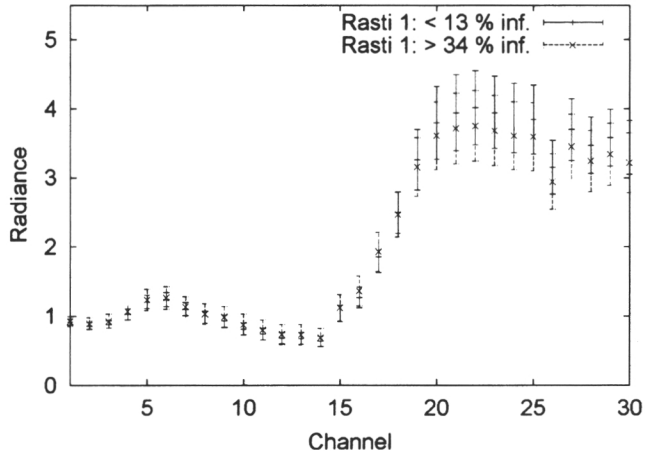
Tree pixels were separated from ground pixels in order to enable analysis of possible changes in the spectrum of the trees resulting from a decrease in vitality. Spectral clustering was applied to the image data of tree pixels in order to classify the pixels into different shadow classes. This was necessary because the variation in the radiance of the tree pixels caused by shadows was higher than the variation caused by other factors.

The spectra and normalised spectra of infected and healthy trees were compared together with the channel-wise standard deviations of the radiance. A non-parametric discriminant analysis with Mahalanobis distance was used to classify the infected and healthy pixels. Cross-validation criteria were applied.

Analysis of the spectra of the root and butt rot caused by *H. annosum* in Norway spruce in four test areas showed that there were no unique regions in the spectra where infected and healthy trees had different radiance. The spectra were different in the visible region in two test areas (Ruotsinkylä and Seutula), in the near-infra-red region in one test area (Mäntsälä), and there were no major differences in one test area (Pornainen). This indicates either that there are factors other than root and butt rot which cause variation in the radiance of trees, or that this type of damage cannot be detected with airborne imaging spectrometer operating in the wavelength region used in this study. The results of the most representative test area, Pornainen, may support the former conclusion.

The spectra of pine trees affected by *H. annosum* root rot differed from those of healthy trees in the visible region, especially the spectra





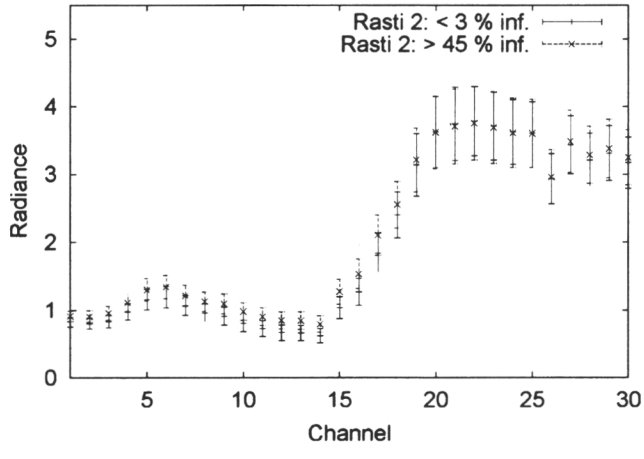


Figure 5. Mean spectra and standard deviations of the infected and healthy training areas in Nurmijärvi and Kesälahti (Rasti 1 and Rasti 2).

of the sunny pixels. A non-parametric discriminant analysis also gave good separation of the pixels of healthy and infected trees. The proportions of correctly classified pixels were 83 % and 91 % for healthy and infected areas, respectively. According to this experiment, detection of *H. annosum* root rot on pine is possible using AISA images. One should note, however, that only one test area was used for this damage assessment, and additional tests are necessary.

The damage caused by *P. pini* were seen as changes in the spectra in the visible region, especially in the red region. The mean spectra were partly affected by reflectance from the ground in younger development classes. The proportions of correctly classified healthy pixels with a non-parametric discriminant analysis varied from 72 to 90 % and for infected pixels from 94 to 97 %. Detection of *P. pini* in pine stands using AISA images therefore appears to be promising.

The study showed that the detection of *H. annosum* root rot and *P. pini* on pine are possible with the images from an AISA imaging spectrometer. As for the spectra of spruce affected *by H. annosum*, final conclusions can only be made after the analysis of additional test areas containing different stages of damage with several images of the test areas. The study showed, however, that the effect of *H. annosum* on the spectra of spruce was much smaller than expected.

The behaviour of the spectra of the trees in the infected test areas was more complicated than expected, and the differences between healthy and infected areas also smaller. The creation of an operative method for use in the multi-source national forest inventory was not possible in this stage. Further tests and methodological development are needed.

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6 Biotic and abiotic forest damage in 1999

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Introduction

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

Abiotic damage

Trees were broken by the snowstorm in February, especially in Länsi-Uusimaa (area 1, in Fig. 1) and along the south coast. These regions do not usually have much snow in the winter, and the trees are therefore not used to carrying heavy loads of snow. Storm damage in June was the worst in the same parts of Etelä-Savo (area 10) as during the previous summer. There were no reports during the summer of associated damage in the areas affected by snow and storm damage.

The leaves on broad-leaved trees started to turn prematurely yellow in the driest areas already in July. Scots pine shed the oldest needle age class exceptionally early, in some areas already at the start of August, as a result of the combined effects of drought and the dry summer. The effects of the drought in summer 1999 on Norway spruce may not become apparent as an increase in individual-tree or group mortality until summer 2000. In most cases tree mortality is a result of the combined effects of drought and attack by the spruce bark beetle (*Ips typographus*) and six-toothed spruce bark beetle (*Pityogenes chalcographus*).

Insect damage

The dry, warm weather in the summer was especially favourable for the development of the pine sawfly (*Diprion pini*) because there was a considerable increase in the area affected by the mass outbreak that has continued for the third year running. Needle damage of varying severity occurred in a broad zone extending from Pohjois-Karjala (area 12), via Etelä-Savo (area 11) and Keski-Suomi (area 13), to the southern parts of Pohjanmaa (area 17) and Kainuu (area 18). There was also a local outbreak in Satakunta (area 4). The most severe damage occurred in seed-tree areas, on the edges of clear-cut areas, and in recently thinned stands. However, the only reports of tree death were restricted to a few seed-tree areas. If the damage continues as severely in the same areas during summer 2000, recovery of the trees will be threatened. The over-wintering of populations in the ground, which in some areas are present in rather high numbers, should therefore be followed. A clear increase in numbers of the bordered white moth (*Bupalus piniarius*) was reported in areas affected by pine sawfly damage.

Relatively restricted outbreaks of the European pine sawfly (*Neodiprion sertifer*) occurred in parts of Etelä-Savo (area 10) and in the archipelago of SW Finland.

As was the case in 1998, the spruce bark beetle (*Ips typographus*) and six-toothed spruce bark beetle (*Pityogenes chalcographus*) killed groups of spruce on sites susceptible to drought. Aphids (*Aphidae*), the gregarious spruce sawfly (*Pristiphora abietina*) and larch sawflies

(*Pristiphora* spp.) occurred in greater numbers in some areas.

Larvae of the northern winter moth (*Operophtera fagata*), and to a lesser extent also those of the winter moth (*O. brumata*), again completely defoliated birches in early summer along the south-west coast. However, the trees were able to produce new leaves at the end of the summer. Damage also occurred inland, for instance at Huittinen in Satakunta (area 4) and at Hyvinkää in Uusimaa (area 1).

