METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 824, 2001
THE FINNISH FOREST RESEARCH INSTITUTE, RESEARCH PAPERS 824, 2001

Forest Condition Monitoring in Finland

National report 2000

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: Erkki Oksanen/Metla.

Metsäekosysteemien intensiivisen seurannan havaintometsikkö nro 10 Juupajoella. Kuva: Erkki Oksanen/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 490 plots) using internationally standardised methods. A survey of needle chemistry on the Level I plots was started in 1987, and a soil survey carried out during 1985–89 (supplemented in 1995).

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

This report presents the results of monitoring carried out within the framework of the Finnish ICP Forests programme during 1999 and 2000, as well as the results of other studies related to forest health.

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 (LRTAP). 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 framework of the Finnish ICP Forests programme during 1999 and 2000, as well as the results of other studies related to forest health.

In the year 2000 the degree of crown defoliation and foliage discoloration on all tree species had remained relatively unchanged compared to previous years. In the Level I network the proportion of moderately or severely defoliated Scots pine was at the same level as in the previous year, but that of Norway spruce and broadleaves increased by 0.8 %. The average tree-specific degree of defoliation was 9 % in pine, 19 % in spruce and 12 % in broadleaves. The proportion of discoloured Scots pine decreased by about 2 % over the previous year, and of Norway spruce increased by about 2 %. Discoloration symptoms were rare in broadleaves.

The mass outbreak of pine sawfly *(Diprion pini)*, which started in 1998, has now passed and there were no extensive epidemics of fungi. The most common epidemic fungal diseases were rusts, especially chrysomyxa needle cast *(Chrysomyxa ledi)* and birch rust *(Melampsoridium betulinum)*, which benefited from the wet summer. The cause of growth disturbances in Norway spruce in Pohjois-Savo has now been confirmed as depressed levels of plant-available boron. The vole populations were low throughout the country, apart from in Metsä-Lappi and northern Kainuu. Trombis felled forest at the end of June in Häme and Pirkanmaa especially. Local tornadoes occurred in the middle of July in northern Finland.

The weather in 1999 was characterised by high annual temperatures throughout the country. Most of the months of the year were warm in the southern and central parts of the country. In northern Finland, however, new cold weather records were set at the end of January. The precipitation in 1999 was very uneven throughout the year. In southern Finland the precipitation was very high in the beginning of the year, while the spring was very dry.

In background areas of Finland there are clear seasonal patterns in many air pollutants. As result of the international abatement programmes implemented during the last decade, primary pollutant concentrations in the atmosphere and the deposition of acidifying compounds (SO_4^{-2}, NH_4^+, NO_3^-) have decreased considerably in recent years. There was a clearly decreasing trend in the deposition of SO_4^{-2}, NH_4^+, NO_3^- and many heavy metals running from south to north in 1999, the southern part of the country receiving 2–8 times more deposition than in the north. The deposition of SO_4^{-2}, NH_4^+, NO_3^- and Ca^{2+} during the year showed considerable episodic variation; the worst day of the year accounted for over 10 % of the total annual deposition. Concentrations of gaseous pollutants (SO_2, NO_x) have decreased since 1985. The downward trend that has occurred during the last ten years is steeper in the winter than in the summer. The largest decrease was recorded in the south-western part of the country, whereas

the change was smallest in the far north and northeast. There was an increasing trend in O_3 concentrations in southern Finland, but not at northern stations.

On the Level II plots there was a clear decrease in sulphur deposition on the forest floor on moving from south to north in 1999. In stand throughfall there was an increasing trend in pH, and a decreasing trend in SO_4^{2-} in southern and central Finland during 1996–1999. Pine canopies increased the proton input to the forest floor while, in contrast, spruce canopies on many of the plots decreased the input. The nitrogen flux decreased as rainwater passed down through the canopy, indicating that the deposition level was relatively low in relation to the nitrogen requirements of the forest stands. Emissions from local NH_3 point sources (fur farms) were clearly reflected in the nitrogen flux in stand throughfall on the spruce plot at Uusikaarlepyy.

The soil solution report consists of an analysis of the composition of soil solution obtained using different sampling techniques. The results indicated that there are considerable differences between the pH and concentrations of SO_4^{-2}, NH_4^+, NO_3^-, Mg^{2+} and K^+ in soil solution sampled using tension and zero-tension lysimeters. The differences are mainly due to the fact that soil solution sampled by tension lysimeters reflects the availability of macro- and micronutrients for the trees and ground vegetation, as well as the capacity of the soil to buffer and neutralize acid inputs. In contrast, the soil solution obtained with zero-tension lysimeters provides information about the movement of ions between the soil horizons required in determining ion fluxes.

The average defoliation level of Norway spruce decreased slightly and that of Scots pine remained at the same level as in 1998 on the Level II plots. Due to the very dry summer, the proportion of discoloured pines and spruces increased compared to the situation in 1998. 30 % of the discoloured pines and 16 % of the discoloured spruces also had signs of fungal infection. There were only small changes in the cover % of understorey plant species compared to the previous year.

The report also includes phenological observations, which have been included in the ICP Forests/Level II programme since 2000 on an optional basis. In addition, the report includes the results of forest damage assessments carried out in connection with the 9th National Forest Inventory, which now covers the whole of the southern half of Finland. The results of a pilot study on variation in the amount and quality of throughfall in relation to collector type and sampling design, and the results of soil chemistry studies on the Integrated Monitoring plots, are also presented.

Yhteenveto

Suomi on vuodesta 1985 lähtien osallistunut yleiseurooppalaiseen metsien terveydentilan seurantaohjelmaan (ICP metsäohjelma), joka perustuu kansainväliseen ilman epäpuhtauksien kaukokulkeutumista koskevaan sopimukseen (LRTAP). 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, laaja-alainen seuranta). Metsien kunnon ja ilman epäpuhtauksien sekä muiden stressitekijöiden välisiä vuorosuhteita tutkitaan 31 metsikössä eri puolilla Suomea (Taso II, intensiivinen seuranta). Tässä vuosikatsauksessa esitetään ICP metsäohjelman Suomea koskevat tulokset vuosilta 1999 ja 2000 sekä muiden Suomen metsien terveydentilaa käsittelevien tutkimusten tuloksia.

Metsien terveydentilan laaja-alaisen seurannan mukaan Suomen metsien kunnossa ei havaittu vuonna 2000 suuria muutoksia vuoteen 1999 verrattuna. Vuonna 2000 harsuuntumattomien puiden (0–10 %) osuus pieneni ja lievästi harsuuntuneiden puiden (10–25 %) osuus kasvoi hieman edellisestä vuodesta. Yli 25 % harsuuntuneiden mäntyjen osuus pysyi ennallaan, kun taas kuusien ja lehtipuiden harsuuntuminen lisääntyi hieman (0,8 %). Mäntyjen keskimääräinen harsuuntumisaste oli 9 %, kuusien 19 % ja lehtipuiden 12 %.Värivikaisten mäntyjen määrä laski noin 2 % edelliseen vuoteen verrattuna, vastaavasti värivikaisten kuusten osuus nousi 2 %, sen sijaan lehtipuilla värivikoja ei havaittu.

Pilkkumäntypistiäistoukkien *(Diprion pini)* aiheuttamat neulastuhot jäivät kesällä 2000 selvästi edellisvuotta vähäisemmiksi, myöskään laajoja sienitautiepidemioita ei esiintynyt. Epideemisistä sienitaudeista yleisiä olivat kesän sateisuudesta hyötyneet ruosteet, erityisesti kuusensuopursuruoste *(Chrysomyxa ledi)* ja koivunruoste *(Melampsoridium betulinum)*. Pohjois-Savossa havaittujen kuusen kasvuhäiriöiden pääasialliseksi syyksi varmistui boorin puute. Myyräkannat olivat niukat koko maassa lukuunottamatta Metsä-Lappia ja Pohjois-Kainuuta. Trombit kaatoivat metsää erityisesti Hämeessä ja Pirkanmaalla kesäkuun lopussa, paikallisia pyörremyrskyjä riehui heinäkuun puolivälissä myös Pohjois-Suomessa.

Vuoden 1999 keskilämpötila oli keskimääräistä korkeampi koko maassa, Pohjois-Suomessa tammi- ja joulukuu olivat kuitenkin erittäin kylmiä. Lapissa saavutettiin jopa kylmyysennätyksiä tammikuun lopulla. Sademäärä jakautui hyvin epätasaisesti vuoden mittaan, Etelä-Suomessa alkuvuosi oli hyvin sateinen, kun taas kevät ja kesä olivat kuivia.

Suomen tausta-alueilla useiden ilman epäpuhtauksien pitoisuudet vaihtelevat vuodenaikojen mukaan. Viime vuosien aikana happamoittavien yhdisteiden (SO_4^{2-}, NH_4^+, NO_3^-) laskeumat ovat vähentyneet merkittävästi päästörajoitussopimusten vaikutuksesta. Happamoittavien yhdisteiden ja joidenkin raskasmetallien laskeuma oli 2–8 kertaa suurempi etelässä kuin pohjoisessa. Tyypillistä SO_4^{2-}-, NH_4^+-, NO_3^-- ja Ca^{2+}- laskeumalle on niiden episodimaisuus, vuoden suurin vuorokausilaskeuma voi kattaa yli 10 % niiden vuosittaisesta kokonaislaskeumasta. Kaasumaisten ilman epäpuhtauksien määrä (SO_2, NO_x) on laskenut vuodesta 1985 lähtien. Lasku on ollut jyrkempää talvella kuin kesällä ja suurin muutos on tapahtunut Etelä-Suomessa. Sen sijaan ilman otsonipitoisuus on noussut koko maassa Pohjois-Suomea lukuunottamatta.

Rikkilaskeuman väheneminen pohjoista kohden havaittiin myös intensiiviseurannan havaintoaloilla vuonna 1999. Seurantajakson 1996–1999 aikana metsikkösadannan pH on noussut ja sulfaattilaskeuma on vähentynyt Keski- ja Etelä-Suomessa. Mäntyvaltaisen puuston todettiin lisäävän vetyionien määrää metsämaahan kohdistuvassa laskeumassa, kuusikoissa vaikutus oli päinvastainen.

Sadeveden typpilaskeuma väheni veden kulkiessa latvuskerroksen läpi. Tämä osoittaa typpilaskeuman määrän olevan edelleen vähäinen suhteessa puuston typen tarpeeseen. Uudenkaarlepyyn havaintokuusikon metsikkösadannassa paikallisten turkistarhojen ammoniumtyppipäästöt näkyivät varsin selvästi.

Maavesianalytiikkaa käsittelevässä erillisselvityksessä tutkittiin ainepitoisuuksien eroja vajovesi- ja alipainelysimetrien välillä, esimerkiksi pH sekä SO_4^{2-}-, NH_4^+-, NO_3^--, Mg^{2+}- ja K^+-pitoisuus erosivat huomattavasti eri keräinten välillä. Alipainelysimetreillä kerätty maavesi heijastaa kasvillisuuden ravinteiden ottoa ja maaperän puskuri- ja neutraloitumisprosesseja. Sen sijaan vajovesilysimetreillä kerätty maavesi kuvaa ionien kulkeutumista maannoshorisonttien välillä ja tilannetta ennen puskuroitumista.

Intensiivisen seurannan havaintoaloilla kuusten harsuuntumisaste laski hieman vuonna 1999, kun taas mäntyjen harsuuntumisaste pysyi vuoden 1998 tasolla. Kuivan kesän seurauksena havupuilla neulasten värivikojen määrä lisääntyi. 30 % värivikaisista männyistä ja 16 % kuusista kärsi myös sienitaudeista. Kasvilajien peittävyyksissä havaittiin vain vähäisiä muutoksia vuosien 1998 ja 1999 välillä.

Raportissa tarkastellaan myös fenologista havainnointia, joka on ollut vuodesta 2000 lähtien seurantaohjelman vapaaehtoinen osio. Lisäksi kerrotaan 9. valtakunnan metsien inventoinnissa tehdyistä metsätuhohavainnoista Etelä-Suomen osalta, raportoidaan metsikkösadannan laadun ja määrän vaihtelua koskevasta pilottitutkimuksesta ja esitetään maaperätuloksia yhdennetyn ympäristön seurannan (YYS) havaintoaloilta.

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

Yleiseurooppalainen metsien terveydentilan seuranta (YK-ECE/EK) Suomessa

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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.

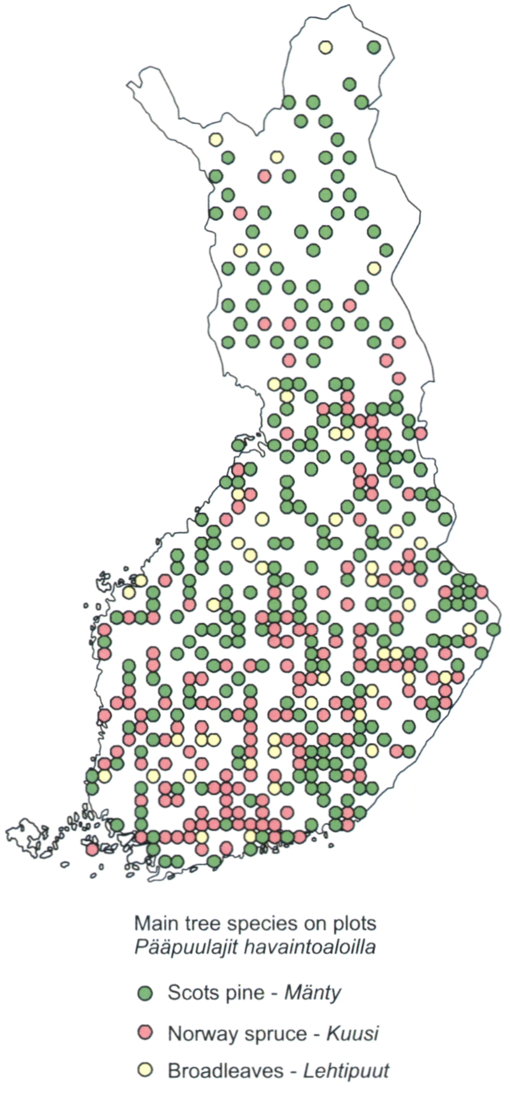

Figure 1. The network of the annual, large-scale crown condition survey (Level I) in Finland.
Kuva 1. *Laajamittainen metsien tilan seuranta (taso I), näytealaverkko Suomessa.*

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.

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,

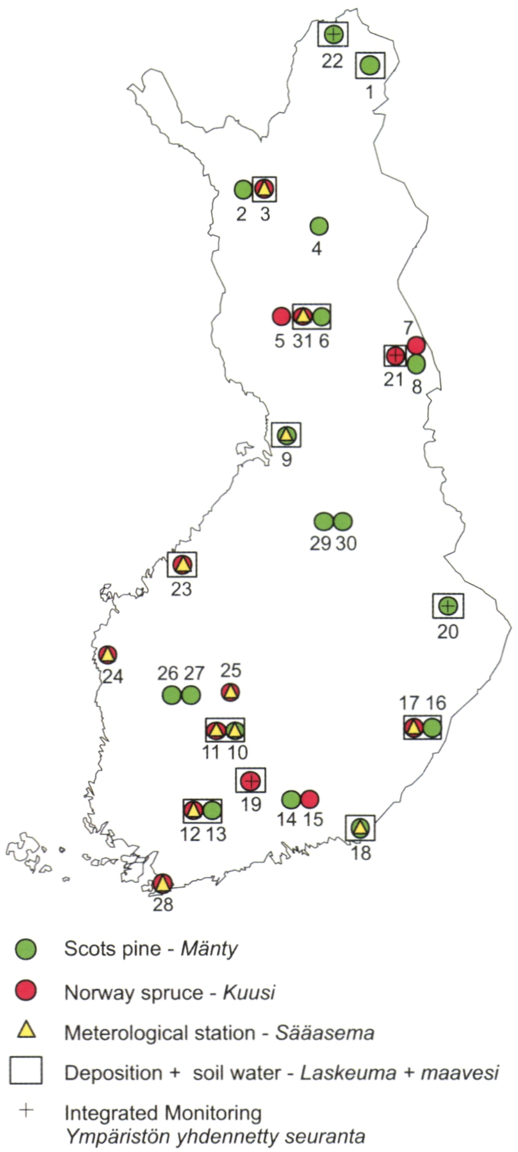

Figure 2. The intensive monitoring network of forest ecosystems in Finland.
Kuva 2. *Metsäekosysteemien intensiiviseurannan havaintoalat Suomessa.*

Table 1. Overview of the intensive monitoring network of forest ecosystems in Finland.
Taulukko 1. Havaintoalojen numero, nimi ja pääpuulaji.

Plot number *Havaintoalan numero*	Plot name *Havaintoalan nimi*	Tree species *Pääpuulaji*
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 – *Mänty*
S = Norway spruce – *Kuusi*
pro = Provenance – *Alkuperä*
Pim = Scots pine, Integrated Monitoring
Mänty, ympäristön yhdennetty seuranta
Sim = Norway spruce, Integrated Monitoring
Kuusi, ympäristön yhdennetty seuranta
fer = Fertilization - *Lannoitettu*

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.

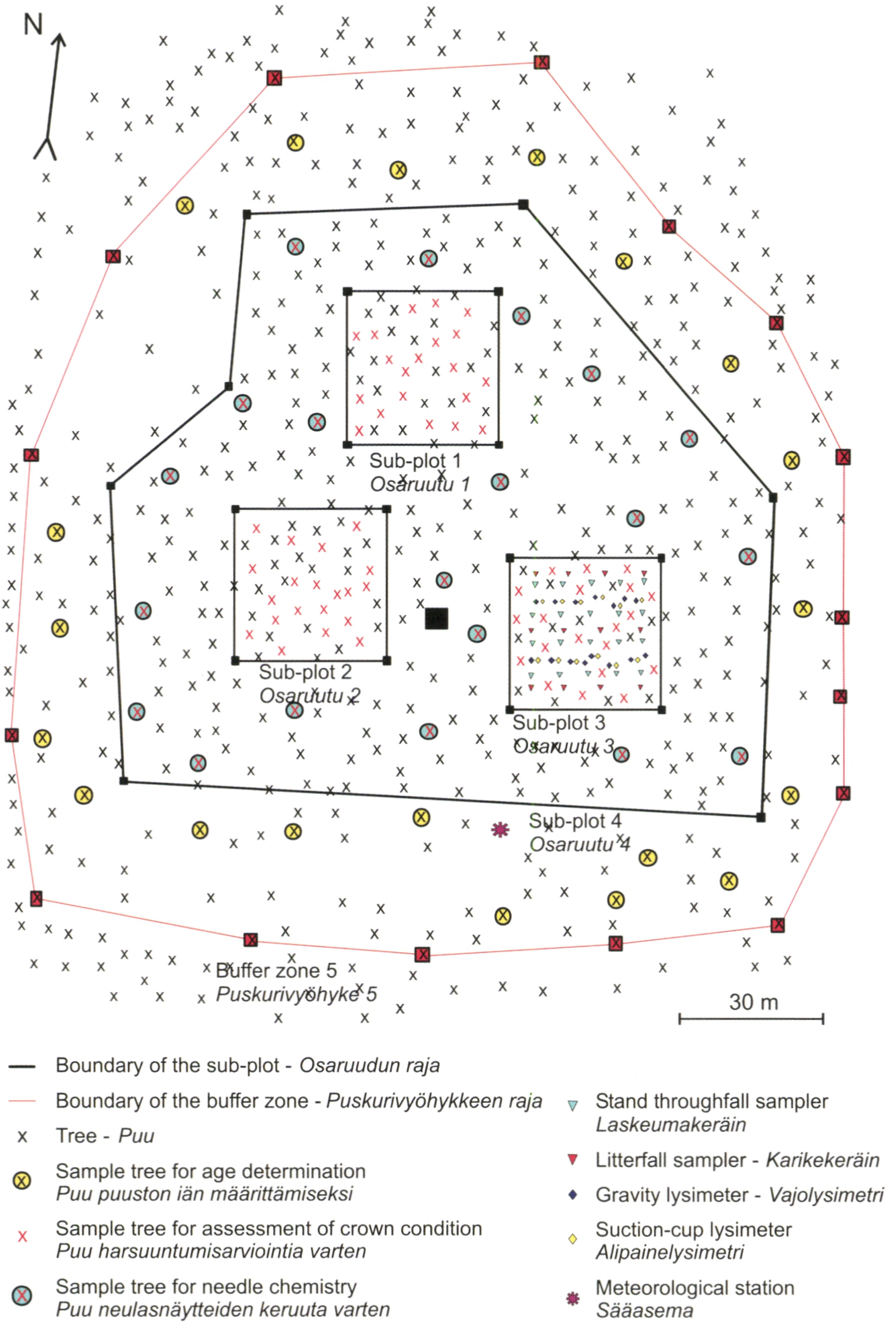

Figure 3. The design of the observation plot and location of the sub-plots.
Kuva 3. *Kaavio metsäekosysteemien intensiivisen seurannan havaintoalasta.*

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 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.