Fungal damage

The dry summer reduced the rust fungi epidemics that had affected all the commercially important tree species in 1998, and rust fungi epidemics no longer affected large areas. Rust fungi epidemics do not usually kill trees, but when severe outbreaks occur in successive years there is a deterioration in tree condition. The crown dieback on downy birch (*Betula pubescens*) in SW Lapland (area 19) was most likely due to a reduction in tree condition resulting from an outbreak of birch rust (*Melampsoridium betulinum*) and the exceptionally severe freezing temperatures in winter 1998/99.

After the wet summer in 1998, there were fears that damage caused by pine canker (*Gremmeniella abietina*) would spread during 1999. Slight signs of the disease, i.e. browning of the youngest needle age class and bud mortality, appeared in early summer especially in young pine stands in parts of South Finland. However, the dry, warm summer effectively stopped the spread of the disease, and no

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 / Lapland
20 Ahvenanmaa

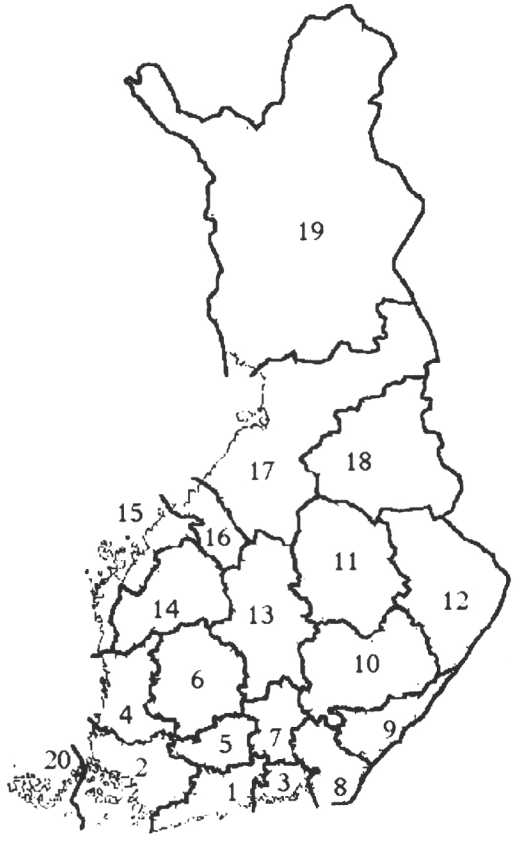

Figure 1. The provinces of Finland.

extensive cases of damage are to be expected next summer.

The weather during summer 1999 did not favour the spread of any of the other more regularly occurring fungal diseases. However, the light epidemic of *Lophodermella* needle cast (*Lophodermella sulcigena*) continued in the northern parts of Keski-Suomi (area 13) and Pohjois-Savo (area 11) and in different parts of South and Central Lapland. The regularly occurring epidemics in seedling and young pine stands growing on fertile sites in these areas are no longer as pronounced as those observed earlier.

Moose damage

According to the damage estimates drawn up by the forestry centres, moose and deer damage in seedling stands reached record proportions. The estimated compensation for an affected area of almost 7 000 ha exceeded FIM 23 million. The damage per 1 000 ha was greatest in the areas of the coastal, south-west and Häme-Uusimaa forestry centres. The damage in Lapland was also relatively high. The increase over the preceding year was the greatest (over 10 x) in Lapland and Kainuu. The damage in the areas of the coastal and SW Finland forestry centres was correspondingly 6- to 7-fold, and elsewhere 2- to 4-fold. The reason for this is assumed to be the unexpectedly sharp increase in the moose population resulting from the too-low hunting quotas, the over-large moose densities in relation to the forest area, and the lack of control measures.

Summary

In 1999, the pine sawfly (*Diprion pini*) caused damage in extensive areas of forest. The larvae ate the needles of Scots pine over a wide zone extending from Pohjois-Karjala (area 12), through Pohjois-Savo (area 11) and Keski-Suomi (Area 13), to the southern parts of Pohjanmaa (area 17) and Kainuu (area 18). There was also a local outbreak at Harjavalta in Satakunta (area 4). Growth disturbances in the crowns of Norway spruce over an estimated area of about 100 000 ha in Pohjois-Savo (area 11), and the crown dieback in downy birch (*Betula pubescens*) in Lounais-Lappi (area 19), caused concern in forestry circles. These outbreaks of damage were not observed in the annual forest condition inventory on permanent sample plots. According to the inventory, there were no changes in the degree of needle loss in these areas.

Snow, storms and drought caused visible damage, and in some areas the damage was severe. No extensive outbreaks of fungal damage were observed during 1999.

According to the damage estimates carried out by the forestry centres, moose and deer damage to seedling and young stands reached record proportions.

7 Forest health monitoring in the national forest inventory of Finland

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Introduction

The National Forest Inventory (NFI) is nowadays a system for monitoring timber resources, forest health and vitality and forest biodiversity throughout the whole country. Finland's forests were inventoried for the first time in the 1920's, and the inventories have been subsequently repeated at intervals of about 10 years. The most recent nation-wide inventory (the 8th NFI) was carried out during 1986–1994. The 9th NFI was started in 1996, and it is expected to have covered the whole country by the year 2003.

The main purpose of the NFIs has been to estimate the volume and growth of the growing stock and the cutting potential. During the past decades, however, additional aims have become important. Measures and descriptions of biological diversity, soil properties and forest damage are nowadays more detailed.

From the very start the NFIs have been sample-based inventories. In the 9th NFI the sampling unit comprises systematically located, sample plot clusters. The shape and size of the clusters, and the distance between them, vary in different parts of the country. In the southernmost part of Finland the clusters consist of two lines, set at right angles to each other, containing a total of 14 sample plots (Fig. 1). The clusters are located at spacings of 6 km, with a distance between adjacent plots of 250 m. The sample plots in every fourth cluster are permanent plots, the others being temporary plots. In the 8th NFI a total of 70 000 plots were measured throughout the whole country (Tomppo et al. 1997). In the 9th NFI there will be slightly less plots because the sampling design has been rationalised.

The NFI plots are restricted relascope sample plots. The trees belonging to the plot are selected using a relascope: the maximum distance of the trees belonging to the plot from the centre point is 12.52 m. A number of characteristics such as tree species, diameter and quality class are determined on all the trees belonging to the plot. Every 7th tree is estimated or measured in more detail, e.g. height, diameter at 6 m height, lengths of the timber assortments in the stem, and damage. An increment core is also taken from sample trees, the age and annual growth being determined in the laboratory. A large number of site and stand parameters are recorded about the stand compartments containing trees belonging to the plot. In the 9th NFI damages are therefore recorded at both the tree and stand level.

At the tree level, the form, causal agent, time of occurrence and severity of the major cases of damage are recorded. The form of the damage can be e.g. a dead standing tree, a fallen or broken tree, rot in a tree, stem injury, needle loss etc. Distinction is drawn between damage that has ceased or is still continuing, and the estimated starting time of the damage is recorded. The main groups of causal agents are abiotic factors, human activities, animals, fungi and competition between trees. Animals causing damage are further classified as voles, moose or deer, other unnamed vertebrates, bark beetles (*Tomicus* spp.), the pine weevil (*Hylobius abietis*), the pine sawfly (*Diprion pini*),

other needle damaging agents, spruce bark beetle (*Ips typographus*) and other unidentified insects. Unidentified causes of damage are also recorded. The total number of identifiable causal agents is 29. The effect of the damages on tree vitality and timber quality is estimated using a quality scale. The degree of needle loss is also estimated.

Damage at the stand level is recorded using the same variables as at the tree level. However, the degree of needle loss is not estimated at the stand level. In contrast, the mean coverages of beard lichens (*Alectoria, Bryoria, Usnea* spp.), leaf lichens (*Hypogymnia, Parmelia, Pseudevernia* spp.) and *Scoliciospermum clococcum* and *Desmococcus olivaeus* on the tree trunks is estimated on the permanent sample plots.