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		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

Background information

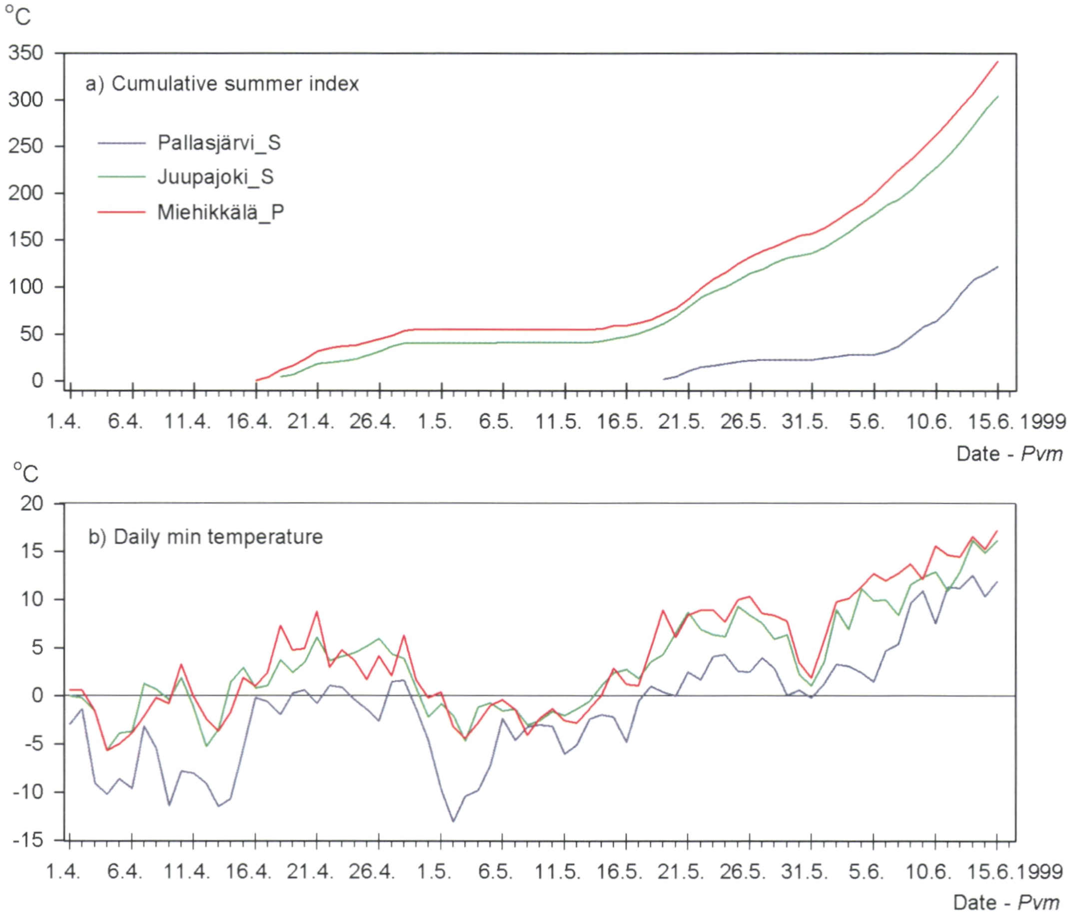

Figure 4a–b. The growing season of 1999 started right after mid April in middle and southern parts of Finland, as indicated by the cumulative summer index curves of Juupajoki_S and Miehikkälä_P in Fig. 4a. This is 1.5–2 weeks earlier than on average. The warm period was followed by an exceptional coldness, which lasted more than two weeks. Subzero temperatures during the night time were observed all over the country (Fig. 4b) and summer index did not accumulate at all (Fig. 4a). In Lapland (Pallasjärvi_S) the growing season started about a month later than in southern Finland (Fig. 4a).
Kuva 4a–b. *Vuoden 1999 terminen kasvukausi alkoi huhtikuun puolivälin jälkeen maan keski- ja eteläosissa, kuten Juupajoen ja Miehikkälän lämpösummakäyrät osoittavat (kuva 4a). Kasvukausi alkoi 1.5–2 viikkoa tavanomaista aikaisemmin. Lämmintä jaksoa seurasi yli kaksi viikkoa kestänyt poikkeuksellisen kylmä jakso. Yöpakkasia esiintyi koko maassa (kuva 4b) eikä lämpösummaa kertynyt lainkaan (kuva 4a). Lapissa (Pallasjärvi_S) kasvukausi alkoi noin kuukautta myöhemmin kuin eteläisessä Suomessa (kuva 4a).*

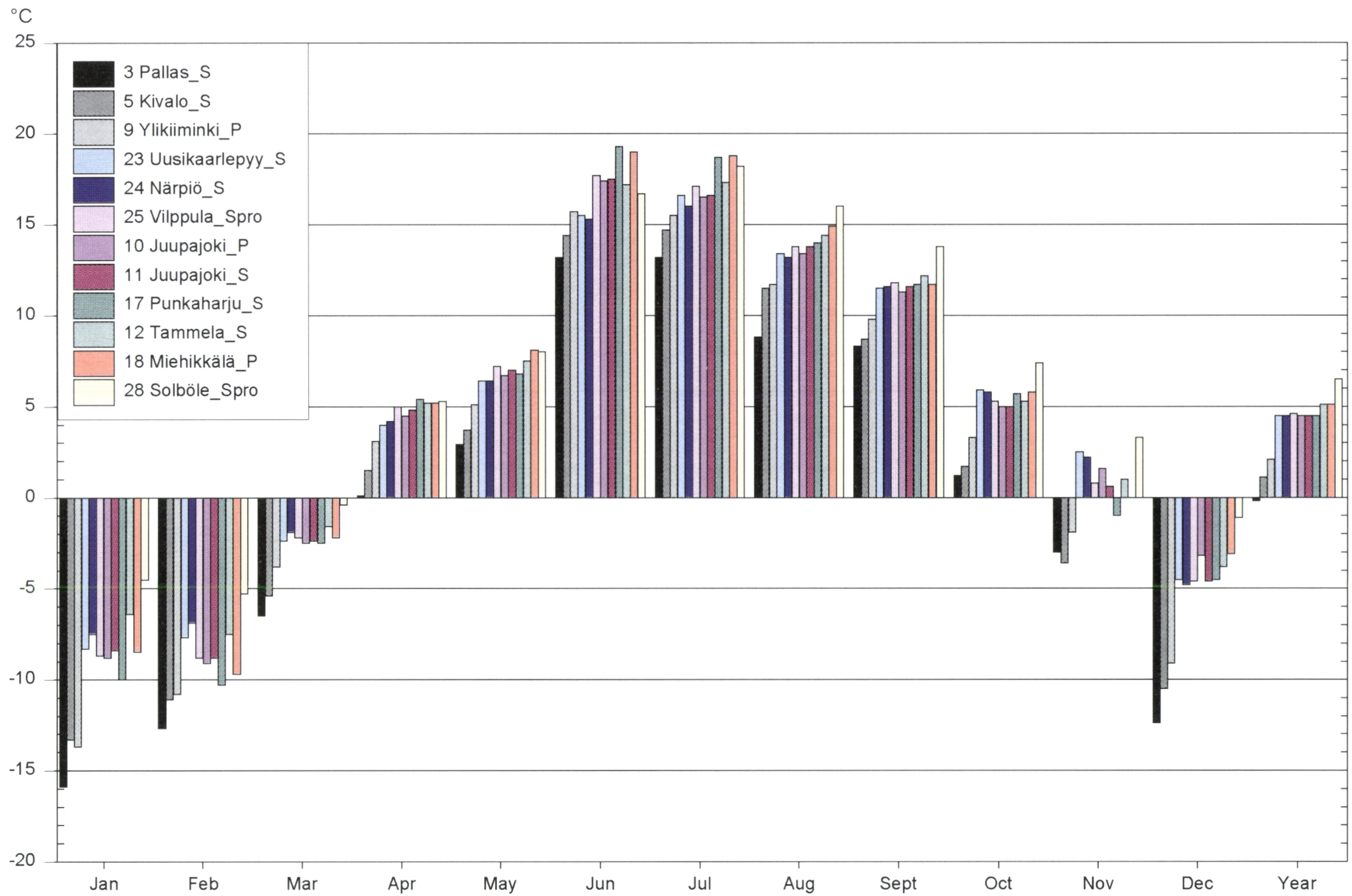

Figure 5. Mean monthly and yearly temperatures on Level II plots (from north to south) with meteorological measurements in 1999.
Kuva 5. *Ilman kuukausi- ja vuosikeskilämpötilat metsien intensiiviseurannan säähavaintoasemilla v. 1999.*

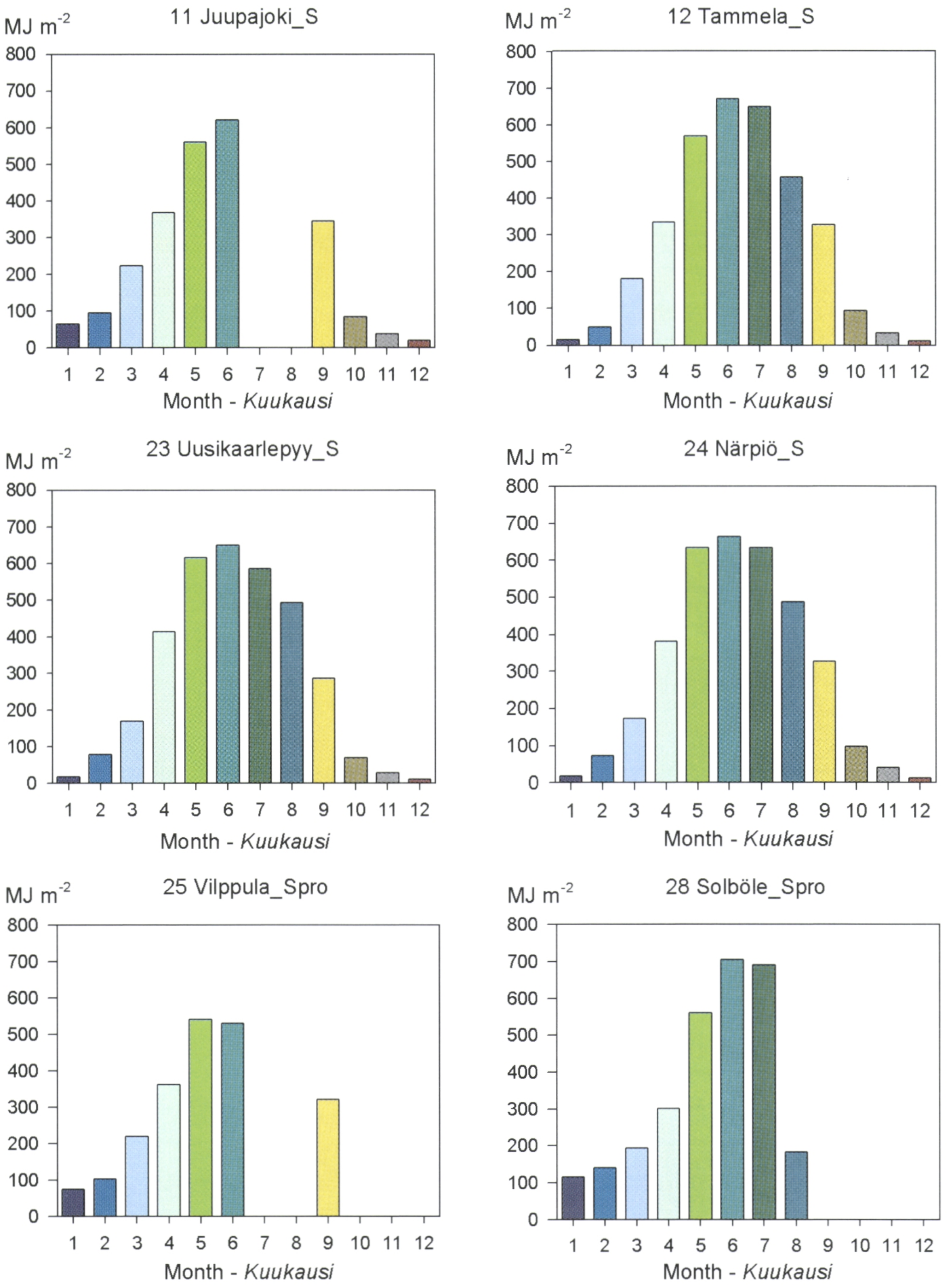

Figure 6. Monthly sums of global radiation on some Level II plots. Snow and ice cover on the sensor may affect the measurement in the winter time.
Kuva 6. *Globaalisäteilyn kuukausisummat eräillä metsien intensiiviseurannan säähavaintoasemilla. Talvikuukausina mittausanturin peittyminen lumella ja jäällä voi vaikuttaa mittaustulokseen.*

Table 2. Winter index 1998–1999, growing season, its length and summer index in 1999, and summer index in 1961–1990 (Ojansuu & Henttonen1983 *) on Level II plots with meteorological measurements. 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.
Taulukko 2. *Talven 1998–1999 pakkassumma, kesän 1999 kasvukausi, sen pituus ja lämpösumma sekä lämpösumma vertailukautena 1961–1990 (Ojansuu & Henttonen 1983*) metsien intensiiviseurannan säähavaintoasemilla. Puuttuvat havainnot saatiin mallittamalla lähimmän Ilmatieteen laitoksen havaintojen perusteella.*

Plot no. and name *Havaintoalan nro ja nimi*	Winter index [1] °C *Pakkassumma [1] °C*		Growing season [2] *Kasvukausi [2]*		Summer index [3] °C *Lämpösumma [3] °C*	
	1.10.–1.4.	Total *Kok.summa*	Period *Jakso*	Length, d *Pituus, pv*	1999	1961–90
3 Pallasjärvi_S	-1593	-1665	19.5.–28.9.	133	749	684
5 Kivalo_S	-1414	-1459	18.5.–5.10.	141	954	826
9 Ylikiiminki_P	-1311	-1333	18.4.–9.10.	175	1109	1029
10 Juupajoki_P	-928	-932	18.4.–10.10.	176	1341	1163
11 Juupajoki_S	-891	-894	18.4.–10.10.	176	1379	1140
12 Tammela_S	-731	-732	18.4.–13.10.	179	1444	1253
17 Punkaharju_S	-1034	-1040	16.4.–12.10.	180	1543	1289
18 Miehikkälä_P	-918	-923	17.4.–12.10.	179	1590	1351
23 Uusikaarlepyy_S	-822	-824	18.4.–15.10.	181	1269	1131
24 Närpiö_S	-754	-755	18.4.–14.10.	180	1248	1187
25 Vilppula_Spro	-890	-891	18.4.–13.10.	179	1414	1179
28 Solböle_Spro	-489	-489	18.4.–15.10.	181	1584	1357

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

[1] Winter index equals the sum of daily mean temperatures below 0 °C in the period from 1 October to 1 April (degree days below 0 °C). The sum was calculated also for the whole period having daily mean temperatures below 0°C.
[1] Pakkassumma (vuorokausikeskilämpötilojen summa päiville, joiden keskilämpötila on alle 0 °C) jaksona 1.10.–1.4. ja koko termisenä talvikautena.

[2] Growing season is the period during which summer index accumulates.
[2] Terminen kasvukausi on se osa vuodesta, jolloin lämpösummaa kertyy.

[3] Summer index is calculated as an effective temperature sum, which equals the sum of differences between daily mean temperatures during the growing season and a threshold of 5 °C.
[3] Lämpösumma on laskettu tehoisan lämpötilan summana, jolla tarkoitetaan vuorokausikeskilämpötilojen summaa +5 °C ylittävältä osalta.

Table 3. The basic stand characteristics of ICP Level II observation plots.
Taulukko 3. *ICP-havaintoalojen (taso II) keskeisimmät puustotunnukset.*

Plot no. *Havainto-alan nro*	Stem number *Runkoluku, kpl/ha*	Basal area, with bark, m^2/ha *Pohjapinta-ala, (kuorellinen), m^2/ha*	Mean diameter, weighted with basal area, cm *Keskiläpimitta, (PPA:lla painotettu), cm*	Mean height, arithmetical, m *Keskipituus (aritmeettinen), m*	Stem volume, with bark, m^3/ha *Runkotilavuus (kuorellinen), m^3/ha*	Stand age *Metsikön ikä*
1	370.0	13.4	24.4	10.1	75.1	200
2	733.3	12.9	17.9	8.4	65.0	90
3	1107.4	13.0	17.2	7.5	66.1	140
4	1133.3	18.3	16.4	11.9	119.8	80
5	1663.0	21.6	14.8	9.6	117.0	70
6	1748.2	21.3	13.3	11.1	126.9	55
7	1188.9	25.1	22.5	10.6	178.7	190
8	688.9	18.7	20.4	14.7	143.0	80
9	548.2	12.5	18.3	12.7	83.3	90
10	377.8	17.9	25.7	21.1	181.7	80
11	866.7	33.2	24.3	19.8	339.1	80
12	677.8	27.6	23.9	20.1	273.0	60
13	603.7	21.9	22.2	19.2	202.7	60
14	1148.2	25.6	17.9	16.0	208.2	50
15	655.6	26.4	23.9	21.1	278.3	65
16	955.6	29.4	20.8	21.4	306.1	80
17	377.8	28.5	31.5	26.1	348.2	70
18	414.8	16.9	23.6	19.4	158.6	120
19	1295.3	54.1	30.2	18.6	649.8	170
20	587.5	28.8	31.9	16.9	310.9	130
21	1741.7	25.6	22.9	8.8	176.3	170
22	693.8	11.5	28.2	6.2	65.2	180
23	970.4	34.8	22.7	18.9	333.5	55
24	696.3	25.3	26.6	15.2	215.1	55
25	448.2	28.3	29.5	25.9	355.8	75
26	714.8	10.3	16.2	10.5	61.5	90
27	629.6	10.3	16.6	10.7	65.0	100
28	455.6	25.8	27.5	23.5	292.7	75
29	1337.0	13.5	13.2	8.9	70.7	110
30	1255.6	12.5	12.6	9.0	64.8	120
31	1218.5	21.0	16.8	10.5	121.8	75

Table 4. The average element concentrations in the current-year (C) and the previous-year (C+1) needles of Scots pine and Norway spruce on the Level II observation plots in 1999.
Taulukko 4. *Männyn ja kuusen nuorimpien (C) ja edellisenä kesänä syntyneiden (C+1) neulasten keskimääräiset alkuainepitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (taso II) vuonna 1999.*

Element *Alkuaine*	Scots pine - *Mänty*				Norway spruce - *Kuusi*	
	Mineral soil, n = 13 *Kivennäismaat*		Peatland, n = 4 *Turvemaat*		n = 14	
	C	C + 1	C	C + 1	C	C + 1
N mg/g	11.9	11.8	11.4	11.9	11.6	10.7
P mg/g	1.36	1.27	1.34	1.29	1.50	1.25
K mg/g	5.17	4.74	4.40	4.23	6.81	5.32
Ca mg/g	1.70	2.78	1.85	3.15	3.86	6.30
Mg mg/g	0.90	0.83	1.10	1.02	1.09	0.97
S mg/kg	773	813	777	829	797	797
Fe mg/kg	26	37	26	39	27	30
B mg/kg	11.8	11.3	12.3	11.1	11.4	12.9
Cu mg/kg	2.44	2.18	2.25	2.25	2.11	1.84
Zn mg/kg	36.0	46.0	37.1	46.6	35.8	36.9
Mn mg/kg	394	634	257	394	742	1038

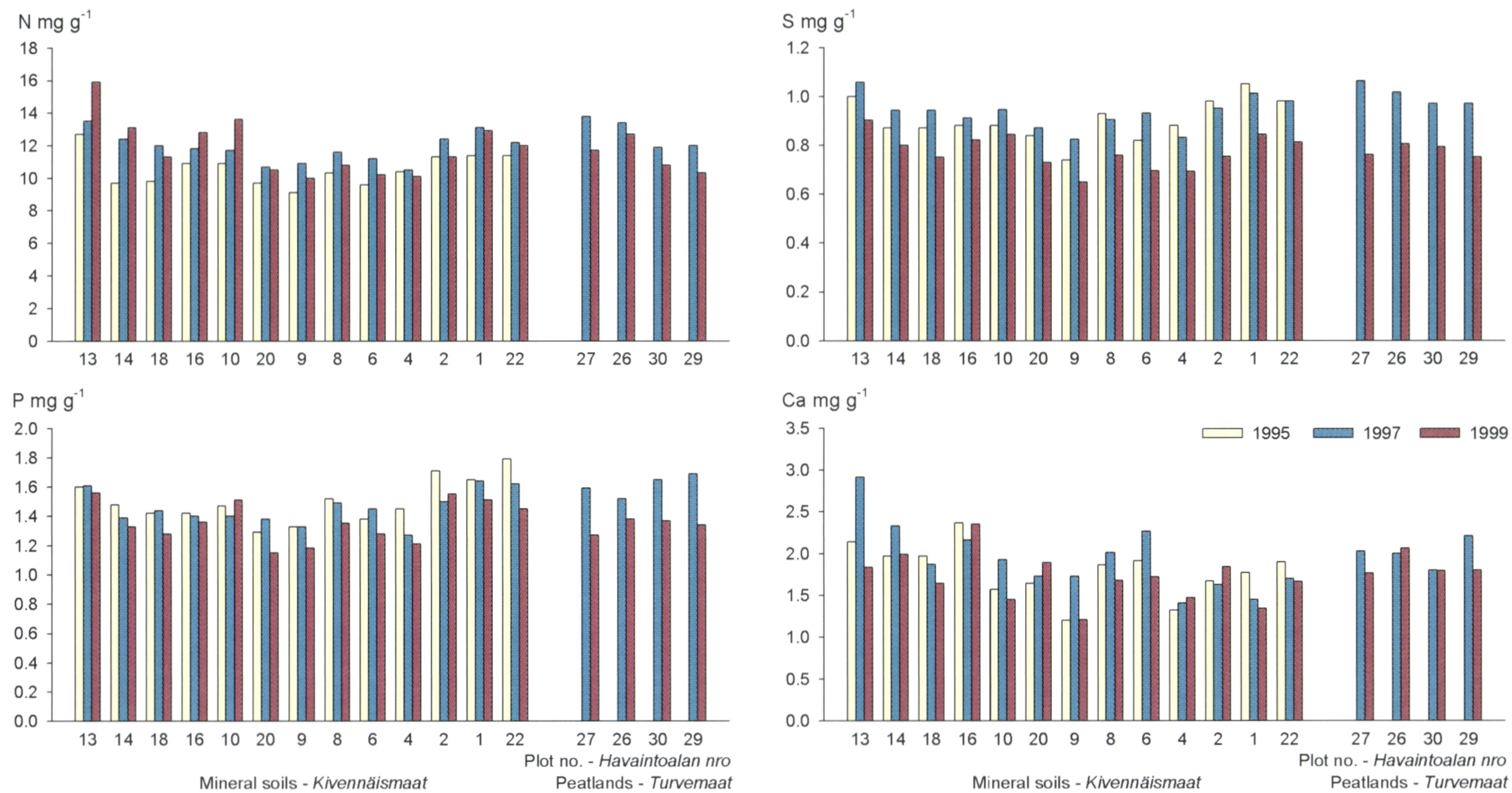

Figure 7a. Average nitrogen, sulphur, phosporus and calcium concentrations of Scots pine current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 7a. *Männyn nuorimpien neulasten keskimääräiset typpi-, rikki-, fosfori- ja kalsiumpitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

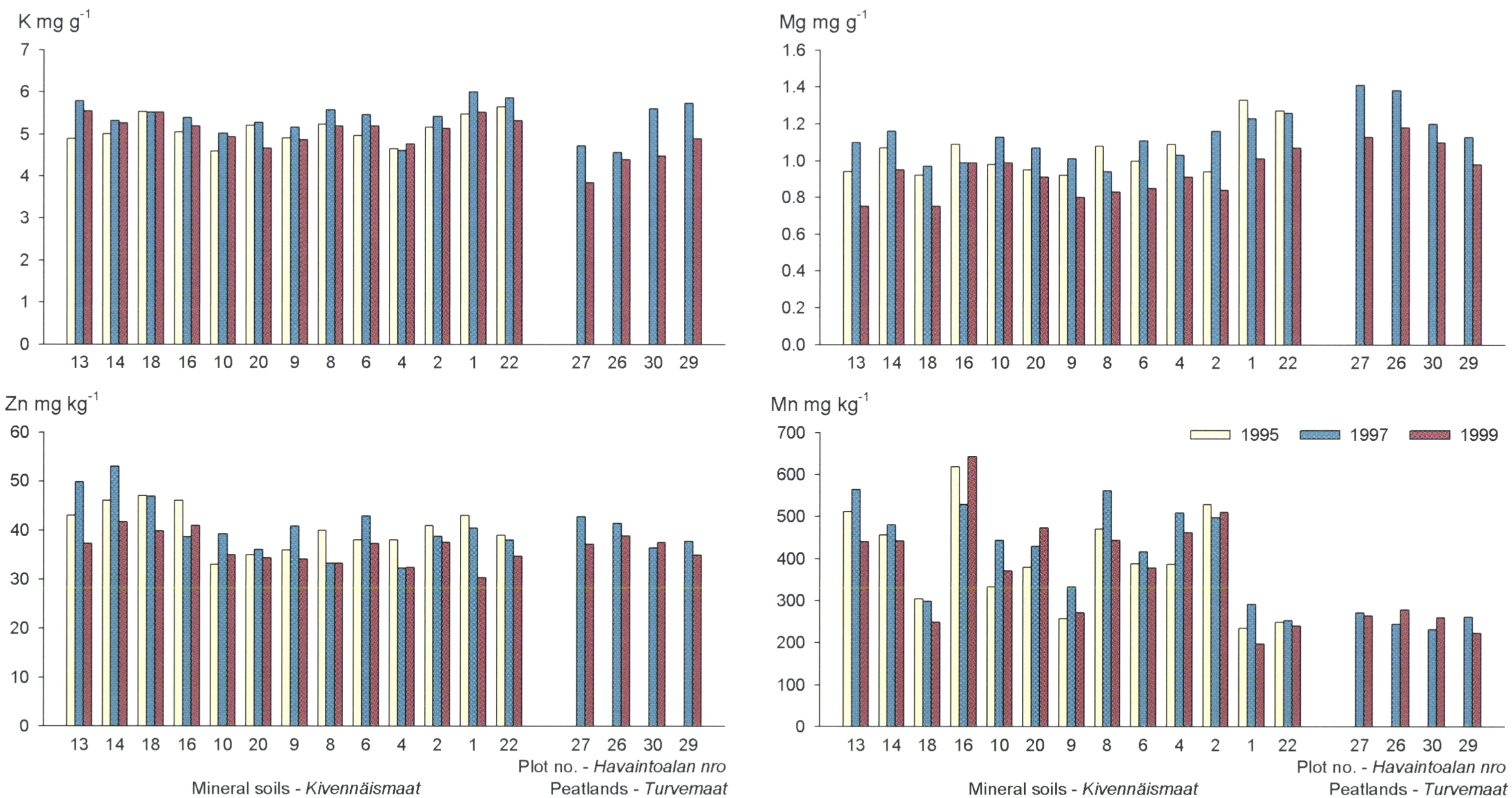

Figure 7b. Average potassium, magnesium, zink and manganese concentrations of Scots pine current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 7b. *Männyn nuorimpien neulasten keskimääräiset kalium-, magnesium-, sinkki- ja mangaanipitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

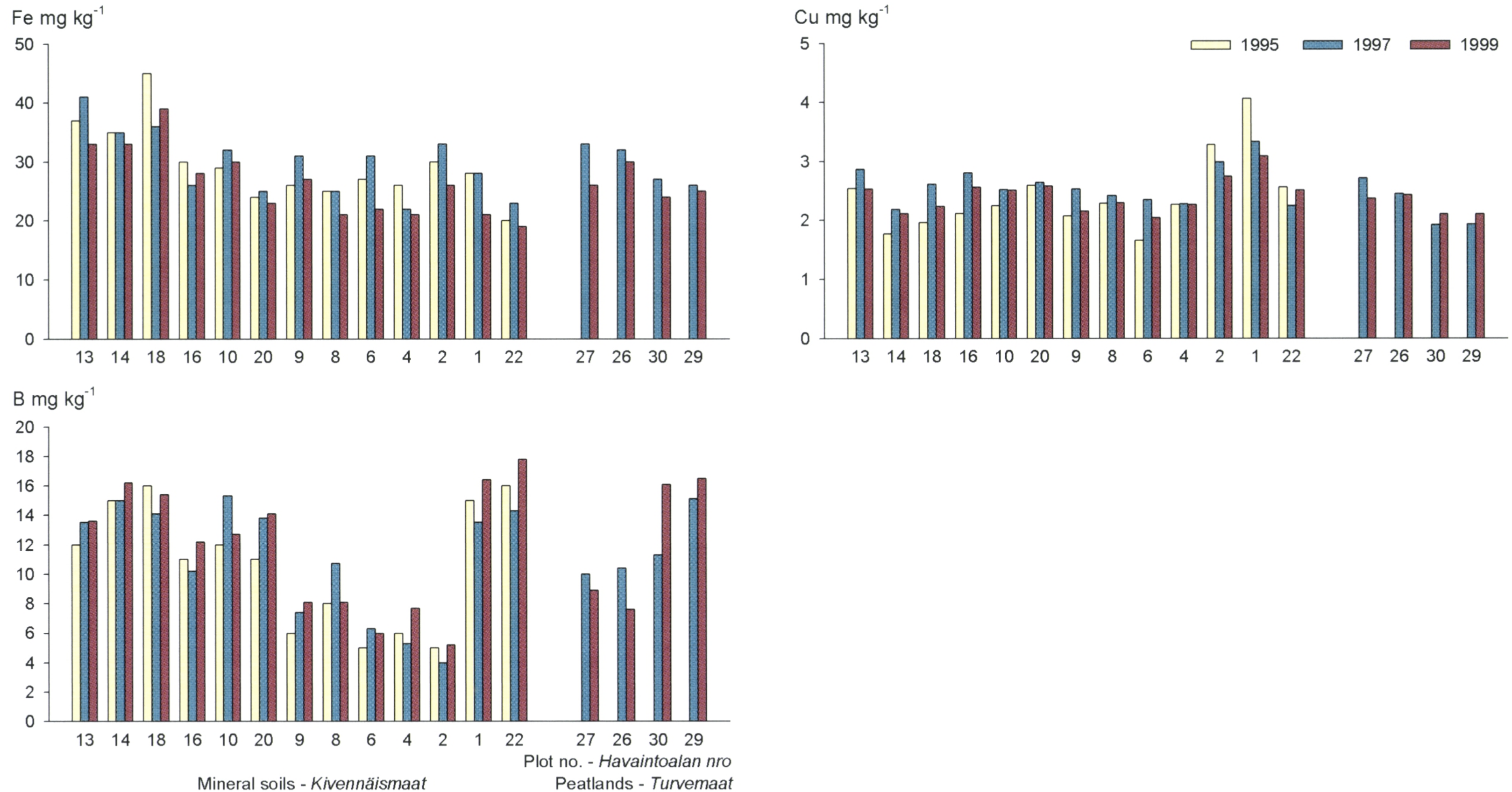

Figure 7c. Average iron, copper and boron concentrations of Scots pine current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 7c. *Männyn nuorimpien neulasten keskimääräiset rauta-, kupari- ja booripitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

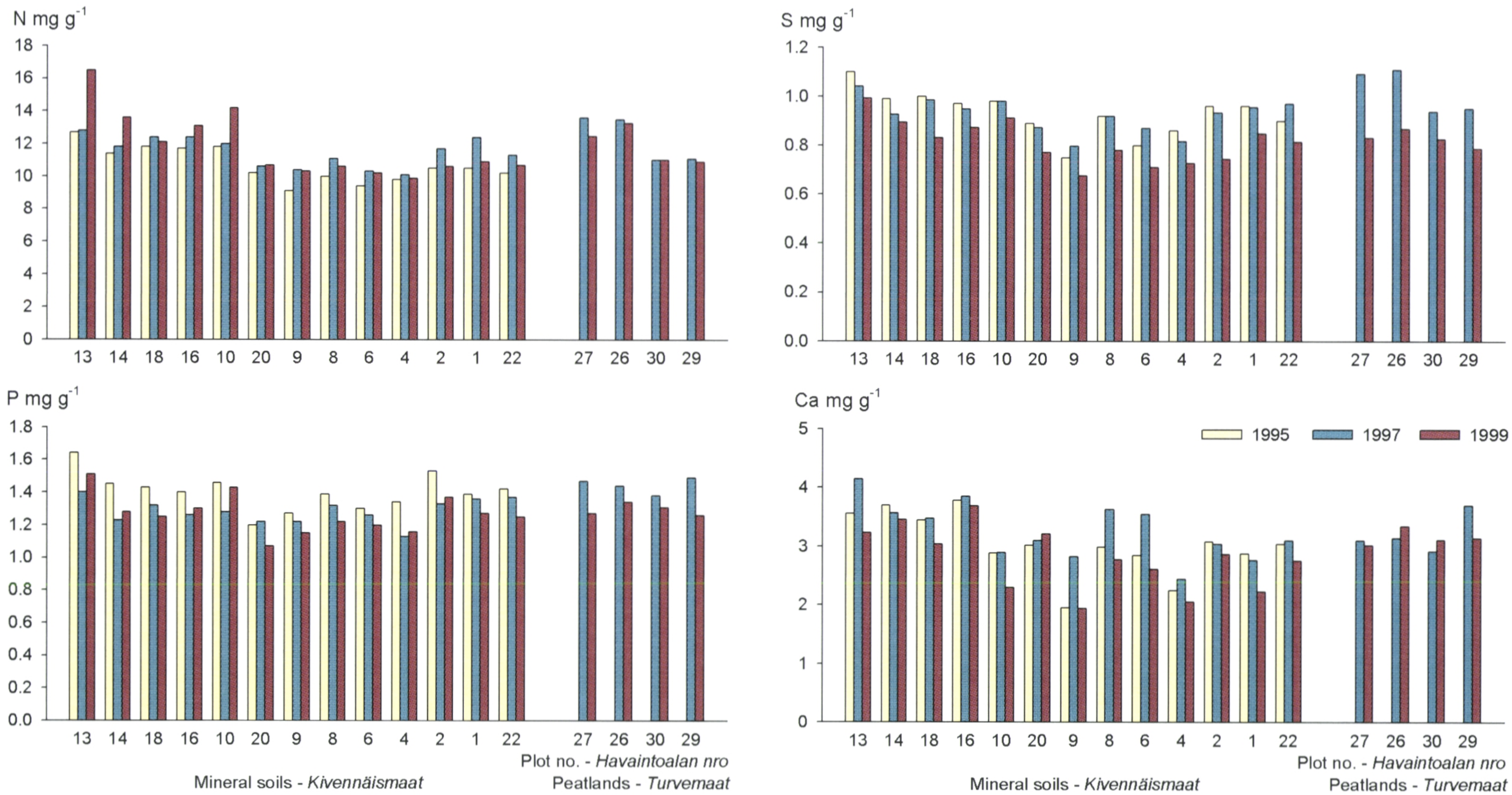

Figure 8a. Average nitrogen, sulphur, phosporus and calcium concentrations of Scots pine previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 8a. *Edellisenä kesänä syntyneiden männyn neulasten keskimääräiset typpi-, rikki-, fosfori- ja kalsiumpitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

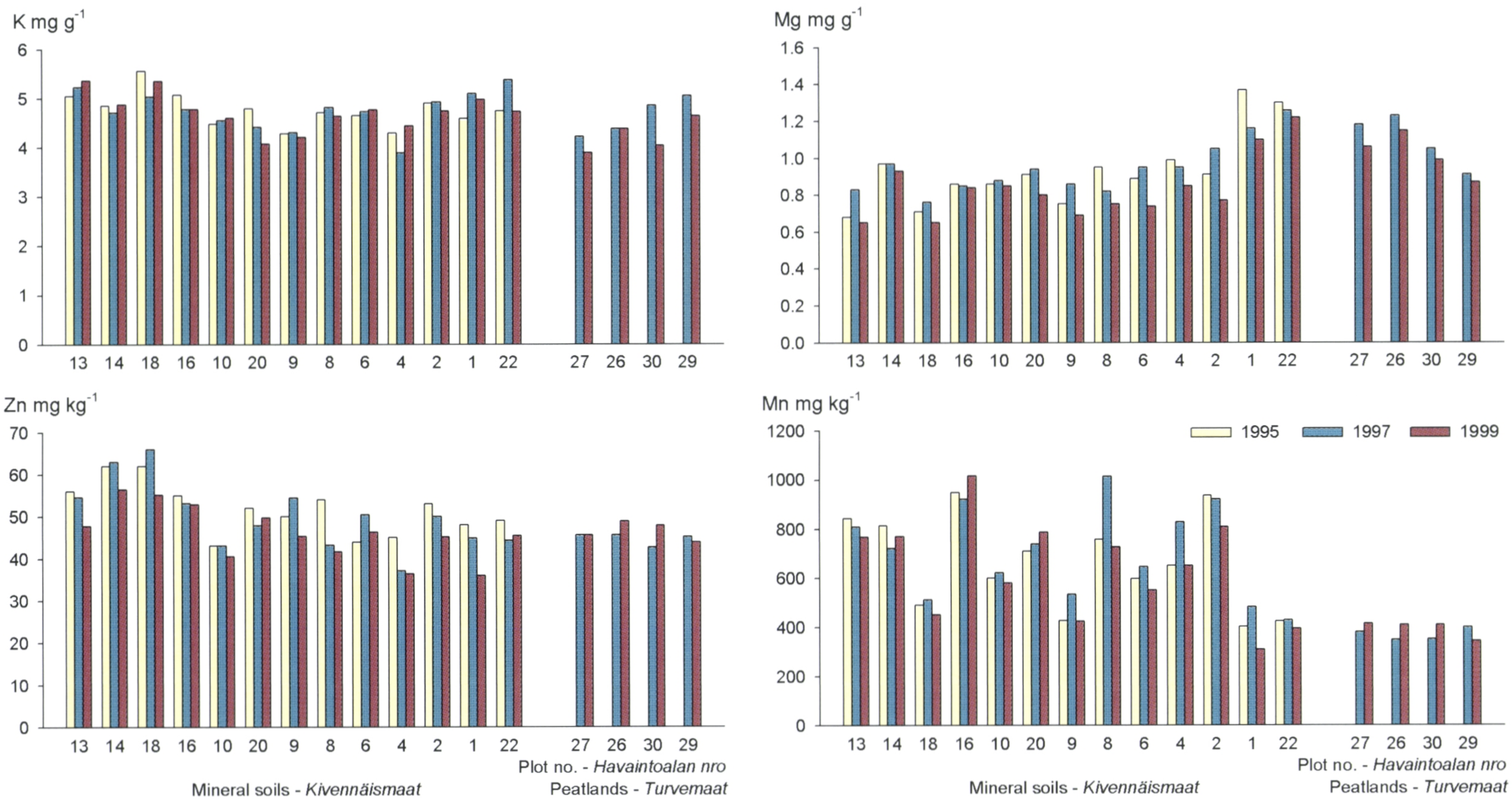

Figure 8b. Average potassium, magnesium, zink and manganese concentrations of Scots pine previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 8b. *Edellisenä kesänä syntyneiden männyn neulasten keskimääräiset kalium-, magnesium-, sinkki- ja mangaanipitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

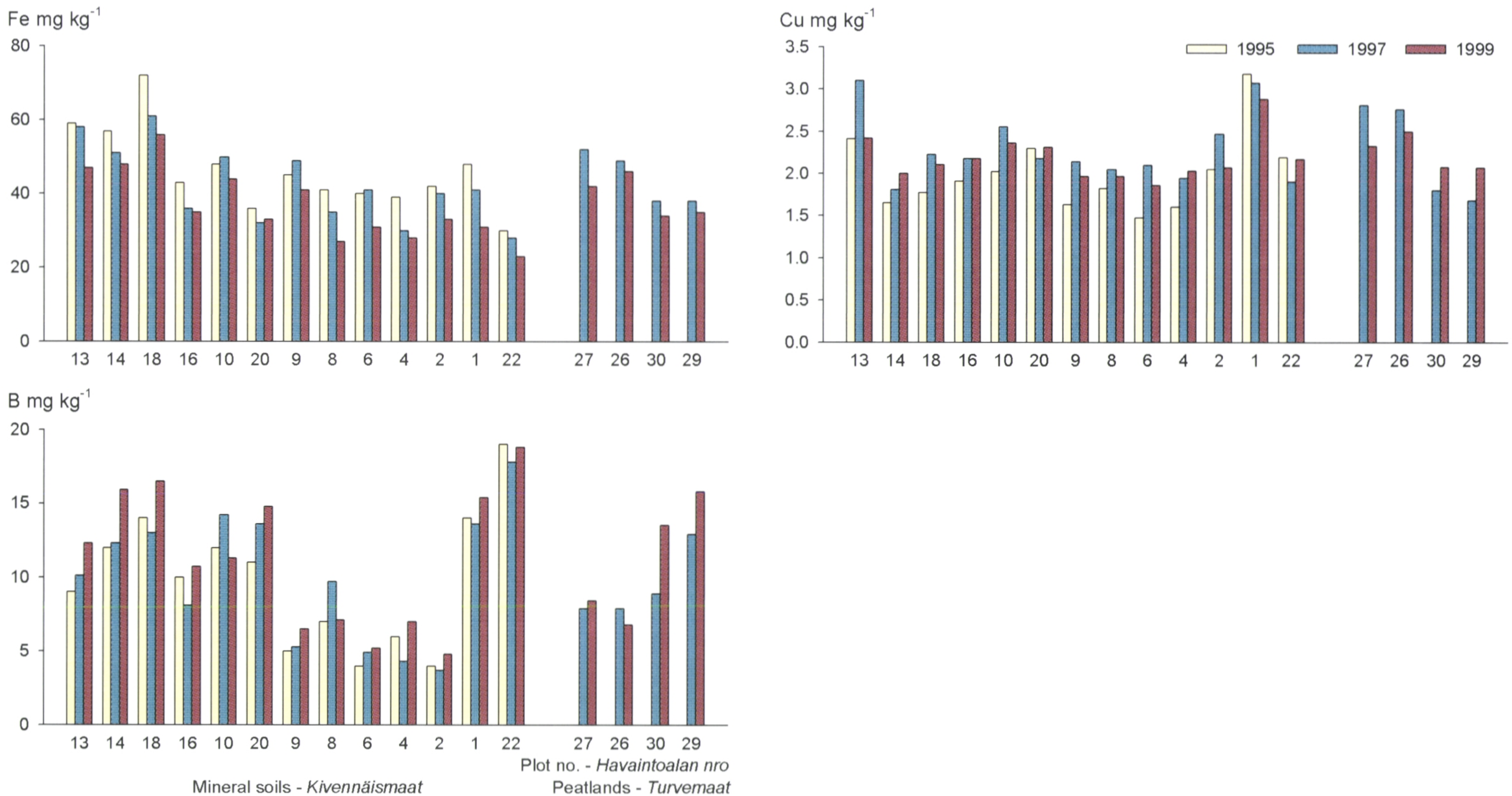

Figure 8c. Average iron, copper and boron concentrations of Scots pine previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 8c. *Edellisenä kesänä syntyneiden männyn neulasten keskimääräiset rauta-, kupari- ja booripitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