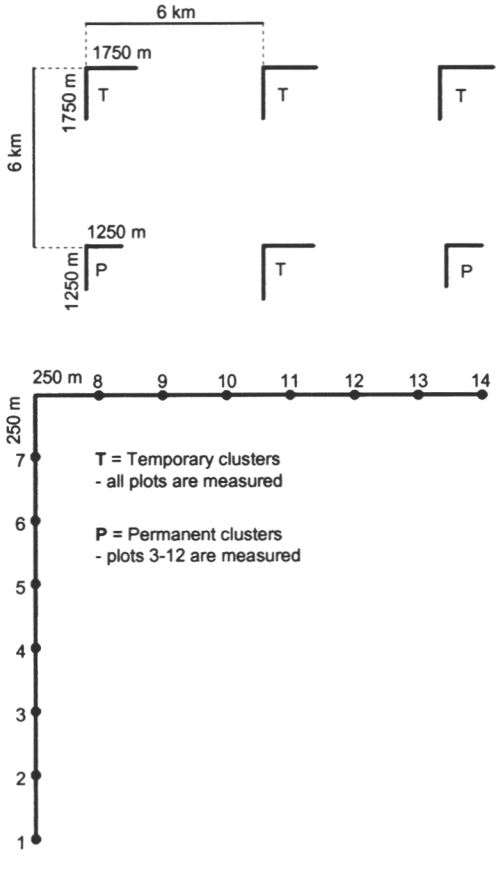

Figure 1. The NFI sampling design in southernmost Finland.

Results and discussion

The results of the inventory are calculated and published on the basis of the forestry centres, each of which typically correspond to 1 to 2 million hectares (Fig. 2) (see e.g. Tomppo et al. 1998, Finnish Statistical....1998). The percentage of damages caused by the individual damaging agents is depicted in Figure 2 for those forestry centers that are covered by the 9th NFI. The total proportion of observed damage out of the area of forest land varies from ca. 30 % to 66 % in the different forestry centres. About half of the damage is slight, and has no significant effect on timber production. In most areas fungal damage, mainly that caused by rot fungi (e.g. *Heterobasidion parviporum*), is the most common cause of damage. Abiotic damage is common in some areas, e.g. in the Åland Islands it is primarily damage caused by wind, and in North Savo growth disturbances propably mostly caused by soil factors. Damage caused by animals, mainly moose and deer, is especially common in the Åland Islands and in North Savo. The causal agent in about one third of the cases could not be identified.

The severity of damage caused by individual damaging agents in the whole area of the 9th NFI is presented in Table 1. Most of the damage is slight. The most serious cases of damage are those caused by soil factors, moose and deer, and pine branch twist (*Melampsora pinitorqua*).

The results inevitably include randomness caused by temporal and spatial variation, because some forms of damage, e.g. insect damage, typically occur as epidemics. An inventory that proceeds from one area to another, and is repeated about every ten years, is not the best possible method for surveying damage. On the other hand, the signs of most damaging agents remain visible in the tree crowns or in growth for a number of years. The NFI is a highly suitable tool for surveying the economic consequences of such damage. For instance, the economic losses caused to forestry by moose can be relatively well estimated from the NFI data, thus providing useful information for the planning of game husbandry. The large number of tree and stand parameters in the NFI

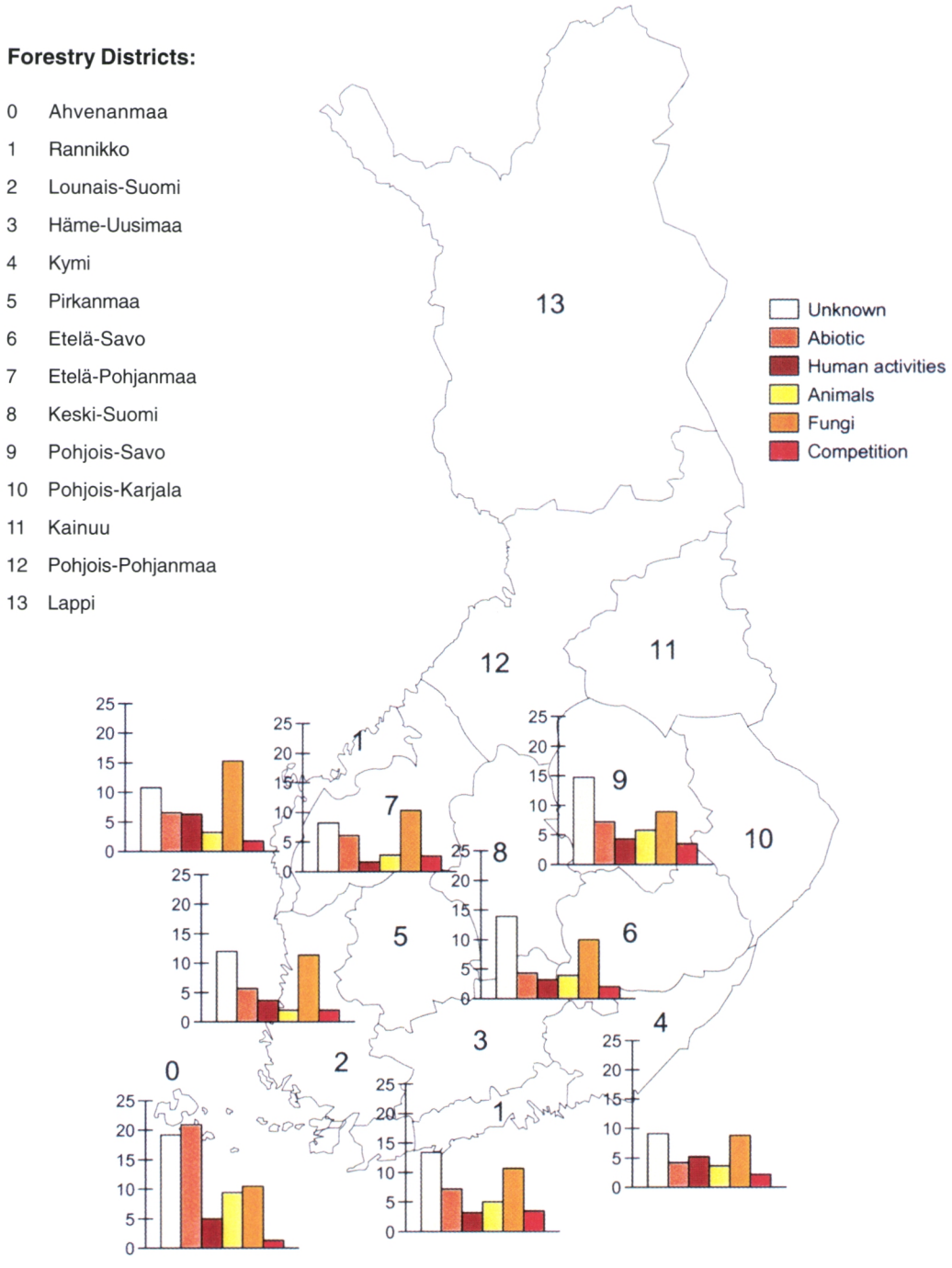

Figure 2. Proportions of different types of damage out of the total forest area in the different forestry centre areas according to the 9th NFI.

Table 1. Proportion of damage of varying severity caused by invidual damaging agents in the area covered by the 9th NFI.