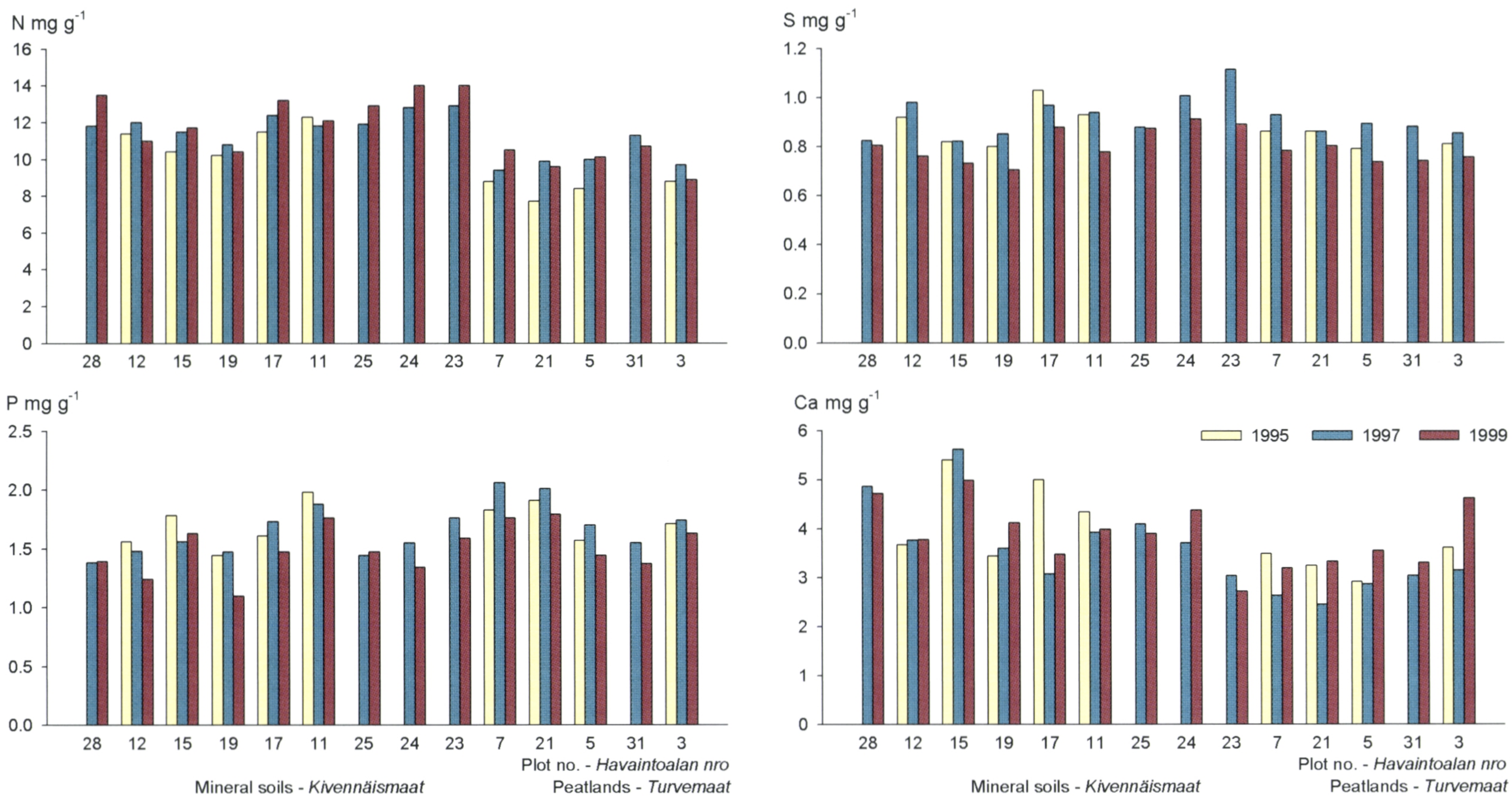

Figure 9a. Average nitrogen, sulphur, phosporus and calcium concentrations of Norway spruce current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.
Kuva 9a. *Kuusen nuorimpien neulasten keskimääräiset typpi-, rikki-, fosfori- ja kalsiumpitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

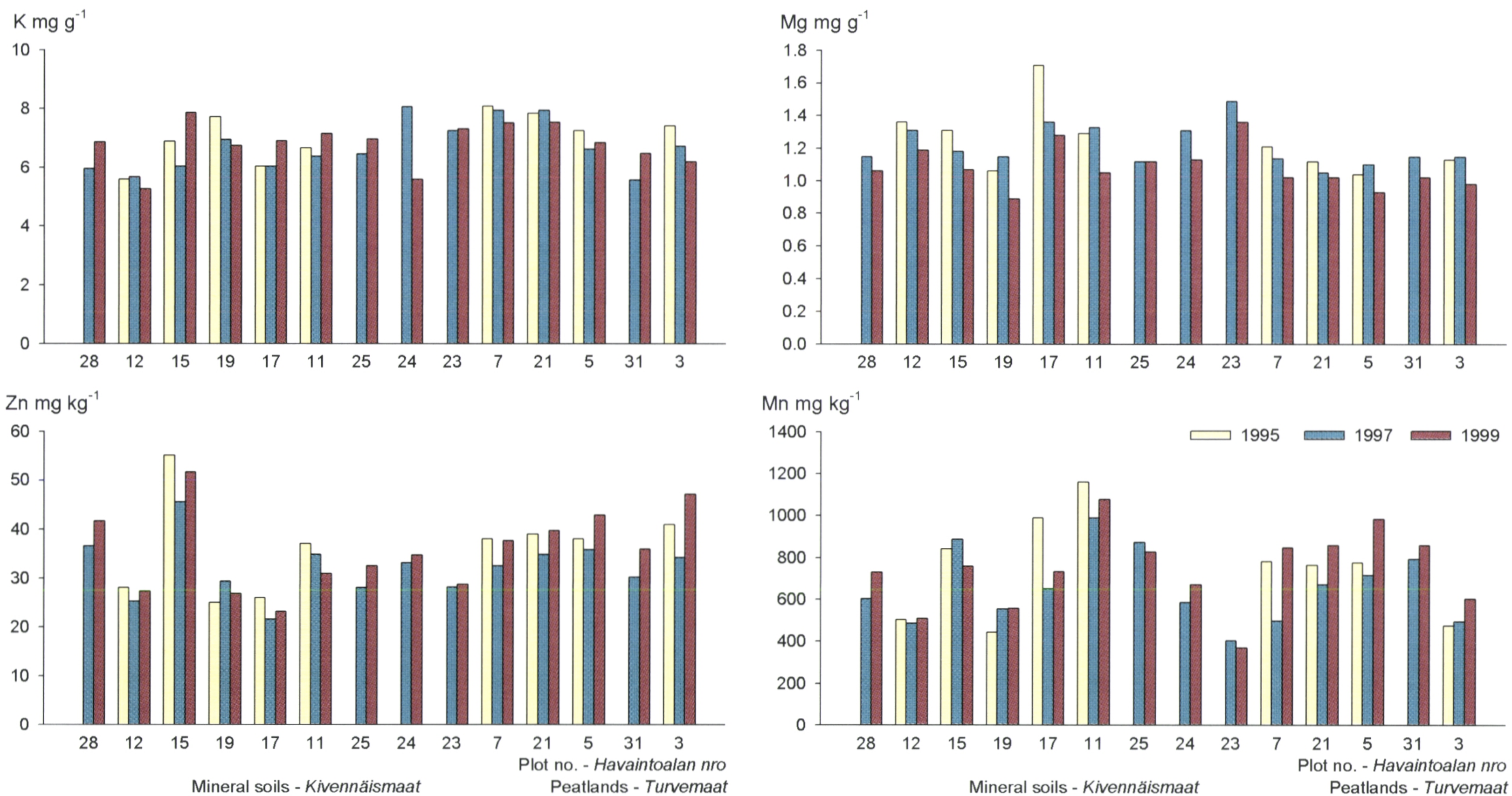

Figure 9b. Average potassium, magnesium, zink and manganese concentrations of Norway spruce current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 9b. *Kuusen nuorimpien neulasten keskimääräiset kalium-, magnesium-, sinkki- ja mangaanipitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

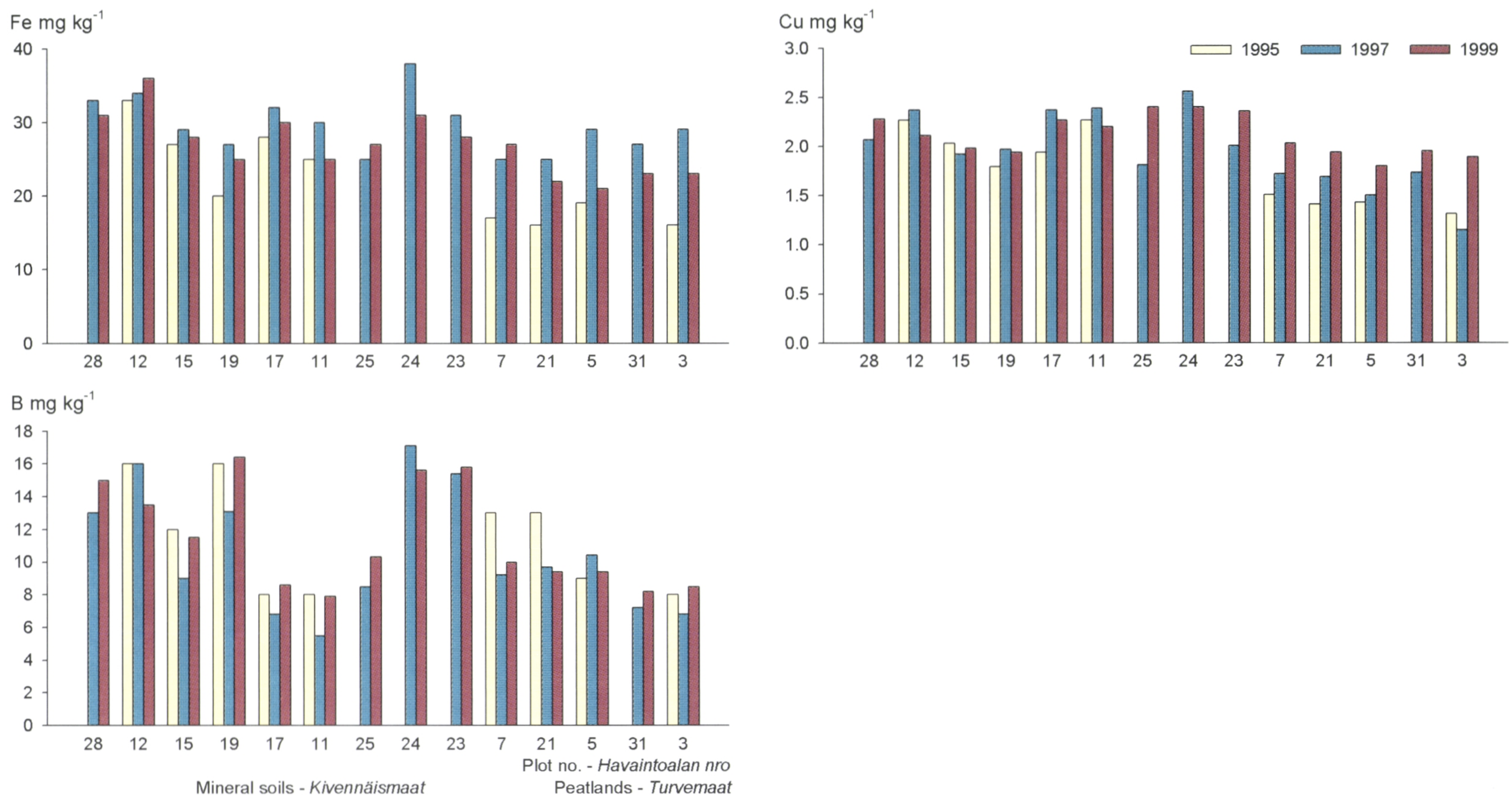

Figure 9c. Average iron, copper and boron concentrations of Norway spruce current needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.
Kuva 9c. *Kuusen nuorimpien neulasten keskimääräiset rauta-, kupari- ja booripitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

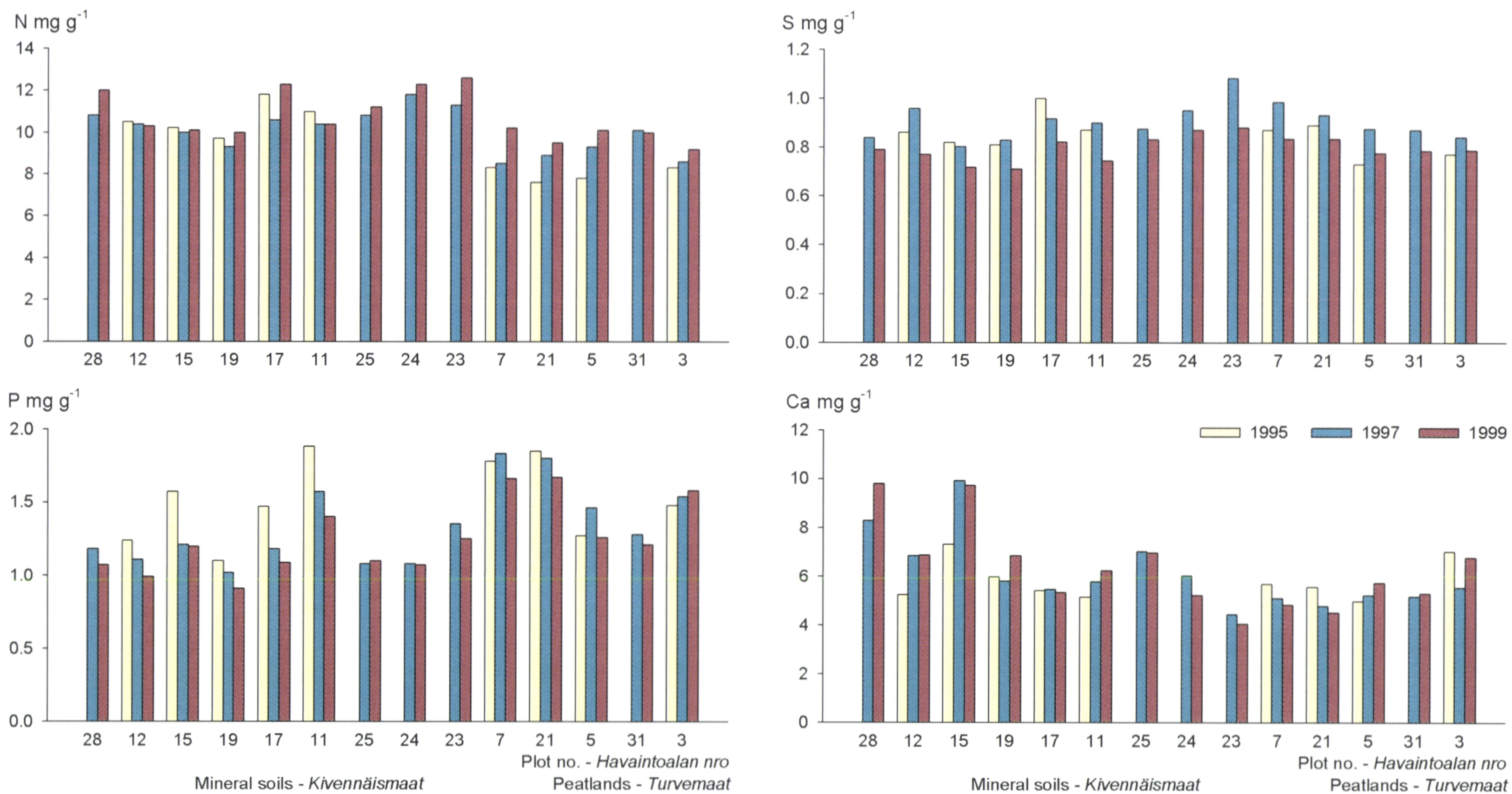

Figure 10a. Average nitrogen, sulphur, phosporus and calcium concentrations of Norway spruce previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.

Kuva 10a. *Edellisenä kesänä syntyneiden kuusen neulasten keskimääräiset typpi-, rikki-, fosfori- ja kalsiumpitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

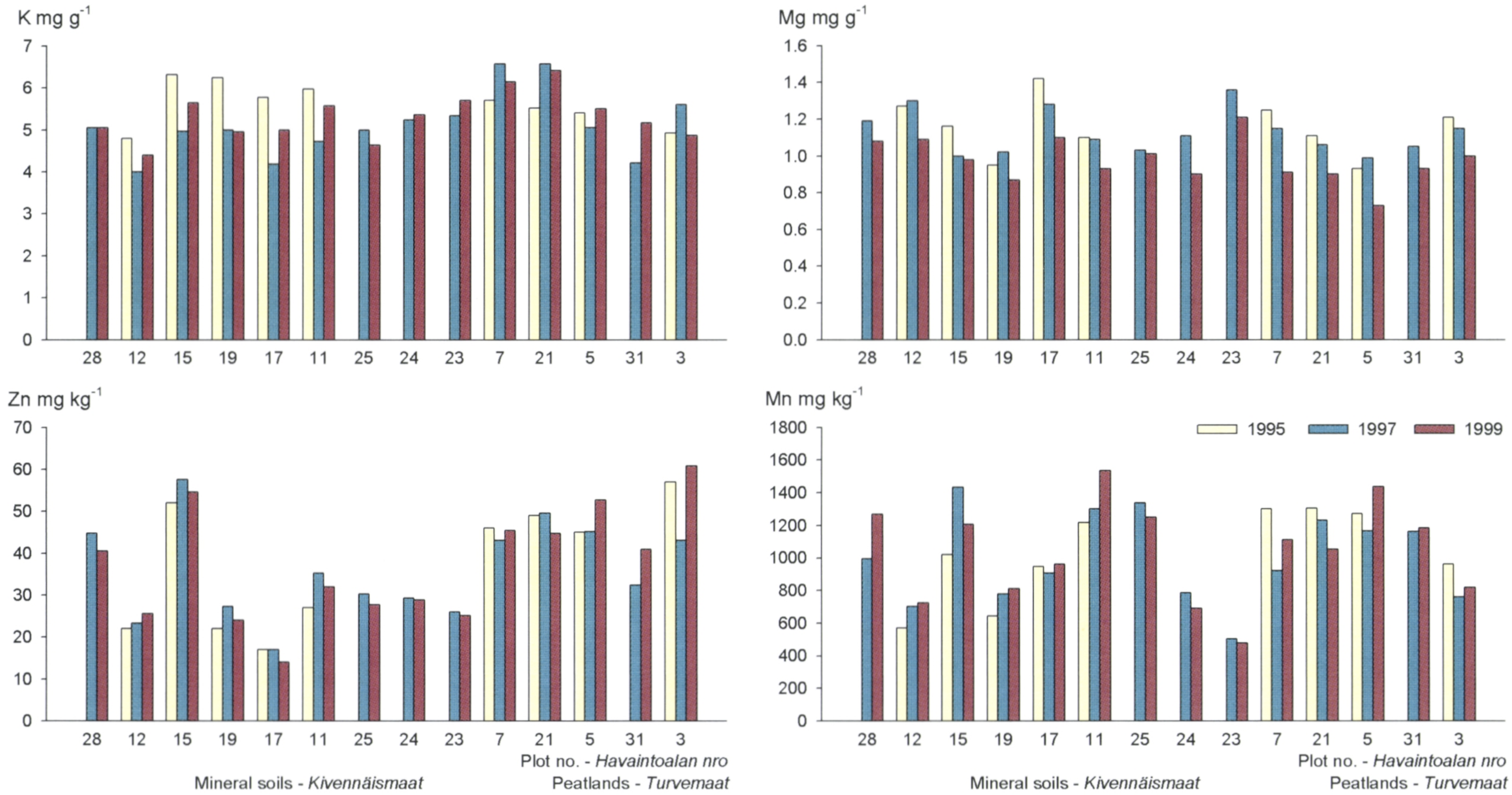

Figure 10b. Average potassium, magnesium, zink and manganese concentrations of Norway spruce previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.
Kuva 10b. *Edellisenä kesänä syntyneiden kuusen neulasten keskimääräiset kalium-, magnesium-, sinkki- ja mangaanipitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

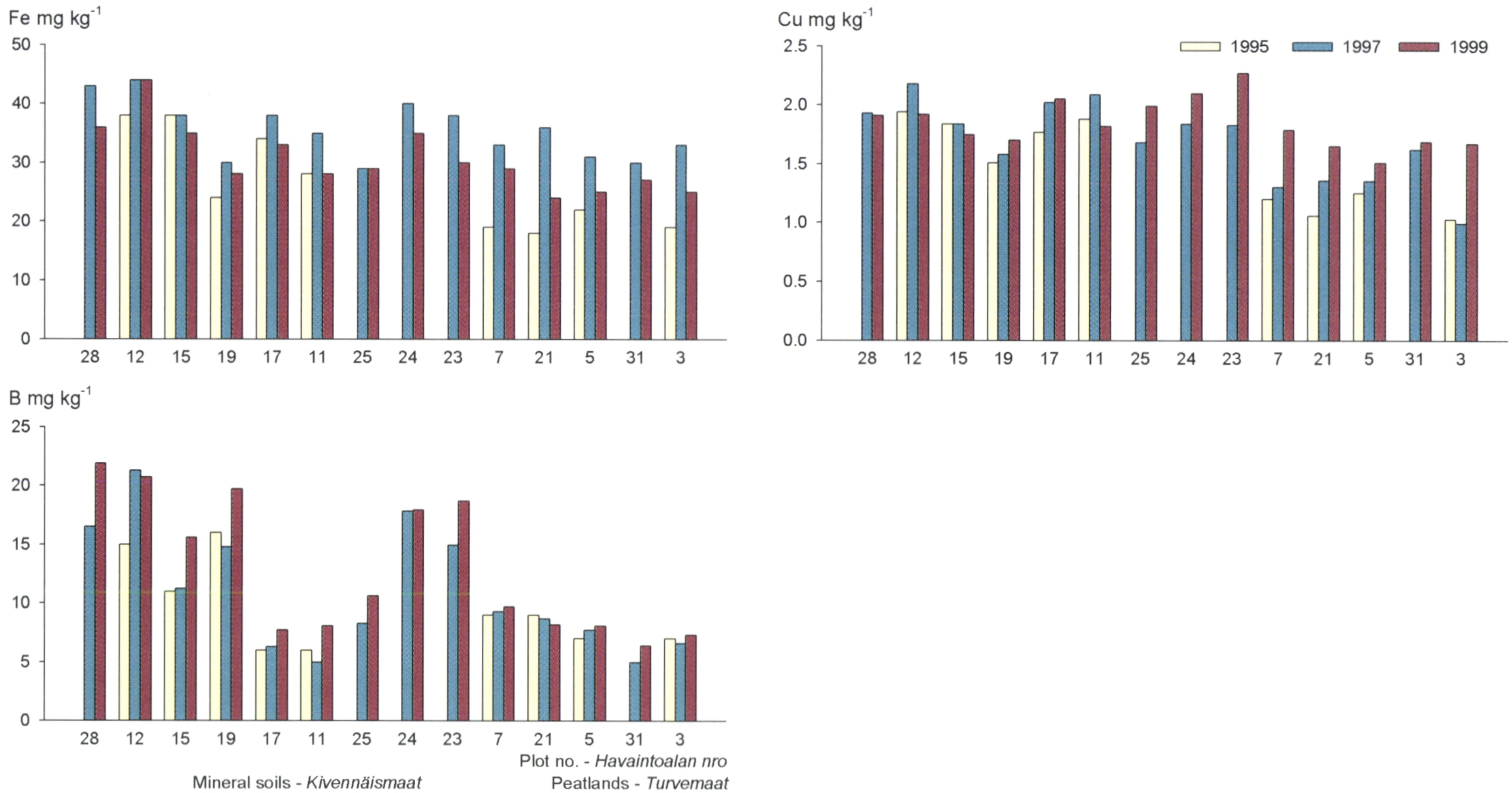

Figure 10c. Average iron, copper and boron concentrations of Norway spruce previous-year needles on the observation plots (Level II) in 1999. The plots are arranged running from south to north.
Kuva 10c. *Edellisenä kesänä syntyneiden kuusen neulasten keskimääräiset rauta-, kupari- ja booripitoisuudet metsäekosysteemien intensiivisen seurannan havaintoaloilla (Taso II) vuonna 1999. Havaintoalojen järjestys etelästä pohjoiseen.*

2 Background air quality in Finland in 1999

Tausta-alueiden ilmanlaatu Suomessa 1999

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Summary

The climatological conditions in Finland give rise to a clear seasonal behaviour for 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. Depositions of the major components affecting acidification and of many heavy metals clearly decrease from south to north, the southern part of the country receiving 2–8 times that in the northernmost part. Annual deposition values for the acidifying components are lower in 1999 than the mean values for 1987–96.