		Proportion of damage severity					
		Slight	Notice-able	Serious	Complete	Total	
Damaging agent		%	%	%	%	%	1000 ha
Abiotic							
	Wind	69	25.2	5	0.8	100	72.2
	Snow	61.5	36.4	1.7	0.4	100	68.7
	Frost	50	42.3	6.6	1.1	100	52.3
	Other climatic factor	40.6	41.7	16	1.6	100	17.2
	Forest fire	23.1	61.3	15.6	0	100	1.9
	Soil factor	36.2	48.7	13.2	1.9	100	120.3
	Total	50.9	39.7	8.1	1.2	100	332.5
Human activities							
	Timber harvesting	79.5	20.1	0.5	0	100	63.1
	Air pollution	60.3	39.7	0	0	100	1.4
	Other human activity	43.8	51.5	4.5	0.2	100	140.1
	Total	54.9	41.8	3.2	0.1	100	204.6
Animals							
	Unidentified insects	52.5	47.5	0	0	100	8.4
	Vole	56.5	24.8	18.7	0	100	4.5
	Moose	49.7	40.4	8.1	1.8	100	171.7
	Other vertebrate	39.8	47.1	13.1	0	100	7.5
	Bark beetles	72.5	27.5	0	0	100	28.1
	Pine weevil	40	60	0	0	100	0.7
	Pine sawfly	72.1	27.9	0	0	100	4.2
	Other needle damaging agent	50.9	49.1	0	0	100	1.1
	Spruce bark beetle	68.5	31.5	0	0	100	0.4
	Other identified insect	55.6	44.4	0	0	100	5.1
	Total	52.9	38.9	6.8	1.4	100	231.8
Fungi							
	Unidentified fungus	64.2	32.7	3.2	0	100	9.1
	Annosum root rot	38	53.1	7.8	1.1	100	74.1
	Other rot fungus	33.1	56.4	8.7	1.9	100	89.1
	Scleroderris canker	76.6	20.7	2.2	0.5	100	183
	Pine branch twist	39.8	43.4	16.5	0.3	100	96.2
	Blister rust	78.3	21.4	0.4	0	100	72.9
	Other rust fungus	96.7	3.3	0	0	100	17.0
	Pine needle-cast fungus	92.6	6.2	1.2	0	100	23.4
	Other identified fungus	33.4	53.6	12.9	0	100	2.1
	Total	59.6	33.7	6.1	0.7	100	567.0
Competition							
	Competition	50.7	44.6	4	0.8	100	144.8
	Total	50.7	44.6	4	0.8	100	144.8
No damage							0
	No damage	0	0	0	0	100	3440.9
	Total	0	0	0	0	100	3440.9
Unidentified							
	Total	59.2	37.8	2.7	0.3	100	662.9

data also provides an excellent opportunity to analyse connections between the occurrence probability of damage and background variables.

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8 Effect of emissions from the iron-ore pelleting plant at Kostomuksha, NW Russia, on deposition in the Kostomuksha area and in the Kainuu region, Eastern Finland

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Introduction

SO_2 emissions from the iron-ore pelleting plant at Kostomuksha, NW Russia, located close to the Finnish-Russian border, are carried into the Kainuu region in Finland. The plant is located in the centre of an extensive forested area. During the past decade there has been considerable concern in Finland about the possible harmful effects of these emissions on forest condition in Kainuu. The threat posed by emissions in NW Russia to forests in Finland became apparent at the end of the 1980's when information started to become available about emissions from industrial complexes in the Soviet Union. The tremendous sulphur and heavy-metal emissions from the smelter complexes on the Kola Peninsula, NW Russia, were immediate causes of concern. The effects of these emissions on forest health and vitality in Finnish Lapland were investigated in the Lapland Forest Damage Project (Tikkanen 1995). Airborne pollution from the St. Petersburg, Petroskoi and Kostomuksha areas has been considered to pose a threat to forest condition in south-east and eastern Finland. The Karelian Forest Condition Project, which was carried out during 1992–1995 as a joint project by the Finnish Forest Research Institute and Russian researchers, was established in order to assess the situation. The aims of the project were to determine deposition patterns in the SE Finland-Karelian Isthmus area and the Kainuu-Kostomuksha area, and to investigate the effects of deposition on forest condition (Lumme et al. 1997).

Filtration equipment was installed on one of the chimneys of the Kostomuksha pelleting plant in the middle of the 1990's. As it was assumed that the equipment would come into permanent use by 1997, the deposition studies were continued in order to determine the effect of the filters on deposition in the Kostomuksha and Kainuu areas. Unfortunately, however, the filters are still not functioning. Despite this, research in the area was continued up until the end of 1998. Owing to a downturn in production, emissions from the plant have been reduced to such an extent that they are now almost equivalent to the emission level that would have been achieved if the filters had been operating during 1992–1995.

The chemical composition of wet deposition and its effect on soil water quality in the Kostomuksha and Kainuu areas were investigated. Heavy metal deposition was also surveyed on the basis of moss sampling. This article is based on a report (Poikolainen & Lippo 2000) covering the results of the extended project. The results have been compared to those obtained in the Karelian Forest Condition Project during the period 1992–1995.

Emissions in Kostomuksha, Kainuu and the neighbouring areas

The iron mine and iron-ore pelleting plant at Kostomuksha were built as a joint Finnish-Russian project in 1977–82. The process dust and gases are emitted from the plant with almost no treatment at all, despite the fact that the chimneys are fitted with mechanical filters capable of removing the largest particles. At the end of the 1980's, SO_2 emissions from Kostomuksha were more than 60 000 t yr^{-1}. During the 1990's they declined owing, e.g. to a reduction in production, and in 1998 were below 40 000 t yr^{-1}. However, SO_2 emissions from the plant were still more than 1/3 of the total SO_2 emissions in Finland. NO_x emissions in recent years have been ca. 1 500 t yr^{-1}, and particle emissions 6 000 t yr^{-1}. The particles mainly consist of calcium and iron. Small amounts of other heavy metals are also emitted. The high proportion of calcium in the emissions is due to the fact that limestone is used in the pelletisation process.

Although emissions in NW Russia have clearly decreased in recent years, they are still considerable. In 1996, SO_2 and NO_x emissions in the Karelian Republic totalled ca. 115 000 and 10 000 t, in the St. Petersburg area 130 000 and 70 000 t, and in the Kola Peninsula 450 000 and 25 000 t, respectively (Miljajev & Festshenko 1998). The Kostomuksha iron-ore pelleting plant is clearly the major emission source in the Karelian Republic, accounting for 40 % of the SO_2 emissions and 12 % of the NO_x emissions.

Emissions in Kainuu are very low. In 1998, SO_2 emissions in Kainuu totalled only about 1 500 t, NO_x emissions 3 100 t, and dust emissions 450 t. Two thirds of the NO_x emissions were derived from traffic. The main point emission sources, primarily district heating plants, are located at Kajaani and Sotkamo, and account for over 90 % of the total SO_2 emissions in Kainuu. The largest emission sources in the areas adjoining Kainuu are to be found on the coast of the Gulf of Bothnia, in the western part of the Province of Oulu. At the end of the 1980's total SO_2 emissions in the Province of Oulu, including Kainuu, were still over 40 000 t yr^{-1}, while they are currently only about 10 000 t yr^{-1}. During the past ten years there have no been major changes in NO_x emissions, which are currently about 8 000 t yr^{-1}. Only a small proportion of the pollutants deposited in Kainuu originates in the region. The pollution deposited in Kainuu is mainly derived from other parts of Finland, NW Russia, the Baltic States and Central Europe.

Climatic conditions in the study area

The climatic conditions in Kainuu during the study period did not differ significantly from the long-term mean values (Finnish Meteorological Institute 1991). The annual mean temperature at the nearest weather station of the Finnish Meteorological Institute varied during the period between 0.0–2.5 °C, the July mean temperature between 12.5–17.5 °C, and the December mean temperature between -6.5 – -12.5 °C. Mean annual precipitation was 650–700 mm.

The wind conditions in the area are of considerable importance as regards the transport of emissions into Kainuu. The wind conditions in Kainuu are very variable (Meteorological Yearbook of Finland 1992–97). During the winter period the prevailing winds are from the south-west, south and west. During the summer months the wind direction is even more variable, although the above directions are predominant. The wind pattern at Kostomuksha may differ to some extent from that in Kainuu. In addition to the wind pattern, the amount and type of precipitation also affect the deposition level.

Material and methods

Sample plots

Eight sample plots were established in August 1992 along a line running to the west of Kostomuksha in order to study the effects of emissions from Kostomuksha on deposition and forest condition (Fig. 1). The most westerly plot was located at least 100 km from the pelleting plant. Four of the plots were in Russia and four in Finland.

The sample plots were established in Scots pine stands on dry and dryish sandy sites. The altitude varied from 200 to 240 m above sea level. The soil on the plots had podzol profiles typical of the pine forests in the area. There were some differences between the element concentrations in the organic layer on the plots, primarily due to variations in site fertility. The mean total and exchangeable N, Mg, Fe and Al concentrations were higher, and the Ca concentration lower, in the organic layer on the Kainuu than on the Kostomuksha plots (Lumme et al. 1997).

Stand age on the plots varied from 65 to 120 years. The average stand age of the Kostomuksha plots was slightly higher because it was not possible to find a sufficient number of young pine stands meeting the age criterion. Stand volume (282–166 m^3 ha^{-1}), mean height (16.8–14.6 m) and diameter at breast height (18.3–15.5 cm) were correspondingly higher on the Kostomuksha than on the Kainuu plots. The stands in the Kostomuksha area were in a semi-natural state, while those in the Kainuu area were located in commercially exploited forest.

Deposition measurements

Deposition was collected in open areas and within the stand. The deposition samples included both wet and dry deposition. Stand throughfall was collected using 20 rainfall collectors (total surface area 0.33 m^2) located systematically along the outer edge of circular 600 m^2 plots (Lumme et al. 1997). Deposition in the open was collected using 5 rainfall collectors (0.08 m^2) located in an adjoining forest opening. Snow samples were collected during the winter using 6 snow collectors (0.65 m^2) inside the stand and two collectors (0.10 m^2) in the open area.

The effects of deposition on soil water quality were studied using zero-tension lysimeters (Derome et al. 1991). Each plot had four groups of lysimeters located at depths of 5, 20 and 40 cm below ground level (4 replications at each depth). The results for 40 cm are not discussed here owing to the insufficient number of samples. Rainwater or snow samples were collected at 1-month intervals from September 1992 until the end of 1998, and soil water samples during May–



Figure 1. Location of the sample plots along a line running to the west of the Kostomuksha iron-ore pelleting plant.

September each year. pH, electrical conductivity, total S, sulphate, ammonium, nitrate, K, Ca, Mg, Na and Fe were determined on the rain and snow samples, as well as Al on the soil water samples.

Sulphur and heavy-metal deposition as determined by moss sampling, and determination of the nutrient status of the tree stand on the basis of needle analysis

The deposition of sulphur and heavy metals was also determined by taking moss samples. Glittering feather moss (*Pleurozium schreberi*) or red-stemmed feather moss (*Hylocomium splendens*) were sampled. The samples were collected as five sub-samples from forest compartments where the species were present in 1992 and 1998. The samples were analysed according to the Nordic analysis protocol (Kubin et al. 2000). The Cd, Cr, Cu, Pb, Mn, Ni, Fe, Ti, Zn and V concentrations were determined.

The nutrient status of the tree stands was determined on the basis of needle analysis. Needle samples were collected from the southern side of the upper third of the crown of 10 dominant trees on each plot in 1993, 1994 and 1998. The concentrations of N, P, K, Ca, Mg, S, Mn, Zn, Fe and Cu were determined on the needle samples. However, sulphur was not determined on the samples taken in 1998. The same analytical methods were used for all three sampling rounds (S on a Leco analyser, N by the Kjeldahl method, other elements by wet digestion followed by AAS).

Results

Sulphur and nitrogen deposition

Sulphur deposition was highest close to the pelleting plant throughout the study period, and decreased on moving away from the plant. However, the decreasing gradient was no longer detectable in Kainuu (Fig. 2). Mean SO_4-S deposition during 1993–98 close to the plant was 285 in the open and 460 mg m^{-2} yr^{-1} in throughfall, and in Kainuu correspondingly 200 and 250 mg m^{-2} yr^{-1}. Deposition in throughfall was greater than that in the open because it also included dry sulphur deposition that had earlier accumulated in the stand.

During 1996–98 there was a clear decrease in sulphur deposition along the gradient compared to the situation in 1993–95. In the Kostomuksha area the mean decrease in the open was 12 % (30 mg m^{-2} yr^{-1}) and in throughfall 3 % (10 mg m^{-2} yr^{-1}). The decrease in sulphur deposition was the smallest close to the pelleting plant. In Kainuu the mean reduction in both the open and in throughfall was about 22 % (50 and 60 mg m^{-2} yr^{-1}, respectively). There were no marked differences between deposition collected during the summer and winter periods. However, the decreasing gradient on moving westwards from the plant during the summer was not as distinct during the winter.

Total nitrogen deposition in the area was low. The average deposition of both NH_4-N and NO_3-N was both about 90 mg m^{-2} yr^{-1} in the open, and 60 mg m^{-2} yr^{-1} inside the stand. NH_4-N deposition was the highest in summer, and NO_3-N deposition the highest in the winter. There was some variation in nitrogen deposition between the years and the plots in throughfall especially, but there was no clear overall decrease during 1993–98.

Metal deposition

Calcium deposition close to the plant was relatively high: during 1993–98 160 mg m^{-2} yr^{-1} in the open and 310 mg m^{-2} yr^{-1} in throughfall (Fig. 2). However, Ca deposition decreased sharply on moving to the west, and about 20 km from the plant it was already only one third of that measured close to the plant. There were no large differences in Ca deposition at the different plots in Kainuu, and deposition was to some extent lower than that at the most western plots in the Kostomuksha area. During