Characteristic of the weather in 1999 was the high annual temperature throughout the country. Most of the months of the year were warm in the southern and central parts of the country. However, in northern Finland, January and December were very cold, new cold weather records being set at the end of January in Lapland. The precipitation in 1999 fell very unevenly over the year. In the southern part of the country, the precipitation amount was very high at the beginning of the year, while the spring and the summer were dry.

The annual deposition of the major components affecting acidification accumulates in a highly episodic manner: the worst day of the year can bring over 10 percent of the annual deposition of sulphate, ammonium, nitrate or calcium. On March 28th a strong episode of acid deposition was measured at the stations of Virolahti, Ähtäri and Oulanka. Air masses with heavy pollution from a sector reaching from the United Kingdom in the south-west to the Balkan countries in the south passed over large areas of Finland. The daily deposition for all five compounds were within the ten highest during the year.

Concentrations of gaseous pollutants have decreased since 1985. The downward trend during the last ten years is steeper in the winter than in 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. Concentrations in certain wind sectors do not reveal the general trend. At Virolahti, the sulphur dioxide mean daily value has decreased most when the wind was from the eastern sector. At Ähtäri the decline was steepest with south-easterly winds.

Yhteenveto

Suomen tausta-alueilla useiden ilman epäpuhtauksien pitoisuudet vaihtelevat vuodenaikojen mukaan ilmastosta johtuen. Viime vuosien aikana ovat ilman primääriepäpuhtauksien ja happamoittavien yhdisteiden laskeumat vähentyneet merkittävästi päästörajoitussopimusten vaikutuksesta. Happamoittavien yhdisteiden ja eräiden raskasmetallien laskeuma pienenee selvästi etelästä pohjoiseen. Happamoittava laskeuma vuonna 1999 oli Suomessa alempi kuin vuosien 1987–96 keskimääräinen arvo.

Vuoden 1999 keskilämpötila oli korkea koko maassa. Etelä- ja keskiosissa maata useimmat kuukaudet olivat lämpimiä. Pohjois-

Suomessa tammi- ja joulukuu olivat sitä vastoin erittäin kylmiä, Lapissa saavutettiin kylmyysennätyksiä tammikuun lopulla. Sademäärä jakautui hyvin epätasaisesti vuoden mittaan, etelässä vuoden alku oli hyvin sateinen, kevät ja kesä kuivia.

Happamoittava laskeuma kerääntyy episodimaisesti, vuoden suurin vuorokausilaskeuma voi kattaa yli 10 % sulfaatin, ammoniumin, nitraatin tai kalsiumin vuosikuormasta. Maaliskuun 28. havaittiin voimakas episodi Virolahdella, Ähtärissä ja Oulangalla. Tällöin kulkeutui Suomeen saastunutta ilmaa sektorista, joka ulottui Iso-Britanniasta Baltian maihin.

Ilman kaasumaisten yhdisteiden pitoisuudet ovat vähentyneet vuodesta 1985 lähtien, alenema on voimakkaampaa talvikaudella. Virolahdella rikkidioksidin keskimääräinen vuorokausipitoisuus on vähentynyt voimakkaimmin silloin, kun tuuli on käynyt idästä, Ähtärissä suurimmat alenemat liittyvät kaakkoistuuliin.

Stations and methods

The Finnish Meteorological Institute (FMI) carries out air quality measurements at background stations that are part of several national and international networks. The first measurement station was founded at the beginning of 1970. In 1999 air quality measurements were conducted at eighteen stations throughout Finland, and deposition measurement was started at a new station at Värriö, Salla. The network of air quality measurement stations in the background areas of Finland 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 of 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 2000).

Quality assurance of the results is based on guidelines given in the EMEP Data Quality Objectives (EMEP 1996) and GAW (Mohnen et al. 1992). Samples are analyzed in an accredited testing laboratory. Regarding deposition sample measurements, the laboratory participates annually in intercomparisons 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.

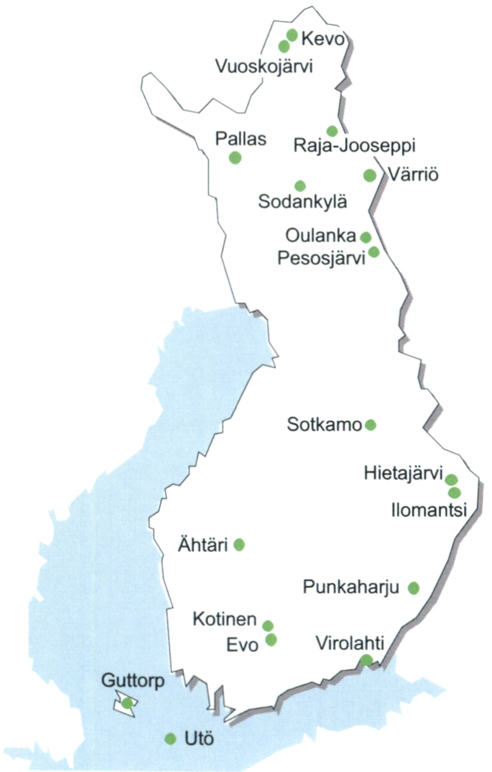

Figure 1. Finnish background air quality measuring stations in 1999.
Kuva 1. *Taustailman laatua mittaavat asemat Suomessa 1999.*

The weather in 1999

The meteorological conditions affecting air quality and deposition in general have been described in the report for the year 1997 (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 1–12/99 of Ilmastokatsaus (IL 1999) published by the FMI.

Figures 2–4 show some of the meteorological parameters (precipitation, temperature and global radiation) for 1999 compared to their long-term means.

In 1999 the precipitation fell very unevenly over the year. In the southern part of the country, the precipitation amount was very high at the beginning of the year, while the spring and the summer were dry. In central Finland, the spring and early summer were dry, but in late summer and autumn the long-term average rain amount was exceeded during several months. In northern Lapland the precipitation amount in August was exceptionally high.

The annual temperature was higher than the long-term average throughout the country. In southern Finland, at the station of Utö, all the monthly temperatures were at least as high as the average temperature. The same was true for central Finland, with the exception of the cold month of May. In northern Finland, January and December were very cold, new cold weather records being set at the end of January in Lapland.

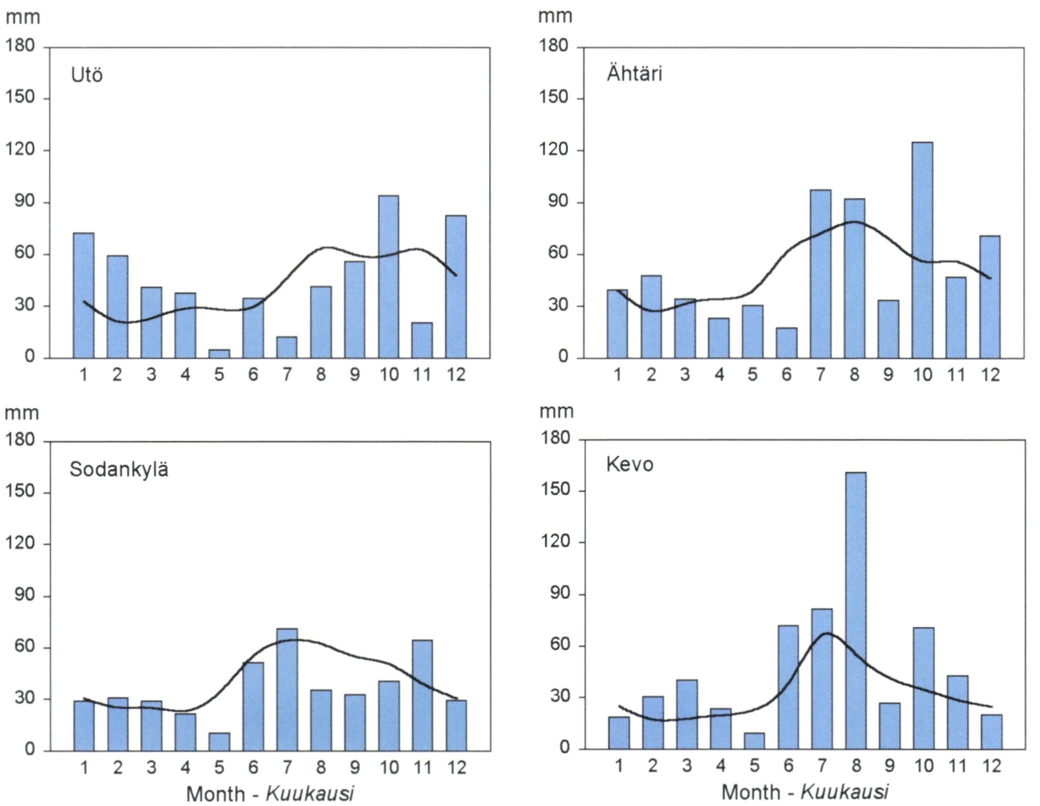

Figure 2. Monthly precipitation in 1999 (bars) and long-term (1961–90) averages (line) at Utö, Ähtäri, Sodankylä and Kevo.
Kuva 2. *Sademäärä kuukausittain vuonna 1999 (pylväät) ja vertailukauden (1961–90) keskimääräinen sademäärä (viiva) Utössä, Ähtärissä, Sodankylässä ja Kevolla.*

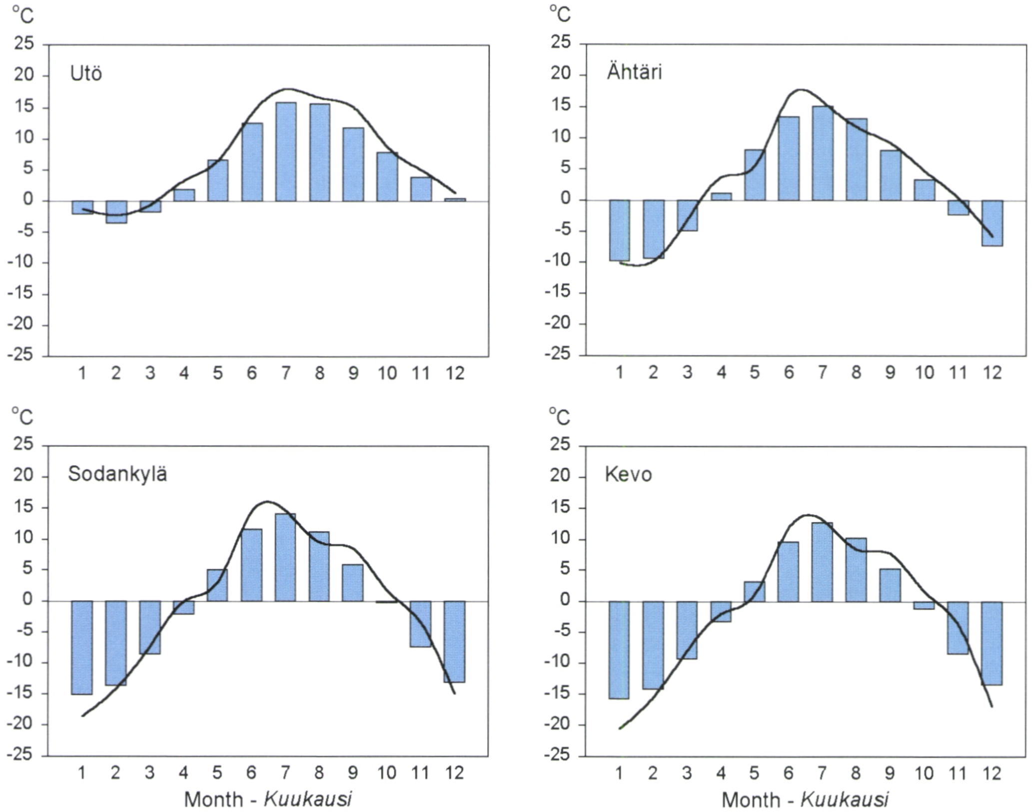

Figure 3. Mean monthly temperatures in 1999 (bars) and long-term (1961–90) averages (line) at Utö, Ähtäri, Sodankylä and Kevo.
Kuva 3. *Lämpötilan keskiarvo kuukausittain vuonna 1999 (pylväät) ja vertailukaudella (1961–90) keskimäärin (viiva) Utössä, Ähtärissä, Sodankylässä ja Kevolla.*

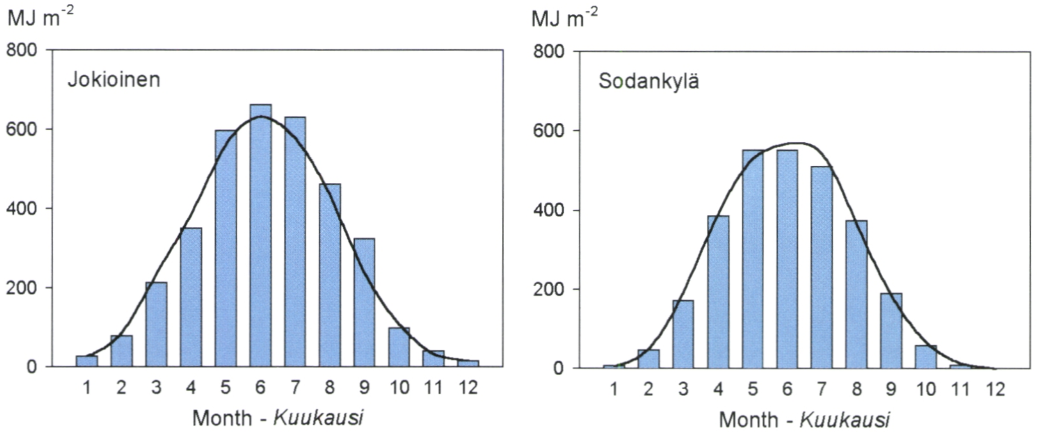

Figure 4. Monthly amounts of global radiation in 1999 (bars) and long-term (1961–90) averages (line) at Jokioinen and Sodankylä.
Kuva 4. *Globaalisäteilyn kuukausisummat vuonna 1999 (pylväät) ja vertailukauden (1961–90) keskiarvot (viiva) Jokioisissa ja Sodankylässä.*

Solar radiation is essential for many chemical reactions in the atmosphere, e.g. the 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 annual sum of global radiation was about 4 % higher than normal, while northern areas received about 2 % less radiation than the long-time average.

Deposition

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

The annual depositions at four stations in different parts of the country in 1999 are given in Fig. 5. The stations have been arranged along the abscissa from south to north.

Depositions of the major components affecting acidification clearly decrease from south to north, the southern part of the country receiving 2–8 times that in the northernmost part. The geographical difference is strongest for calcium and ammonium, and weakest for hydrogen ion depositions.

The annual deposition values in 1999 are lower than the mean values for 1987–96, except for nitrate and ammonium 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, Leinonen et al. 2000). The decrease in 1999 compared to the period 1987–96 is strongest for calcium deposition: about 60 % at the southern station, 20 % at the central Finland station, and 30 % in the north. The decline in sulphate depositions was 50 % at the southern station, 40 % at the central Finland station, 30 % in the southern part of Lapland and 20 % in the far north. Hydrogen ion deposition decreased by between 20 and 30 % in the southern and central parts of the country, respectively, and by 30 % in the southern part of Lapland, but remained almost unchanged in the far north. The deposition of nitrate decreased by 20 % at the southern station, remained unchanged at the central Finland station, decreased slightly in southern Lapland and increased by 20 % in the far north. Finally, the ammonium deposition in 1999 decreased by 30–40 % at the southern and central Finland stations compared to the 1987–96 mean value, while no change was observed at the southern Lapland station and an increase of 50 % was calculated for the northern Finland station of Kevo.

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).

Annual deposition of some heavy metals

The annual depositions in 1999 of some heavy metals 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 differences in the depositions from south to north are rather similar for lead, cadmium and chromium: the deposition measured in the far north is only 15–30 % of that on the south coast. The south-north gradient in copper deposition is weaker. The relatively high copper depositions at the northern and eastern stations are presumably connected with the huge copper emissions from the Kola peninsula (AMAP 1997). The unusually high annual deposition of chromium at Virolahti is due to high monthly depositions in March and December.