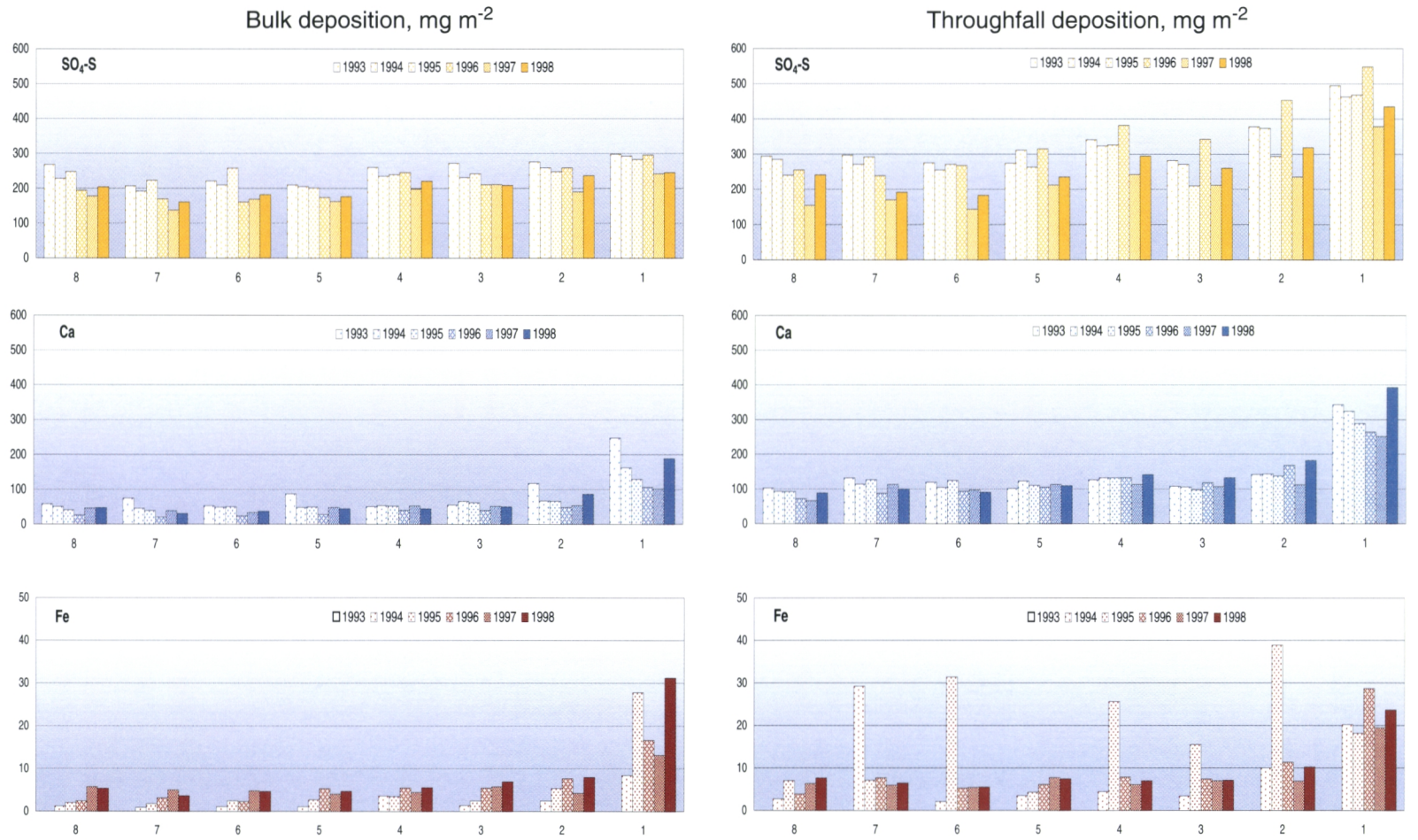

Figure 2. Deposition of SO_4-S, Ca and Fe in the open and in throughfall during 1993–1998 (measurement year 1.9.–30.8.) in eight sample plots (see Fig. 1 for plot localities).

1996–98 Ca deposition decreased at all plots along the line by an average of 30 % in the open and 5 % in throughfall compared to the corresponding values during 1993–95. The relative decrease was greater in Kainuu than in Kostomuksha.

The amounts of Mg and K in throughfall reflect the effect of acidic deposition on the leaching of these two base cations from the tree crowns. During the study period the amount of Mg in the open was 30 % and of K 10 % higher on the Kostomuksha plots than on those in Kainuu ones. The average amount of Mg along the whole line was 11 mg m^{-2} yr^{-1} and of K 43 mg m^{-2} yr^{-1}. The amount of Mg in throughfall close to the plant (mean 55 mg m^{-2} yr^{-1}) was clearly higher than that on the other plots (mean 32 mg m^{-2} yr^{-1}). There were no significant changes in the amount of Mg during the study period. In contrast, the amount of K decreased during 1996–98 in both the Kostomuksha and Kainuu areas by over 25 % in the open and by over 10 % in throughfall compared to the situation during 1993–95.

The average deposition of Fe close to the pelleting plant was about 20 mg m^{-2} yr^{-1} in both the open and throughfall (Fig. 2). Fe deposition in the open decreased sharply with increasing distance from the plant, and at 16 km it was already about 5 mg m^{-2} yr^{-1}. In Kainuu it was only 3 mg m^{-2} yr^{-1}. The amount of Fe in throughfall did not decrease as steeply because at 16 km from the plant it was still 10 mg m^{-2} yr^{-1}, and in Kainuu 6 mg m^{-2} yr^{-1}. No explanation was found for the exceptionally high Fe concentrations in throughfall at a number of the plots in 1995. Fe concentrations in the open increased to some extent in 1996–98 compared to 1993–95, while the concentration in throughfall decreased on most of the plots.

Soil water quality

The S and Al concentrations in soil water are important soil acidification parameters. The S concentration in soil water at both 5 and 20 cm depth was the highest at the plot closest to the pelleting plant throughout the study (Fig. 3). The difference in the S concentration at a depth of 5 cm between the first two plots to the west of the plant was not large. The S concentration varied to a greater extent at a depth of 20 cm, and there was no decreasing gradient on moving to the west. Apart from the plot immediately next to the plant, the S concentration at 5 cm depth at all the other plots along the line decreased during 1996–98 on the average by about 30 %, and at 20 cm by about 20 %, compared to 1993–95.

The mean Al concentration at 5 cm depth on all the plots was about 0.70 mg l^{-1}, and there were no significant differences between the Kostomuksha and Kainuu plots, nor between the two monitoring periods (1993–95 and 1996–98). The Al concentration at a depth of 20 cm on the plot next to the plant was high, and the concentration during 1996–98 clearly increased compared to 1993–95. The Al concentrations at 20 cm depth on the other plots were clearly lower than those at 5 cm, and there were no differences between the two monitoring periods.

The Ca concentration of soil water at both 5 and 20 cm depth at the plot closest to the pelleting plant was, on the average, about 5-fold that on the plots in Kainuu, where the mean Ca concentration during 1993–98 at 5 cm was 0.75 mg l^{-1} and at 20 cm 0.45 mg l^{-1}. The Ca concentration clearly increased at 5 cm depth during 1996–98, apart from at the two westernmost plots. There were no clear changes in the average Mg, K and Na concentrations between the two monitoring periods.

There was no clear east-west gradient in the Fe concentration at a depth of 5 cm. The concentration varied considerably between the plots, the average value during 1993–98 being 0.57 mg l^{-1}. In contrast, the Fe concentration at 20 cm on the plot closest to the plant was about 5-fold that on the other plots, where the concentration was clearly lower than that at 5 cm. The Fe concentration at 5 cm depth decreased, on the average, by about 30 % during 1996–98 compared to 1993–95, and at 20 cm depth remained at approximately the same level.