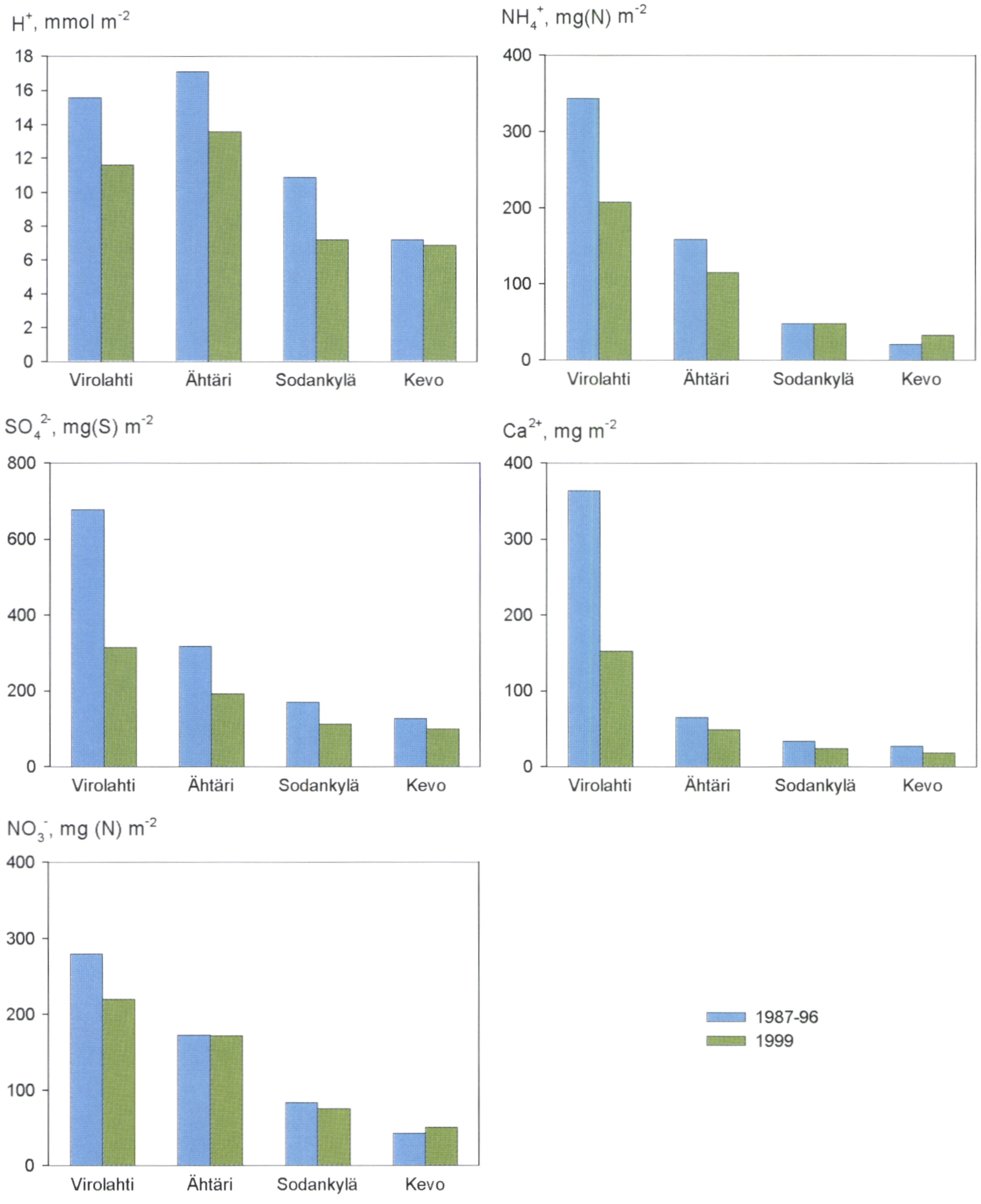

Figure 5. Deposition of components in 1999 compared with average values for 1987–96 data.
Kuva 5. *Happamoitumiseen liittyvien yhdisteiden vuosilaskeuma 1999 verrattuna keskimääräiseen arvoon vuosina 1987–96.*

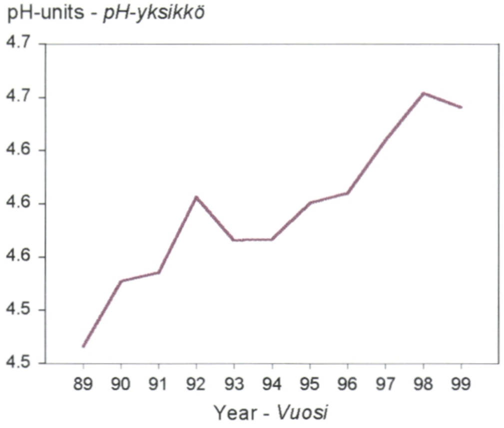

Figure 6. Increase in the mean pH of precipitation in Finland during the last 10 years. The value is the precipitation-amount-weighted mean value of the annual averages of 12 air quality stations covering the whole country.
Kuva 6. *Sadeveden pH-arvon kohoaminen Suomessa 10 viime vuoden aikana. Kuvaaja on laskettu 12 eri puolilla Suomea sijaitsevan ilmanlaatuaseman pH:n vuosikeskiarvoista sademäärällä painottaen.*

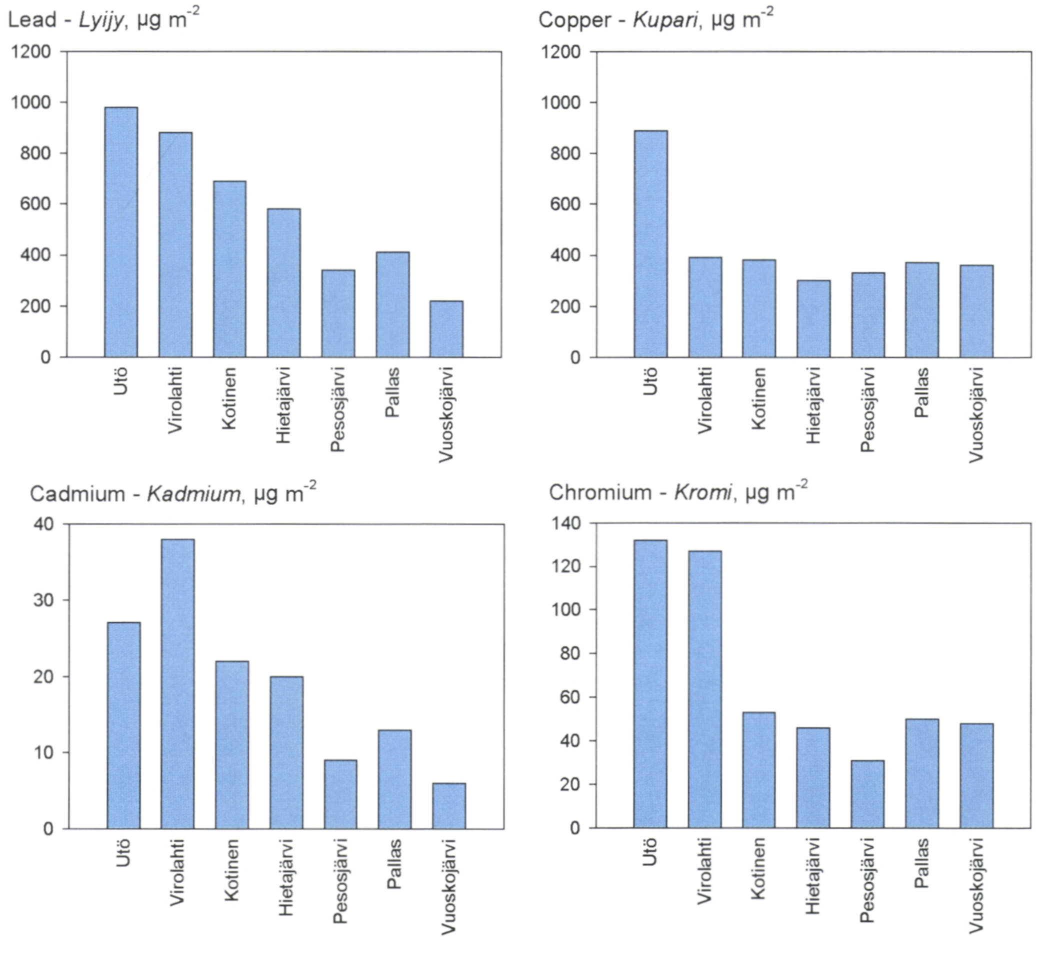

Figure 7. Deposition of some heavy metals in 1999.
Kuva 7. *Eräiden raskasmetallien laskeuma vuonna 1999.*

Seasonal variation of deposition

The seasonal variations in the amount of precipitation and the 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 the monthly means for February, March, November and December 1999 were calculated from data representing 50–75 % of the official amount of precipitation (Leinonen 2000). 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 the far north, at Kevo, the precipitation amount in August was exceptionally high. Isolated high monthly values were also measured during summer and autumn at some other northern and central Finland stations.

The seasonal variation of hydrogen ion deposition (Fig. 8b) usually follows the variation in the amount of precipitation rather closely. In 1999 the deposition is distributed relatively evenly at the central and northern Finland stations; in the south, peaks occurred at the beginning and end of the year as well as in October.

The normal maximum deposition of sulphate in summer is not very clear at any of the stations (Fig. 8c). In the south, the small amount of precipitation during the summer caused low depositions. The monthly deposition values at the central and northern stations fluctuated more, and there maximum values were also measured during some of the summer months. At Ähtäri a high monthly value was measured in October, half of this being due to a high sulphate concentration on a single rainy day at the beginning of the month.

The overall seasonal variation for nitrate deposition (Fig. 8d) closely resembled that for sulphur deposition, especially at the southern stations. High values were measured at the southern stations in January and December. The seasonal variation in the north, as well as at the Sotkamo and Punkaharju stations in the east and south-east, respectively, was weak. One day in the middle of March was responsible for the high monthly deposition at Oulanka.

The overall seasonal variation in ammonium fluctuated greatly, especially in the south. Most stations received a high monthly deposition in March and October. A summer maximum in June or July is also visible (Fig. 8e). At Ähtäri, the high October deposition was mainly caused by the same episode at the beginning of the month that also raised sulphate and nitrate deposition to an annual maximum.

Figure 8f shows the variation in calcium deposition. In the north, and at all southern stations except Guttorp, the seasonal variation is rather low, the summer values being slightly higher than those in winter. An autumn maximum is visible at Sotkamo and Ähtäri in October, and rather high depositions were also measured in March or April at most of the stations. The high deposition at Guttorp in April might be caused by local emissions from bare soil.

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

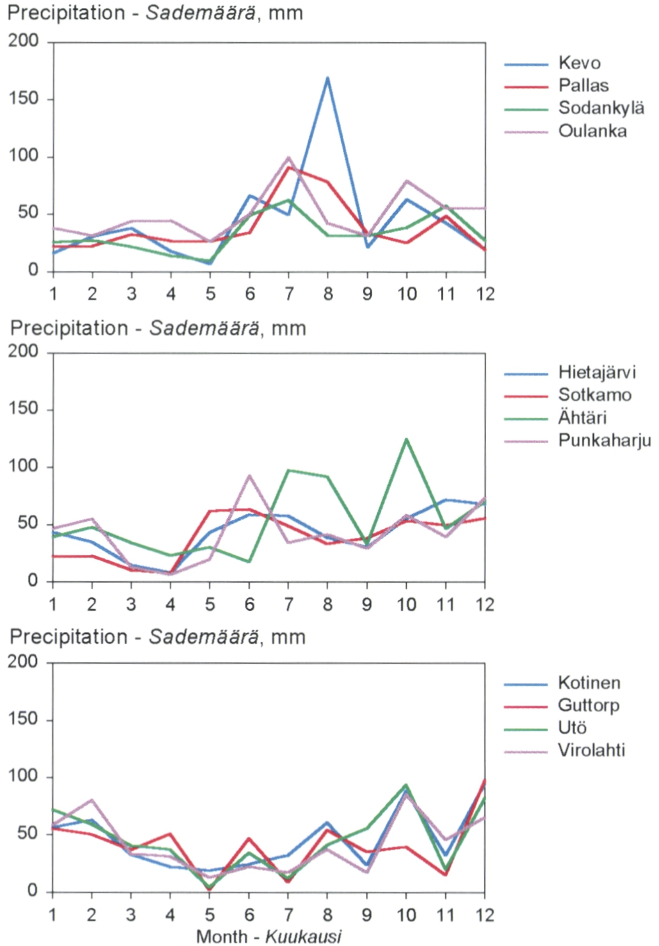

Figure 8a. Seasonal variation in the amount of precipitation in 1999.
Kuva 8a. *Sademäärän vuodenaikaisvaihtelu vuonna 1999.*

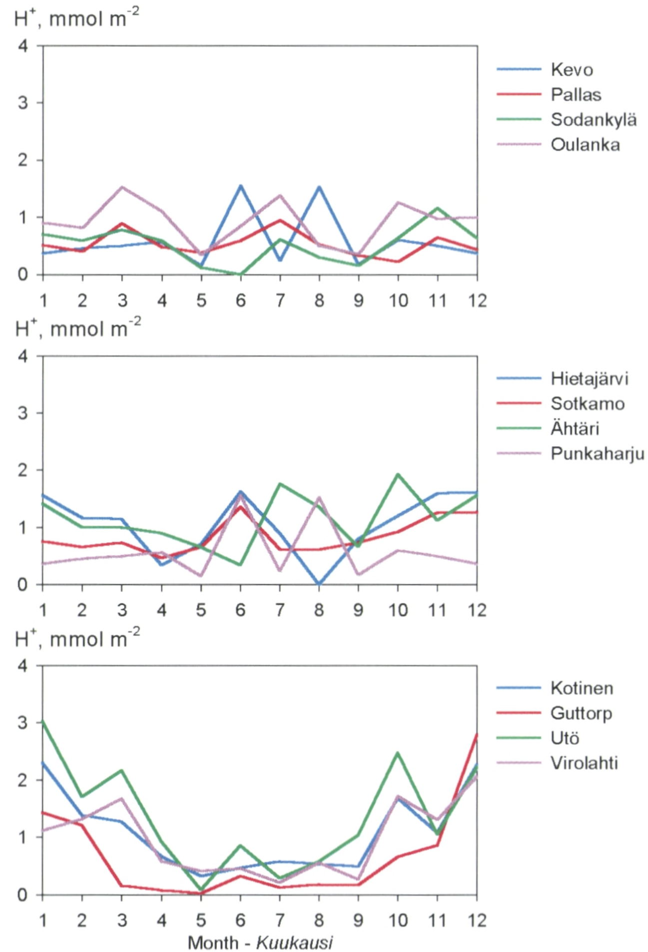

Figure 8b. Seasonal variation in hydrogen ion depositions in 1999.
Kuva 8 b. *Vetyionilaskeuman vuodenaikaisvaihtelu vuonna 1999.*

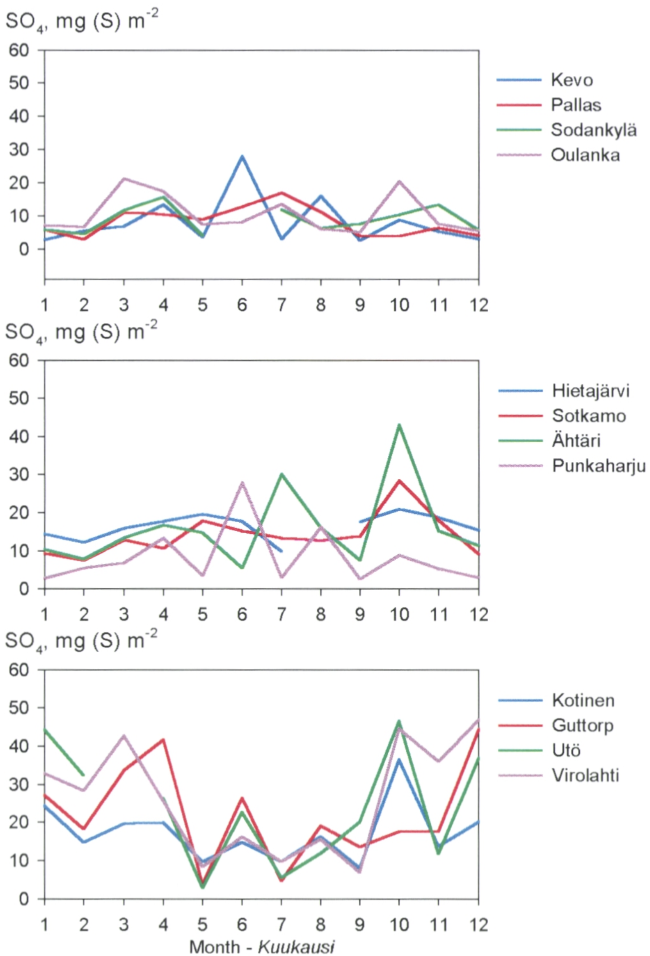

Figure 8c. Seasonal variation in sulphate depositions in 1999.
Kuva 8c. *Sulfaattilaskeuman vuodenaikaisvaihtelu vuonna 1999.*

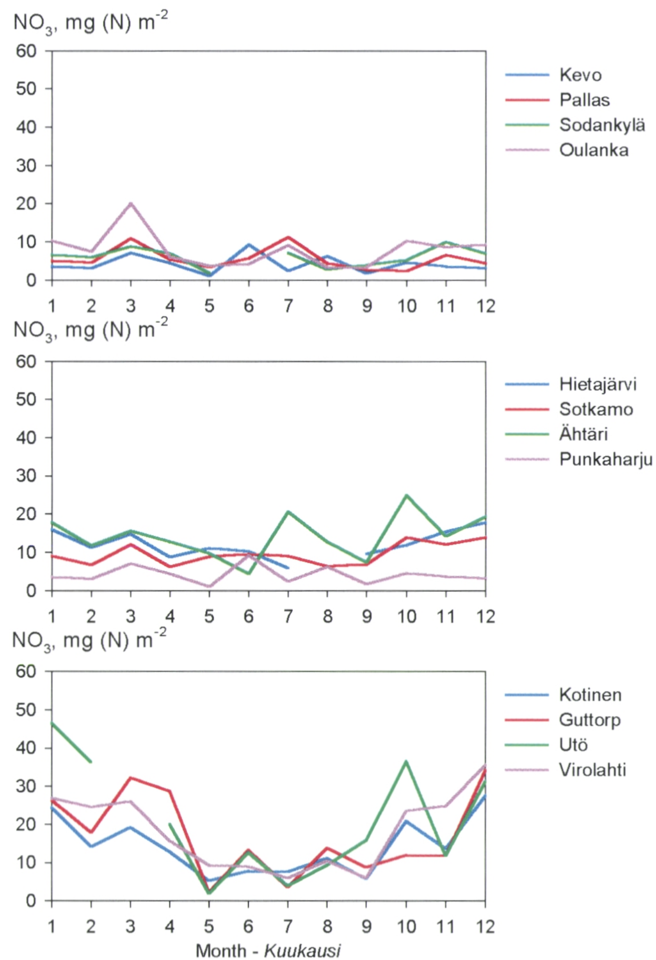

Figure 8d. Seasonal variation in nitrate depositions in 1999.
Kuva 8d. *Nitraattilaskeuman vuodenaikaisvaihtelu vuonna 1999.*

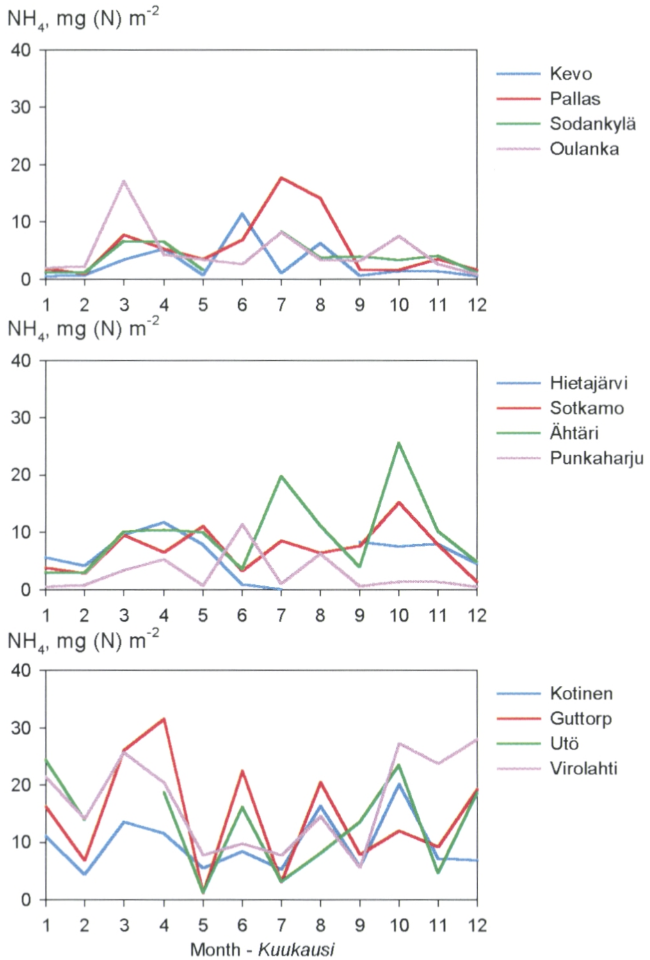

Figure 8e. Seasonal variation in ammonium depositions in 1999.
Kuva 8e. *Ammoniumlaskeuman vuodenaikaisvaihtelu vuonna 1999.*

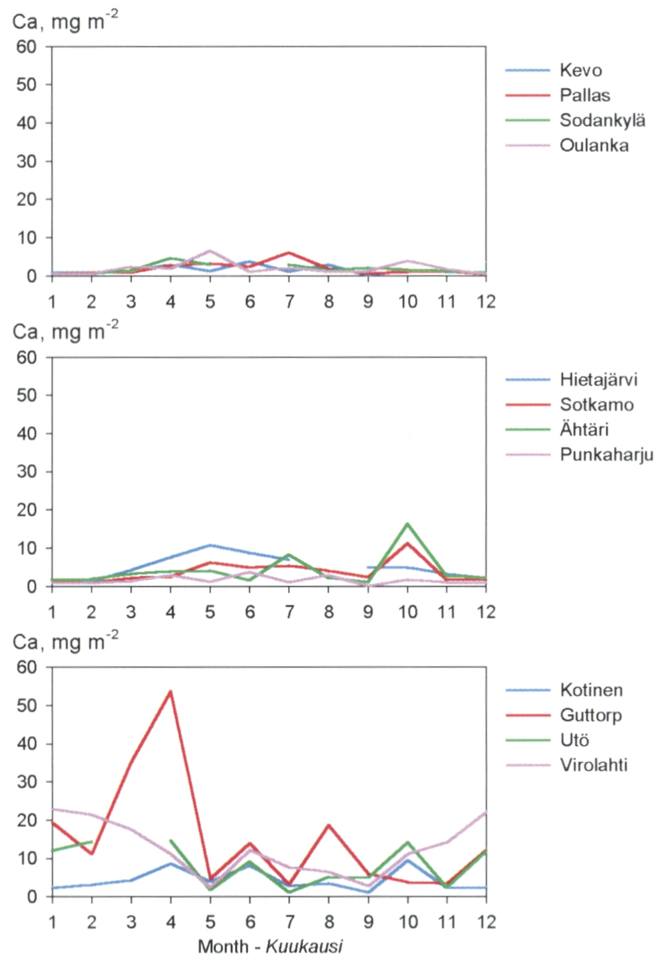

Figure 8f. Seasonal variation in calcium depositions in 1999.
Kuva 8f. *Kalsiumlaskeuman vuodenaikaisvaihtelu vuonna 1999.*

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 the calcium deposition at all stations except for Virolahti, the worst day of the year bringing almost 20 % of the annual load, and the load of the ten worst days amounting to 50 % of the annual load. The nitrogen deposition at Utö is also episodic: the worst day brings over 20 % of the total annual load.

The days with high deposition values were often the same for several of the stations. Many of the episodes were connected with high precipitation values and moderate concentrations of contaminants, but a low precipitation value with a high concentration can also cause an episode. On March 28th, highly polluted air masses from central Europe passed over large areas of Finland, and with a rather low amount of precipitation (3–6 mm) high depositions were measured at background stations. Fig. 9 shows the tracks of the air masses for the previous 96 hours at the stations of Virolahti, Ähtäri and Oulanka. At Utö there was no rain. Four trajectories describing the track of the air masses and arriving at the station at 00, 06, 12 and 18 GMT have been drawn in the same figure. At Virolahti and Oulanka, the daily depositions for all five compounds were within the ten highest for the year; at Ähtäri, nitrate and ammonium depositions reached peak values for the year. At Oulanka, the episode had already begun on 27th March, with high deposition values for all the components concerned.

Table 1. The percentage fraction of the largest, 5 largest and 10 largest daily deposition values in the annual deposition.
Taulukko 1. *Suurimman, 5 suurimman ja 10 suurimman vuorokausilaskeuman prosenttiosuus vuosilaskeumasta.*

	H^+	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}
Oulanka (182 days with precipitation amount > 0.2 mm - *182 päivänä sademäärä > 0.2 mm*)					
largest, % - *suurin*, %	4.9	6.4	9.8	14.5	22.6
5 largest, % - *5 suurimman*, %	16.6	23.9	20.5	33.3	41.0
10 largest, % - *10 suurimman*, %	25.8	34.3	28.6	48.2	50.4
Ähtäri (170 days - *päivää*)					
largest, % - *suurin*, %	4.3	8.8	4.5	9.9	21.5
5 largest, % - *5 suurimman*, %	12.5	25.2	14.8	30.2	41.1
10 largest, % - *10 suurimman*, %	20.6	34.7	24.2	43.5	51.5
Virolahti (150 days - *päivää*)					
largest, % - *suurin*, %	5.6	5.6	3.2	4.3	4.2
5 largest, % - *5 suurimman*, %	18.8	18.1	13.0	15.6	19.0
10 largest, % - *10 suurimman*, %	29.6	29.1	22.1	26.2	30.7
Utö (152 days - *päivää*)					
largest, % - *suurin*, %	3.9	10.3	21.8	5.3	19.2
5 largest, % - *5 suurimman*, %	16.8	20.7	30.9	18.1	41.4
10 largest, % - *10 suurimman*, %	28.5	29.5	38.2	29.3	47.8

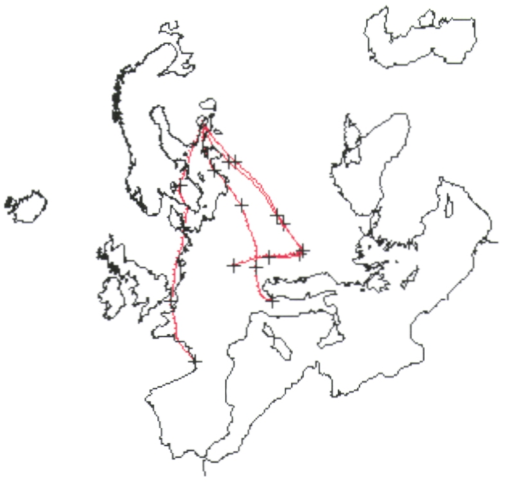

Figure 9a. Virolahti
Kuva 9a. Virolahti

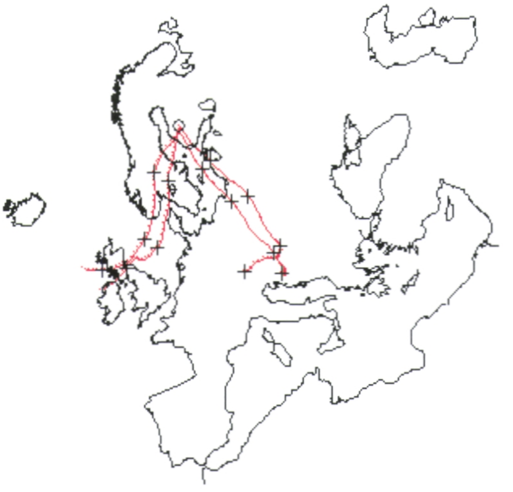

Figure 9b. Ähtäri
Kuva 9b. Ähtäri

Figure 9c. Oulanka
Kuva 9c. Oulanka

Figure 9. The four trajectories arriving at the stations at 00, 06, 12 and 18 GMT on 28.3.99.
Kuva 9. *Neljälle havaintoasemalle 28.3.99 klo 00, 06, 12 ja 18 GMT saapuneiden trajektorien reitit.*

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. Although acidification is well understood, research work is still going on, especially on questions as to why acidification is still migrating in the lakes and rivers and in soils.

The main source of sulphur dioxide is industry and energy production. Amounts from natural sources, such as volcanos and biomass burning, only total 1/6 of that from man made emissions. 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 decrease in the sulphur dioxide concentration in ambient air is due to the abatement programmes on the European level and also globally. The Protocol on the Reduction of Sulphur Emissions at the European level, which was adopted in 1985 and came into force in 1987, committed European countries to cut their emissions by 30 % from those of the year 1980 by the year 1993. Furthermore, the Second Protocol of Further Reduction of Sulphur Emissions was adopted in 1994, committing participant countries to further individual reductions of sulphur dioxide. 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. 10a and at Oulanka, Sodankylä and Kevo in Fig. 10b. The reader is reminded of the change in the sampling method for sulphur dioxide within the EMEP-programme occurring in June 1989. This applies to data from the stations of Utö, Virolahti, Ähtäri and Oulanka. The sampling methods for sulphur dioxide at EMEP stations include both filter pack sampling on a daily basis since 1989 (EMEP 1996), and continuous

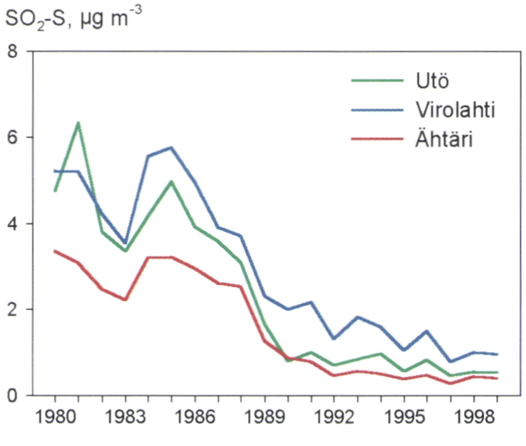

Figure 10a. Mean annual sulphur dioxide concentrations (expressed as sulphur) at Utö, Virolahti and Ähtäri.
Kuva 10a. *Rikkidioksidin vuosikeskiarvo (rikiksi laskettuna) Utössä, Virolahdella ja Ähtärissä.*

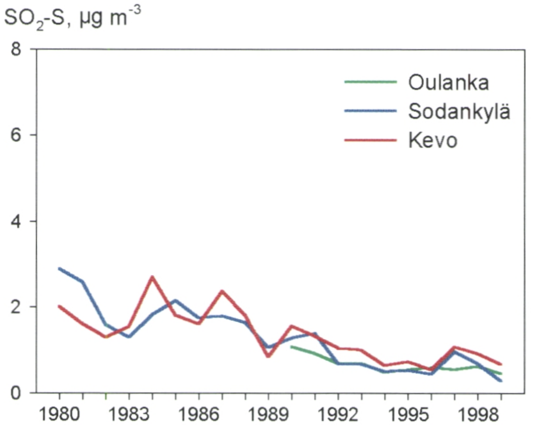

Figure 10b. Mean annual sulphur dioxide concentrations (expressed as sulphur) at Oulanka, Sodankylä and Kevo.
Kuva 10b. *Rikkidioksidin vuosikeskiarvo (rikiksi laskettuna) Oulangalla, Sodankylässä ja Kevolla.*

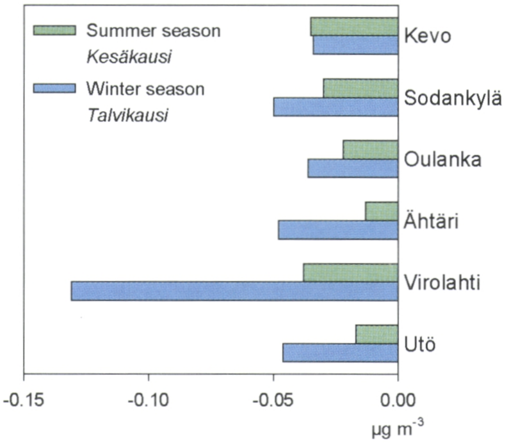

Figure 11. Summer and winter trends for sulphur dioxide, slope estimates from Utö, Virolahti, Ähtäri, Oulanka, Sodankylä and Kevo from 1989 to 1999.
Kuva 11. *Rikkidioksidin trendit kesäkaudella ja talvikaudella, kulmakerroinestimaatit Utössä, Virolahdella, Ähtärissä, Oulangalla, Sodankylässä ja Kevolla ajanjaksolla 1989–99.*

monitoring by UV-fluorescence analysers starting in 1990. At the stations of Kevo and Sodankylä, 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 the stations of Utö, Virolahti, Ähtäri, Oulanka, Sodankylä and Kevo in Fig. 11.

There are spatial differences in sulphur dioxide concentrations across the country. There is an overall decrease in concentrations on moving northwards from the southern coast. 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 measurement stations are also influenced by local sources even when the stations are classified as background stations. At some stations, local emissions can decrease faster than average emissions over the whole country or in certain wind sectors concentrations do not reveal the general trend. This can be seen in Fig. 12, in which the pollution roses are presented for Ähtäri and

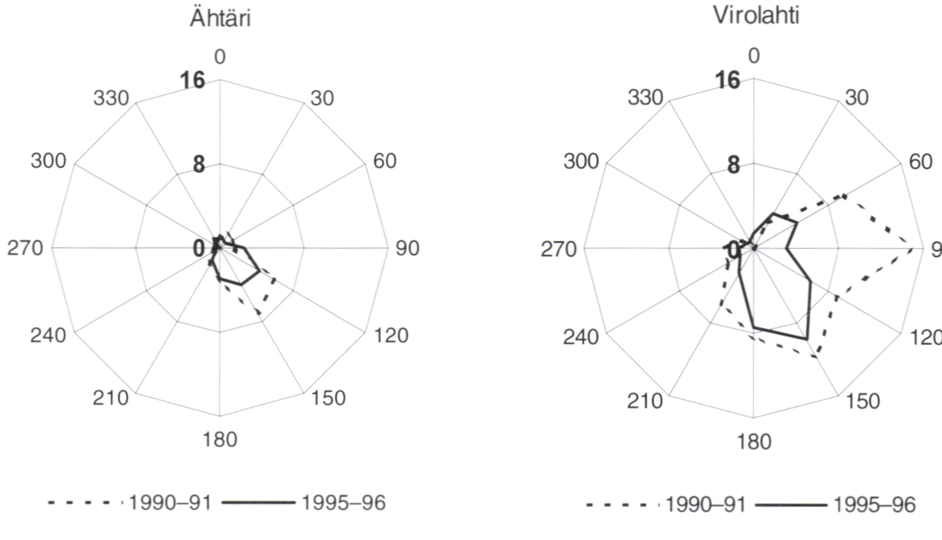

Figure 12. Pollution roses for mean daily concentrations (µg m^{-3}) of sulphur dioxide (expressed as sulphur) at Ähtäri and Virolahti during 1990–91 and 1995–96.
Kuva 12. *Rikkidioksidin keskimääräisen vuorokausipitoisuuden (µg m^{-3}) saasteruusut Ähtärissä ja Virolahdella vuosina 1990–91 ja 1995–96 (rikiksi laskettuna).*

Virolahti from the periods 1990–91 and 1995–96. The concentrations are mean daily values obtained from such days when the wind has blown from the same sector during the sampling time of the filters. Because the prevailing wind direction is south-westerly, there are not so many data from the northern sectors. However, in general there are not so many emission sources either. Also notice that the highest concentrations at Virolahti are from the east and south-east, as pointed out in the previous chapter.

The seasonal pattern in sulphur dioxide is primarily due to the heating period in winter time, as is shown in Fig. 13. 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.

Oxides of nitrogen

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 together 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. Oxidized

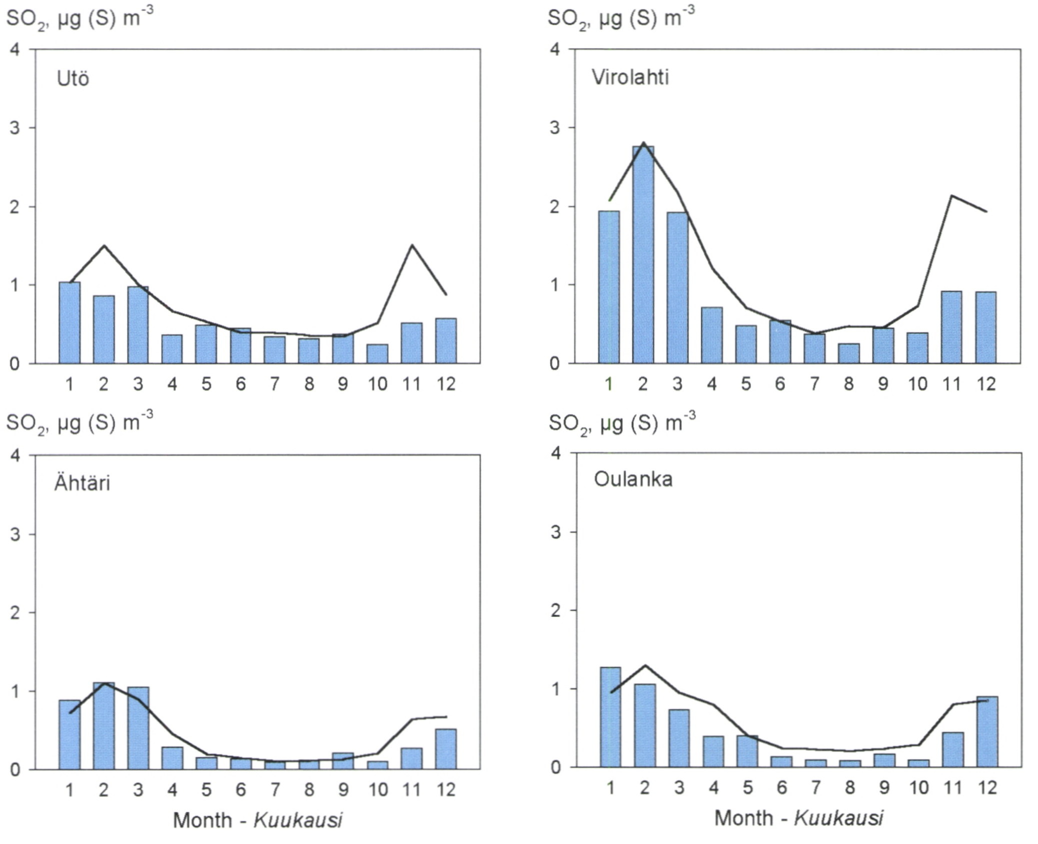

Figure 13. Monthly averages of sulphur dioxide concentrations (expressed as sulphur) in 1999 (bars) compared with the long-term (1992–98) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.
Kuva 13. *Rikkidioksidin kuukausikeskiarvot (rikiksi laskettuna) vuonna 1999 (pylväät) verrattuna pitkän ajan (1992–98) keskiarvoon (viiva) Utössä, Virolahdella, Ähtärissä ja Oulangalla.*

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.

Measurements of oxides of nitrogen at background stations were started at Utö in 1987 with nitrogen dioxide measurements. Difficulties were found in detecting low concentrations of nitrogen dioxide with the method used, and it was replaced in 1997 by measurements of nitrogen monoxide and nitrogen dioxide using chemiluminescence analyzers.

The seasonal variation in nitrogen dioxide concentrations at EMEP stations is shown together with the monthly averages for the years 1991–98 in Fig. 14.

Ozone

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 background air quality stations is shown in Fig. 15.

The increasing trend in the ozone concentration, reported in Kulmala et al. (1998), is also evident in southern Finland, but at northern stations the trend does not exist: see Table 2.

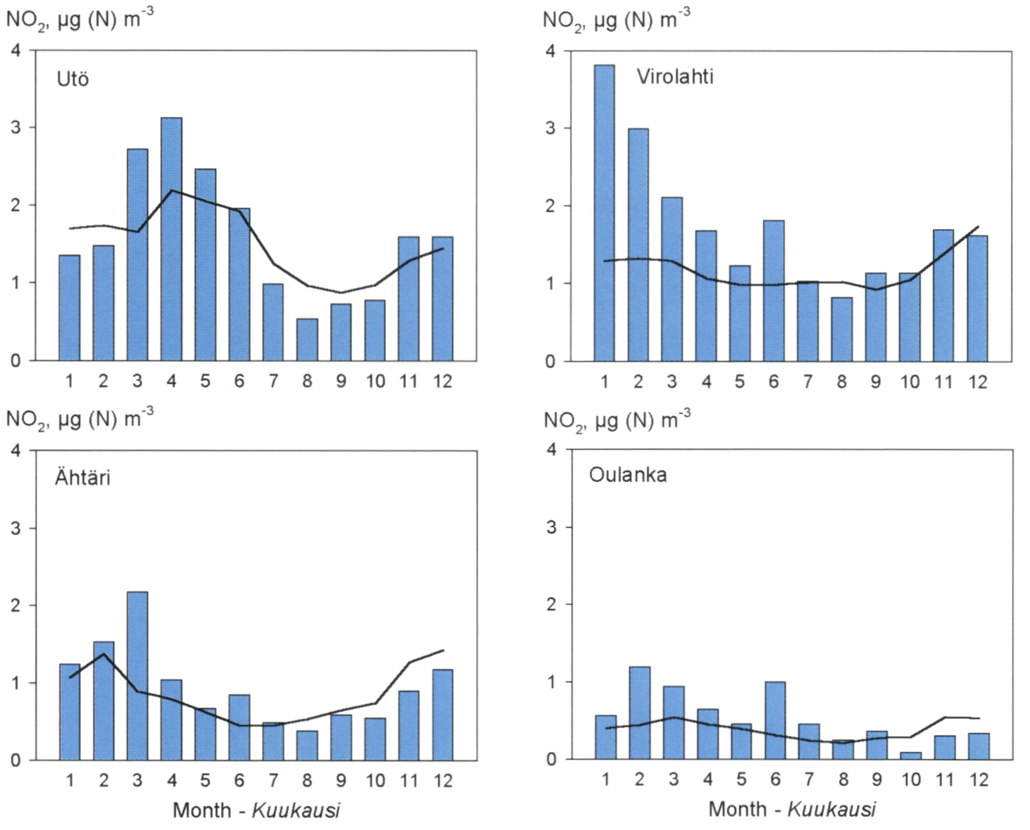

Figure 14. Monthly averages of nitrogen dioxide concentrations (expressed as nitrogen) in 1999 (bars) compared with the long-term (1992–98) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.
Kuva 14. *Typpidioksidin kuukausikeskiarvot (typeksi laskettuna) vuonna 1999 (pylväät) verrattuna pitkän ajan (1992–98) keskiarvoon (viiva) Utössä, Virolahdella, Ähtärissä ja Oulangalla.*

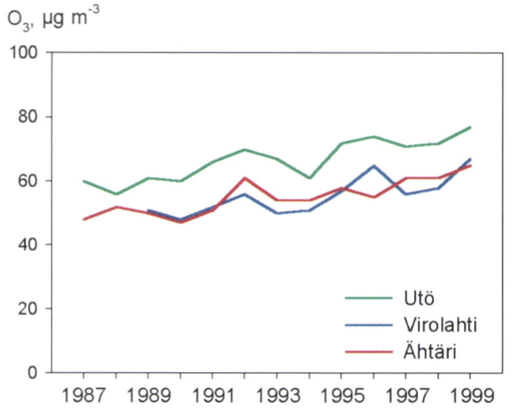

Figure 15. Mean annual concentrations of ozone.
Kuva 15. *Otsonin keskimääräinen vuosipitoisuus.*

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 ozone concentrations also display some spatial and temporal features. In Fig. 16 we show the regression matrix from all the stations as monthly means during the period 1992 to 1999. There is good correlation between the coastal stations of Utö and Virolahti and also a good correlation between the northern stations of Oulanka, Sammaltunturi and Raja-Jooseppi. In Central Finland there is only one station, Ähtäri, which does not seem to correlate with the others.

Some spatial changes in the distribution of ozone monthly mean concentrations are also seen from the quantile-quantile plots (qq-plots) from the stations above. In Fig. 17a qq-plots against the normal distribution at Utö, Virolahti and Ähtäri are shown, and in Fig. 17b those from Oulanka, Sammaltunturi and Raja-Jooseppi. We can see that in general the monthly means do fit the normal distribution, except at lower concentrations. However, statistical methods assuming a normal distribution of the data can be used for the monthly means of ozone concentrations.

The seasonal pattern of ozone concentrations has some typical features (Fig. 18). 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 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 importance of particulate sulphate as a negative factor acting against the so-called greenhouse effect has became evident in recent years through global models (IPCC 1995). Sulphate particles reflect sunlight back into space, decreasing the intensity of the sunlight at the ground. The density of sulphate particles in the atmosphere is at its highest in mid- and high latitudes (in the northern hemisphere).

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 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 in which 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 1999 is shown in comparison with the mean values for 1993–98 in Fig. 19. Concentrations of particulate sulphate along the south coast of Finland are higher than those in other parts of the country. The spatial variation of particulate sulphate follows that of sulphur dioxide (Fig. 13) and the total deposition of sulphate (Fig. 5).