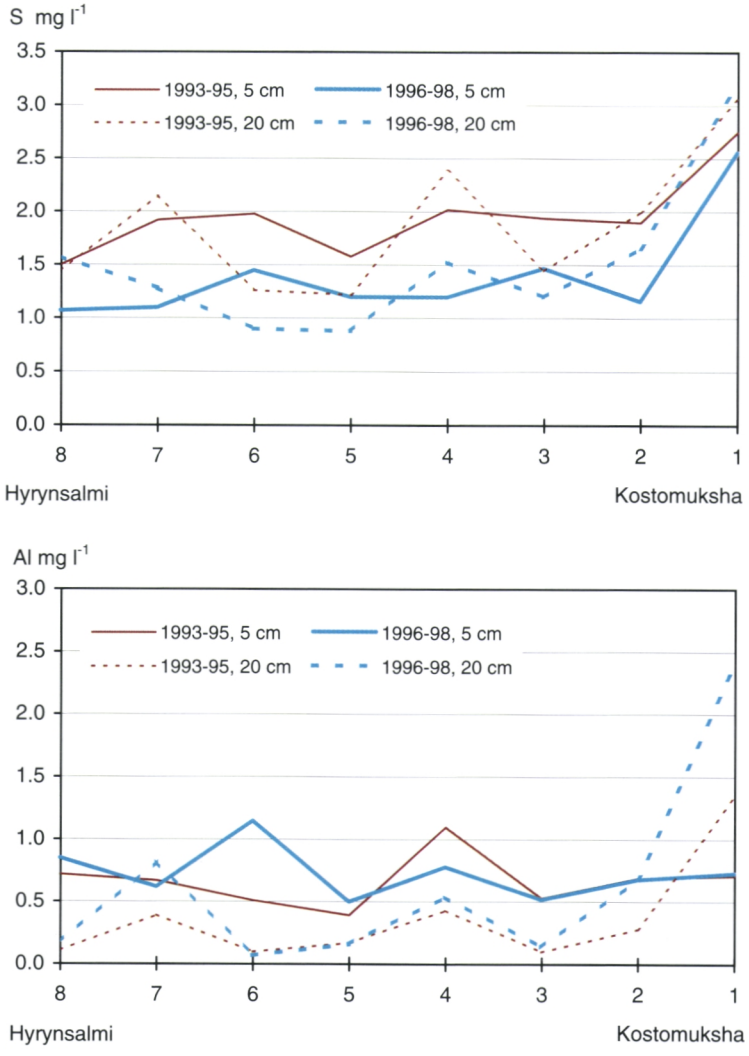

Figure 3. Mean S and Al concentrations at depths of 5 and 20 cm on the sample plots during 1993–95 and 1996–98 (see Fig. 1 for plot localities).

Survey of sulphur and heavy metal deposition using mosses

The S concentration in moss samples collected in 1992 was clearly the highest (1030 mg kg^{-1}) on the plot closest to the iron-ore pelleting plant (Fig. 4). The concentration fell to a level of 800 mg kg^{-1} already at a distance of 16 km, and even more on moving westwards into Kainuu. The S concentration in moss samples collected in 1998 were, on the average, 7 % lower than those collected in 1992 on all the plots along the line. The greatest decrease (almost 20 %) occurred close to the plant.

The high Fe emissions from the plant were reflected in the moss samples in both sampling years, the Fe concentration close to the plant being more than 20-fold those on the plots at the western end of the line (Fig. 4, Table 1). The concentration decreased sharply on moving westwards from Kostomuksha. However, the concentration on the plot at Vartius (plot No.

5) in Kainuu was 1.5-fold those on the other plots in Kainuu. The Fe concentrations in moss collected in 1998 at all plots along the line were, on the average, more than 30 % lower than those in moss sampled in 1992. In absolute terms the Fe concentrations decreased the most close to the plant. However, they decreased proportionally the most in Kainuu (on the average almost 50 %), where the concentrations had already been low in 1992.

The concentrations of other heavy metals were low compared to that of Fe. The Ni, Cr and Ti concentrations were about 3-fold, and that of V 5-fold close to the plant compared to those on the other plots. There were no significant differences between the Cu, Pb, Cd and Zn concentrations on the different plots. Apart from Ti and Cu, the heavy metal concentrations were lower in 1998 than in 1992 (Table 1). The Pb concentration in moss

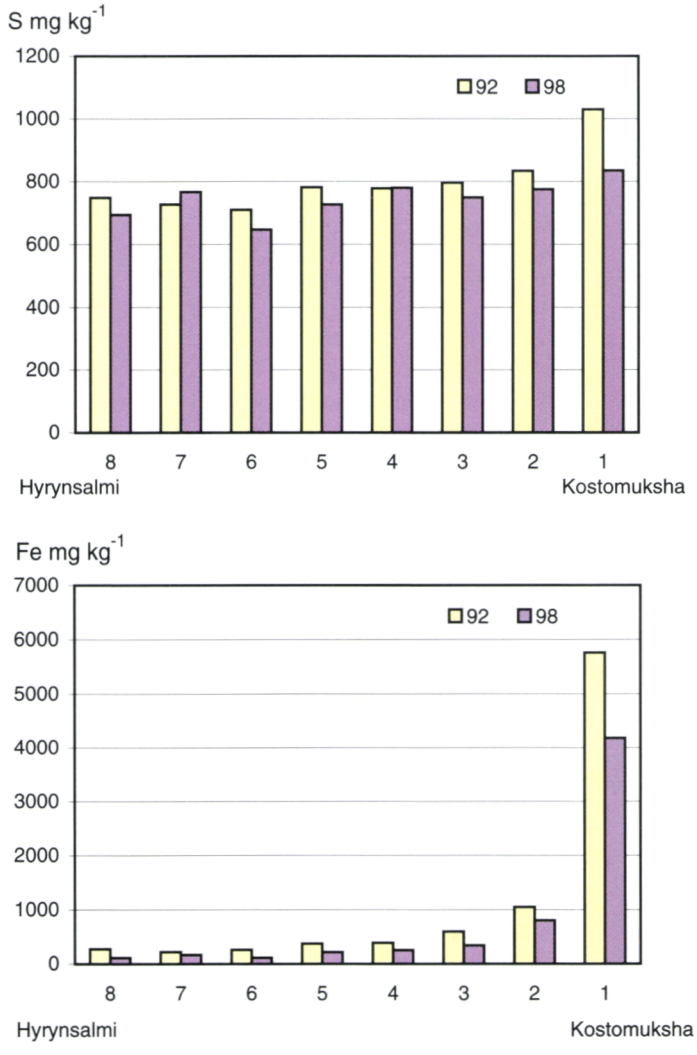

Figure 4. Sulphur and iron concentrations (mg kg^{-1}) in moss on the sample plots in 1992 and in 1998 (see Fig. 1 for plot localities).

Table 1. Heavy metal concentrations (mg kg^{-1}) in moss collected on the sample plots in 1992 and in 1998. 1–4 = mean concentrations for the plots in Kostomuksha, 5–8 = mean concentrations for the plots in Kostomuksha.

Sample plot	Fe		Ti		V		Cu		Ni		Pb		Zn	
	92	98	92	98	92	98	92	98	92	98	92	98	92	98
1	5761	4178	34.2	34.6	15.35	11.71	3.99	4.23	4.73	3.99	6.27	2.54	29.9	22.3
2	1048	799	10.1	12.9	4.38	1.78	3.90	3.34	2.25	1.42	6.00	1.76	26.7	18.3
3	596	339	8.1	8.8	3.42	1.15	4.07	3.29	1.99	1.14	6.58	1.80	26.5	21.2
4	386	251	8.2	8.5	2.95	0.92	3.90	3.64	1.96	1.22	6.40	2.01	31.6	23.3
5	374	217	16.0	9.1	2.82	0.89	2.89	4.04	1.44	1.27	7.78	1.88	27.8	21.6
6	259	112	11.3	6.1	2.59	0.71	3.66	3.29	1.57	1.18	8.16	2.30	27.8	22.6
7	219	166	10.4	17.2	2.14	0.84	3.22	3.52	1.50	1.20	6.59	2.33	25.9	23.7
8	274	110	12.9	7.9	3.11	0.83	3.36	3.29	1.65	1.40	9.70	2.54	27.0	21.3
1–4	1948	1392	15.2	16.2	6.53	3.89	3.97	3.63	2.73	1.94	6.31	2.03	28.7	21.3
5–8	282	151	12.7	10.1	2.67	0.82	3.28	3.54	1.54	1.26	8.06	2.26	27.1	22.3

Table 2. Element concentrations in current Scots pine needles on the sample plots along the Kostomuksha-Kainuu study line in 1993, 1994 and 1998.

Sample plot	N %			K mg g^{-1}			Ca mg g^{-1}			Mg mg g^{-1}			Fe µg g^{-1}		
	93	94	98	93	94	98	93	94	98	93	94	98	93	94	98
1	0.96	0.89	0.98	4.50	5.42	5.42	2.12	2.03	1.61	1.00	0.99	1.03	56.4	61.9	66.6
2	0.96	0.90	1.04	4.47	5.06	5.13	2.25	2.29	1.87	1.07	0.99	1.08	36.5	31.8	50.2
3	0.98	0.92	1.04	4.01	5.13	4.94	2.18	2.09	1.73	0.84	0.87	0.86	30.9	32.9	27.3
4	1.02	0.95	1.00	4.17	5.05	4.87	1.71	1.64	1.41	0.95	0.99	1.00	37.0	28.2	27.4
5	0.95	0.94	1.03	4.40	5.38	5.31	2.14	1.99	1.73	1.01	1.01	1.07	33.3	24.3	23.5
6	1.07	1.11	1.21	3.72	4.72	4.61	2.00	1.56	1.64	0.99	0.93	1.02	36.1	26.8	22.8
7	0.89	0.93	1.00	4.12	5.62	5.10	1.62	1.36	1.38	0.97	0.91	0.95	30.3	20.8	18.7
8	1.21	1.11	1.20	4.05	4.80	4.48	1.45	1.25	1.31	0.94	0.95	0.96	38.8	26.7	24.3
1–4	0.98	0.92	1.02	4.29	5.17	5.09	2.07	2.01	1.66	0.97	0.96	0.99	40.2	38.7	42.9
5–8	1.03	1.02	1.11	4.07	5.13	4.88	1.80	1.54	1.52	0.98	0.95	1.00	34.6	24.7	22.3

decreased the most – in 1998 it was only one third of the concentration in 1992.

Nutrient status of the tree stand on the basis of needle analysis

The results of the needle analyses indicated that there were no marked differences between the nutrient status of the tree stands on the sample plots (Table 2). The difference between the Ca concentrations on the Kostomuksha and Kainuu plots was the clearest; in 1993 and 1994 it was 15–20 % higher in Kostomuksha than in Kainuu. In 1998 the difference levelled out because the needle Ca concentrations on the Kostomuksha plots especially were lower than those in 1993 and 1994. In contrast, there were no marked differences in the Mg and K concentrations between the plots. In 1993 and 1994 the needle S concentrations close to the plant were to some extent higher than those on the other plots, the mean for the whole line being 0.75 mg g^{-1}.

Emissions from the pelleting plant were clearly reflected in the needle Fe concentrations which, close to the plant, were more than double those measured in Kainuu. The Fe

concentration in the needles sampled in 1998 increased on the two plots closest to the plant, but decreased on all the other plots compared to the values for 1993 and 1994. The needle Cu concentration was, on the average, slightly higher in Kainuu (1998: 2.93 μg g^{-1}) than at Kostomuksha (1998: 2.76 μg g^{-1}). The Mn concentration was clearly the lowest (ca. 400 μg g^{-1}) closest to the plant, the mean concentration for all the plots being about 500 μg g^{-1}. There were only slight differences in the Cu and Mn concentrations between the sampling years.

Discussion

Of the emissions from the Kostomuksha pelleting plant, sulphur represents the greatest threat to the environment. Most of the sulphur is deposited within a distance of 15 km around the plant. Close to the plant, sulphur deposition in the open (300 mg m^{-2} yr^{-1}) is of the same order of magnitude as sulphur deposition in southern Finland (Leinonen 1998). Sulphur deposition in Kainuu is relatively low, 150–200 mg m^{-2} yr^{-1}, owing to the fact that the prevailing south-westerly and westerly winds carry most of the emissions from the Kostomuksha plant away from Finland. The decrease in sulphur emissions from the pelleting plant, as well as in sulphur derived from long-distance transport, reduced sulphur deposition in the study area during the 1990's. Although sulphur deposition in most parts of Kainuu is about half that in southern Finland, sulphur deposition in western Lapland, which has the lowest sulphur deposition in Finland, is clearly below 100 mg m^{-2} yr^{-1}.

So far sulphur emissions from Kostomuksha have had only minor effects on the forest ecosystems. The effects are evident only close to the pelleting plant, where sulphur deposition is relatively high. Elevated sulphur concentrations in mosses, in the organic layer of the soil and in soil water occur at least 5 km from the plant. However, the concentrations have decreased in recent years. Changes in microbial activity in the soil, in the acidity of pine bark and in the permeability of the cell membranes of lichens, have also been reported close to the plant (Lumme et al. 1997, Potasheva et al. 1994). The amount of cellular damage in needles close to the plant is also higher than that on the other sample plots. However, sulphur emissions have not had a detrimental effect on the growth of pine stands, not even in the immediate vicinity of the plant.

Of the soil parameters, only the relatively high Al concentrations in soil water at a depth of 20 cm close to the plant suggest that soil acidification is occurring. The Al concentration has clearly increased during the past few years. Al concentrations in the soil water are dependent on the pH; the lower the pH, the higher the Al concentrations (Lindroos et al. 2000). At high concentrations, Al has a toxic effect e.g. on the growth of plant roots. One reason why no clear signs of soil acidification have been found close to the plant is the high Ca emissions from the plant, which are presumably in the form of oxide or carbonate that counteract the acidifying effect of the sulphur emissions. No changes have been found in the soil or in the pine stands in the Kainuu area that could be clearly attributed to the effects of sulphur deposition (Lumme et al. 1997, Lindgren et al. 2000).

The Kostomuksha pelleting plant has not significantly increased the nitrogen load in the study area. The deposition of NH_4 and NO_3 in Kainuu is less than half that in southern Finland. Nitrogen deposition is so low that most of the nitrogen is bound in the tree stand and ground vegetation.

The deposition of Fe (ca. 20 mg m^{-2} yr^{-1}) is relatively high close to the plant, and is at the same level as in southern Finland. Although the Fe emissions are evident as slightly elevated levels in the eastern parts of Kainuu, Fe deposition in the whole of Kainuu is low. Fe emissions are not a very significant threat to the state of health of the forests. Fe, even in high concentrations, is not very toxic to plants compared to the effects of many other heavy metals (Merian 1991).

On the basis of heavy metal concentrations in the mosses, most of the heavy metal

emissions from Kostomuksha are deposited within a 10 km radius of the plant. Fe is the only heavy metal found in elevated concentrations in Kainuu, and even there only in the easternmost parts of the area. Similar results were obtained in the national heavy metal surveys in 1985, 1990 and 1995 (Kubin et al. 2000). In general, heavy metal concentrations in mosses in Kainuu are low and correspond to background levels (Kubin et al. 2000, Rühling et al. 1996). In addition to Fe, the concentrations of As, Cr, Ni, Ti and V in mosses in the Kostomuksha area are above the background values (Rühling et al. 1996, 1998).

The N, P, K and Mg concentrations in pine needles did not differ from the values measured in pine stands growing on dry sandy sites in the study area, although the concentrations were relatively low compared to the values reported for different parts of Finland in 1987–89 (Raitio et al. 2000). The Fe and Ca concentrations close to the pelleting plant are higher than those in background areas, and Mg and K appear to have been leached at a higher rate from the crown canopy, thus reflecting the effects of acidic deposition (Lindroos et al. 2000).

Needle S concentrations have been reported to increase when the SO_2 concentrations in the air and S concentrations in the soil increase (Manninen & Huttunen 1995). For instance, the needle S concentrations close to the large smelters on the Kola Peninsula, NW Russia, exceed 1.20 g kg^{-1}. However, no clear increase in the needle S concentrations were observed in the Kostomuksha area, even though the SO_2 emissions from the pelleting plant are relatively high. The normal, maximum winter background value for Scots pine needles is considered to be 0.90 g kg^{-1} (Raitio et al. 2000). The S concentration in current needles (0.64 – 0.94 g kg^{-1}) at almost all the plots along the line were below this value. Despite the fact that the needle S concentrations were relatively low with respect to the level of S emissions, the amount of needle damage caused by SO_2 has been reported to be higher close to the pelleting plant (Lumme et al. 1997).

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