Table 2. The seasonal trend of ozone over the period 1987–99. The seasonal slope with its confidence interval, as well as the significance of the trend, have been calculated. The slope is given as O_3 µg m^{-3}/season.
Taulukko 2. *Otsonin vuodenaikaistrendi ajanjaksona 1987-99. Taulukossa on laskettuna kulmakerroin vuodenajoittain, luotettavuusväli sekä trendin merkitsevyys. Kulmakertoimen yksikkö on O_3 µg m^{-3}/vuodenaika.*

Month *Kuukausi*	Utö	Virolahti	Ähtäri	Oulanka	Sammal-tunturi	Raja-Jooseppi	All stations *Kaikki asemat*
January	1.86 **	1.0 #	1.90 **	1.9 *	- 1.0 #	0.4 #	1.60 ***
Tammikuu	0.3–3.2		0.3–3.0	0.4–3.2			0.4–2.2
February	2.19 ***	2.00 **	2.17 ***	1.40 **	1.3 #	1.0 #	1.80 ***
Helmikuu	1.0–3.7	0.8–4.0	0.3–4.0	0.0–1.8			1.3–2.4
March	0.9 *	2.50 **	1.60 **	1.50 **	1.0 #	1.0 #	1.40 ***
Maaliskuu	0.0–1.9	0.7–4.7	0.0–3.3	0.3–2.6			0.5–2.5
April	0.1 #	2.29 ***	1.5 *	0.9 *	1.1 #	2.0 #	1.10 ***
Huhtikuu		0.5–4.1	0.1–3.0	0.0–2.0			0.3–2.1
May	0.2 #	1.0 *	0.3 #	0.8 #	- 0.4 #	0.7 #	0.50 **
Toukokuu		0.0–2.3					0.0–1.0
June	1.1 *	1.4 #	0.9 *	0.6 #	- 1.0 #	2.70 **	1.00 **
Kesäkuu	0.0–2.3		0.1–2.0			0.3–5.0	0.0–1.7
July	0.77 **	2.0 *	0.9 *	0.0 #	0.1 #	1.3 *	0.80 ***
Heinäkuu	0.0–1.6	0.2–3.0	0.1–1.9			0.3–2.8	0.2–1.6
August	2.15 ***	1.2 *	1.30 **	- 0.4 #	- 0.4 #	1.1 *	1.20 ***
Elokuu	0.0–4.1	0.1–2.1	0.2–2.1			0.0–2.2	0.3–2.0
September	1.80 ***	0.7 *	1.44 ***	0.3 #	0.1 #	1.3 *	1.00 ***
Syyskuu	0.3–3.6	0.0–1.3	0.0–3.0			0.0–2.6	0.3–1.7
October	1.25 ***	0.2 #	0.50 ***	- 0.3 #	- 1 #	- 0.8 #	0.40 **
Lokakuu	0.0–2.4		0.0–1.0				0.0–0.8
November	1.14 ***	0.3 #	0.75 ***	0.3 #	0.3 #	0.3 #	0.80 ***
Marraskuu	0.0–2.0		0.0–1.5				0.0–1.3
December	1.50 **	0.3 #	0.90 ***	1.60 **	1.20 **	0.1 #	1.00 ***
Joulukuu	0.3–2.4		0.2–1.5	0.3–2.7	0.0–2.0		0.4–1.5
Annual	1.20	1.08	1.11	0.7	0.1	1.0	1.00
Koko vuosi							

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ and # not significant
**** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ ja # ei merkitsevä*

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. 20. The results for 1999 are compared with those for the period 1993–98. The same comparison is shown for ammonium in Fig. 21.

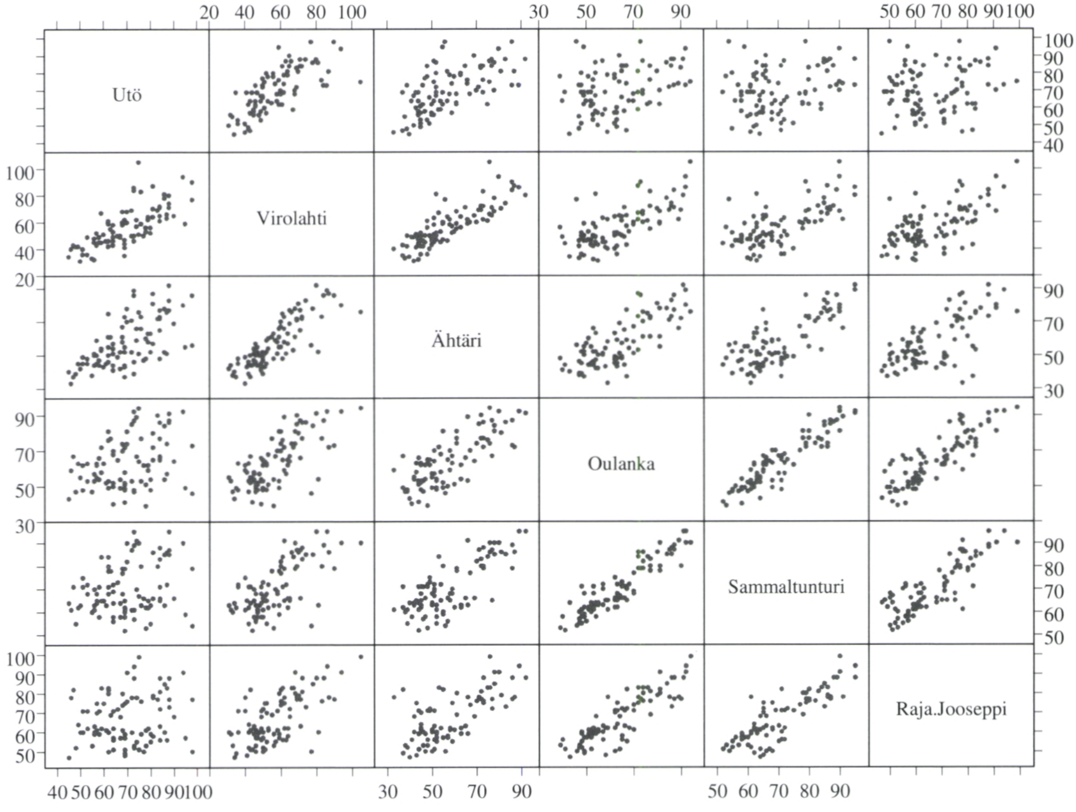

Figure 16. Scatter matrix of the monthly mean ozone concentrations (µg m^{3}) during the period 1992 to 1999 from Utö, Virolahti, Ähtäri, Oulanka, Sammaltunturi and Raja-Jooseppi. The scale of each pair of scatter plots is indicated on the left and right side and upper and lower side of the figure.

Kuva 16. *Otsonin kuukausikeskiarvon (µg m^{-3}) parittaiset pistejoukot Utössä, Virolahdella, Ähtärissä, Oulangalla, Sammaltunturilla ja Raja-Joosepissa ajanjaksolla 1992–1999. Kunkin parin asteikot on esitetty kuvan reunoilla pistejoukon kohdalla.*

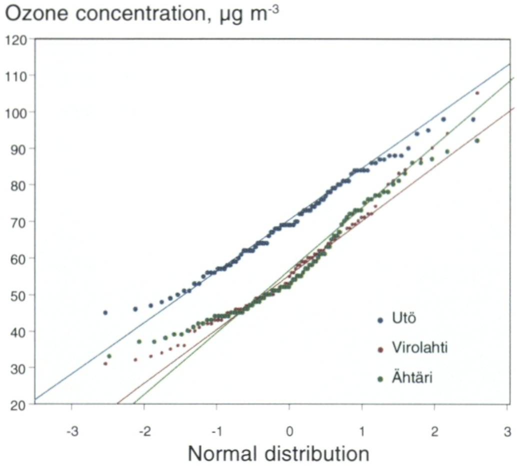

Figure 17a. Quantile-quantile plots of ozone monthly means for Utö, Virolahti and Ähtäri.
Kuva 17a. *Otsonin kuukausikeskiarvon jakaumafunktio Utössä, Virolahdella ja Ähtärissä.*

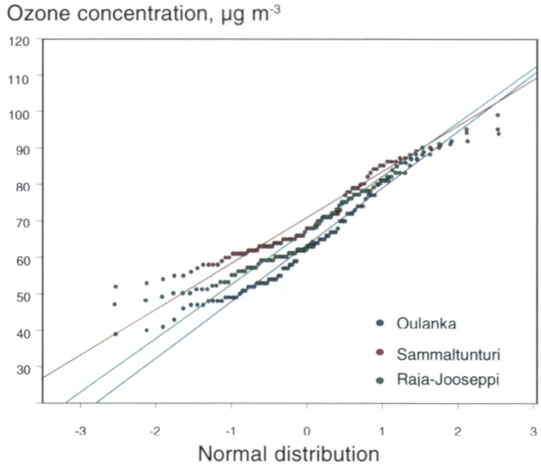

Figure 17b. Quantile-quantile plots of ozone monthly means for Oulanka, Sammaltunturi and Raja-Jooseppi.
Kuva 17b. *Otsonin kuukausikeskiarvon jakaumafunktio Oulangalla, Sammaltunturissa ja Raja-Joosepissa.*

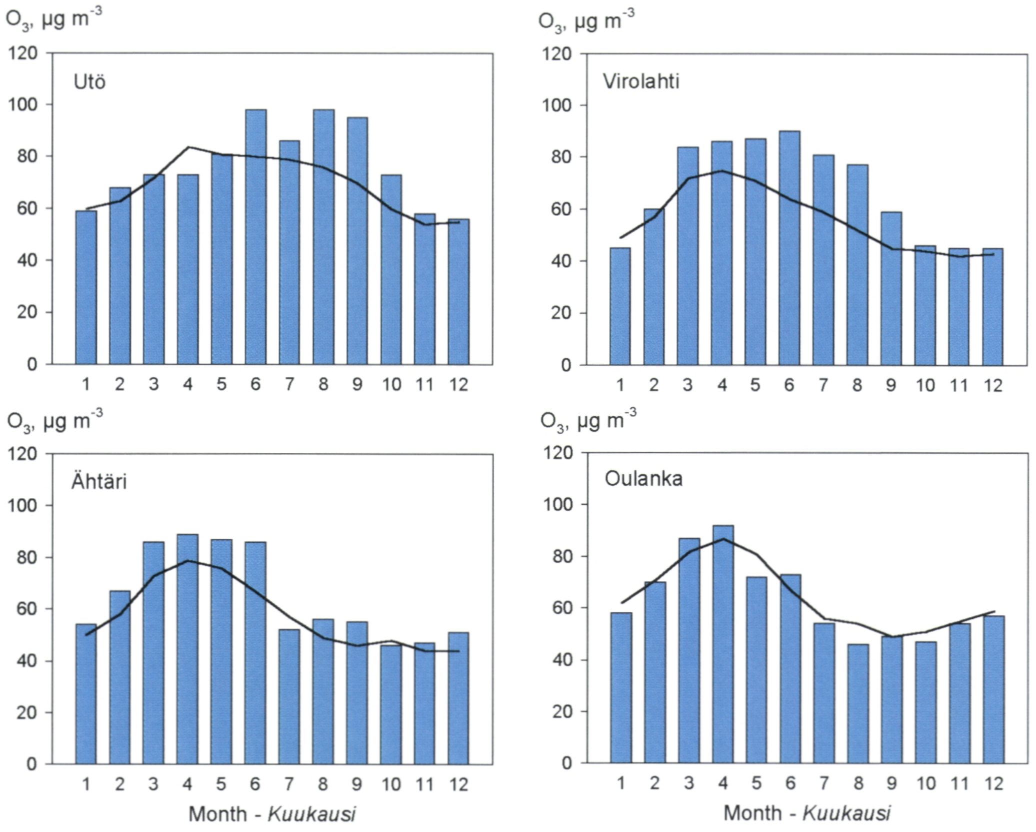

Figure 18. Monthly averages of the ozone concentrations in 1999 (bars) compared with the long-term (1992–98) averages (line) at Utö, Virolahti, Ähtäri and Oulanka.
Kuva 18. *Otsonin kuukausikeskiarvot vuonna 1999 (pylväät) verrattuna pitkän ajan (1992–98) keskiarvoon (viiva) Utössä, Virolahdella, Ähtärissä ja Oulangalla.*

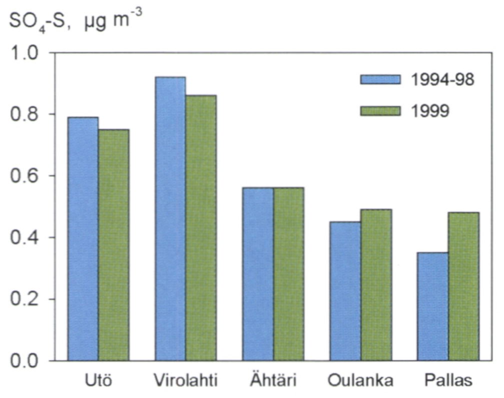

Figure 19. Aerosol sulphate concentrations (expressed as sulphur) in 1999 compared with the period averages for 1994–98.
Kuva 19. *Leijuman sulfaattipitoisuus (rikiksi laskettuna) vuonna 1999 verrattuna vuosien 1994–1998 keskiarvoon.*

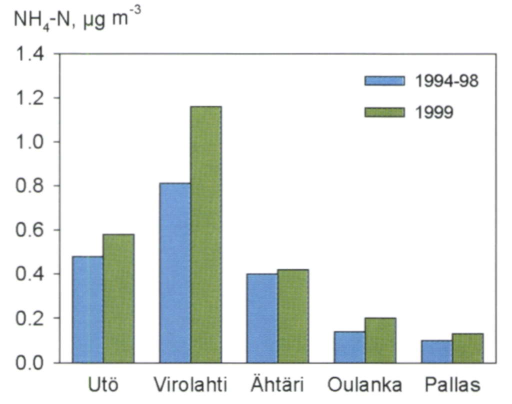

Figure 21. Aerosol ammonium concentrations (expressed as nitrogen) in 1999 compared with the period averages for 1994–98.
Kuva 21. *Leijuman ammoniumpitoisuus (typeksi laskettuna) vuonna 1999 verrattuna vuosien 1994–1998 keskiarvoon.*

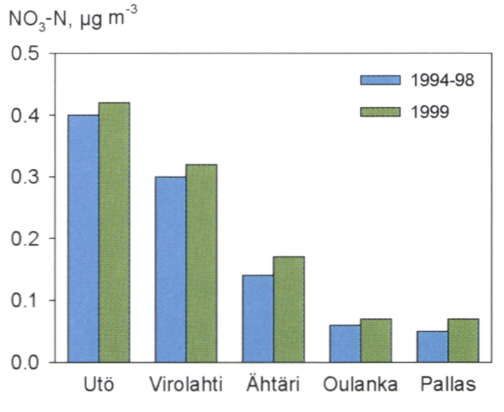

Figure 20. Aerosol nitrate concentrations (expressed as nitrogen) in 1999 compared with the period averages for 1994–98.
Kuva 20. *Leijuman nitraattipitoisuus (typeksi laskettuna) vuonna 1999 verrattuna vuosien 1994–1998 keskiarvoon.*

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3 Results of the 2000 national crown condition survey (ICP Forests/Level I)

Valtakunnallinen latvuskunnon seuranta (ICP metsäohjelma/taso I) vuonna 2000

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Summary

Approximately 450 permanent monitoring plots have been assessed each year since 1986. Degree of defoliation and foliage discolouration on Scots pines, Norway spruces and broadleaves (total ca. 8700 trees) are recorded.

A slight decrease in the proportion of non-defoliated (0–10 %) trees, and an increase in slightly defoliated (11–25 %) trees, were detected in Scots pine, Norway spruce and broadleaves between 1999–2000. The proportion of moderately defoliated (over 25 %) or severely (over 60 %) defoliated Scots pine remained at the same level as in the previous year, but that of Norway spruce and broadleaves increased by 0.8 %. The average tree-specific degree of defoliation was 9 % in pine, 19 % in spruce and 12 % in broadleaves in 2000. No marked changes have been observed in the average defoliation level on any tree species in recent years.

High stand age and weather and climatic factors have a considerable effect on defoliation in background areas of Finland. Epidemics of fungi (e.g. Scleroderris pine canker, *Gremmeniella abietina*) and insects (e.g. sawflies) have also influenced crown condition. No correlation was found between the defoliation pattern and the modelled total sulphur and nitrogen deposition pattern at the national level.

Yhteenveto

Puiden latvuskuntoa on seurattu vuodesta 1986 pysyvillä havaintoaloilla (453 kpl vuonna 2000), joilla kasvaa yhteensä noin 8700 puuta. Puiden kunnon mittareina käytetään latvuksen harsuuntumisastetta, värioireiden määrää sekä tuhoja.

Harsuuntumattomien puiden (harsuuntumisaste 0–10 %) osuus pieneni ja lievästi harsuuntuneiden puiden (10–25 %) osuus kasvoi hieman edellisestä vuodesta. Yli 25 % harsuuntuneiden mäntyjen osuus pysyi ennallaan, mutta kuusien ja lehtipuiden lisääntyi lievästi (0,8 %). Männyn keskimääräinen harsuuntumisaste oli 9 %, kuusen 19 % ja lehtipuiden 12 %. Viime vuosina kaikkien puulajien keskimääräinen harsuuntumisaste on kuitenkin pysynyt melko vakaana.

Harsuuntuminen johtuu Suomessa pääasiassa puuston ikääntymisestä, erilaisista epäedullisista ilmasto- ja säätekijöistä sekä erilaista sieni- ja hyönteistuhoista. Koko maata tarkasteltaessa ei havaittu merkitsevää yhteyttä ilman epäpuhtauksien ja neulaskadon välillä vuonna 2000.

Introduction

Concern about a large-scale decline in forest vitality 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 of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Manual on... 1998) and, since 1995, also of Commission regulations (EEC) Nos. 3528/86 and 1398/95. According to the latest report on Forest Condition in Europe (Forest ... 2000), the forests in Finland were less defoliated than those in the majority of the other 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 (Level I) is carried out in Finland on a systematic network of permanent sample plots established on mineral soil sites (totalling 453 plots in 2000) 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 (390 plots in 2000), and that in the northern region on a 32 x 24 km grid (63 plots in 2000). 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 network (Table 1). The new trees were added systematically to the network by increasing the radius of the plot. Fourteen sample plots were terminated owing to cuttings, and eleven new plots were added to the network in 2000.

In 2000, the total number of sample trees was 8576, of which 4560 were Scots pine (*Pinus sylvestris*), 2706 Norway spruce (*Picea abies*) and 1310 broadleaves (mainly *Betula* spp.). The number of common sample trees (cst) in 1999/2000 was 8264.

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 defoliation degree was calculated 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 discoloured when 10 % of its leaf or needle mass has abnormal coloration (e.g. needle yellowing). The degree of easily identifiable damage was also assessed and grouped into three categories: 1) slight, 2) moderate and 3) severe. The survey was carried out by eight forest technicians during the period June 27 to September 16.

Training and check survey

Before starting the fieldwork 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 in 2000, 45 % of the pines (n = 217), 34 % of the spruces (n = 164) and 36 % of the broadleaves (n = 53) were assessed uniformly. Allowing for ± 5 %

Table 1. The number of assessed trees, sample plots and observers during 1986–2000.
Taulukko 1. *Seurantajakson 1986–2000 aikana arvioitujen puiden, näytealojen sekä arvioijien lukumäärät.*

Year *Vuosi*	Number of trees *Puiden lkm*	Scots pine *Mänty*	Norway spruce *Kuusi*	Broadleaves *Lehtipuut*	Number of plots *Näytealojen lkm*	Trees/plot *Puita/ näyteala*	Number of observers *Arvioijien lkm*
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
2000	8576	4560	2706	1310	453	19	8

tolerance, the corresponding percentages were 92 %, 88 % and 81 % respectively.

Results

Of the 8576 trees examined in 2000, 58 % of the conifers and 57 % of the broadleaves were not defoliated (leaf or needle loss 0–10 %). The proportion of conifers in class 1 (needle loss 11–25 %) was 30 %, and in classes 2–3 (needle loss more than 25 %) 12 %. The corresponding proportions for broadleaves were 33 % and 10 %, respectively. There was a slight decrease in the proportion of non-defoliated (0–10 %) and an increase in slightly defoliated (11–25 %) Scots pine, Norway spruce and broadleaves in the Level I data between 1999–2000. The proportion of moderately defoliated (over 25 %) or severely (over 60 %) defoliated Scots pines remained at the same level as the previous year, but that of Norway spruce and broadleaves increased by 0.8 % (Fig. 1). In 2000, the average, tree-specific defoliation degree was 9 % (9 % in 1999) in Scots pine, 19 % (18 %) in Norway spruce, and 12 % (11 %) in broadleaves (Fig. 2). No marked changes were observed in the average defoliation level on any tree species between the years 1999 and 2000. Tree mortality was at the same level as in the previous years (0.2 %) (Table 2).

The proportion of over-25 % defoliated trees (common sample trees 1986–2000) increased by 1.1 %-units in Scots pine (n = 1514), 10.1 %-units in Norway spruce (n = 884) and 2.7 %-units in broadleaves (n = 144). The proportion of over 25-% defoliated trees was higher in older (≥ 60 years) than in younger stands (under 60 years) (Table 2). The proportion of over-25 % defoliated stands was 1.2 % (1.5 % in 1999) in Scots pine, 28 % (28 % in 1999) in Norway spruce and 5 % (3 % in 1999) in broadleaves (Fig. 3).

No correlation was found between the defoliation pattern of conifers or broadleaves

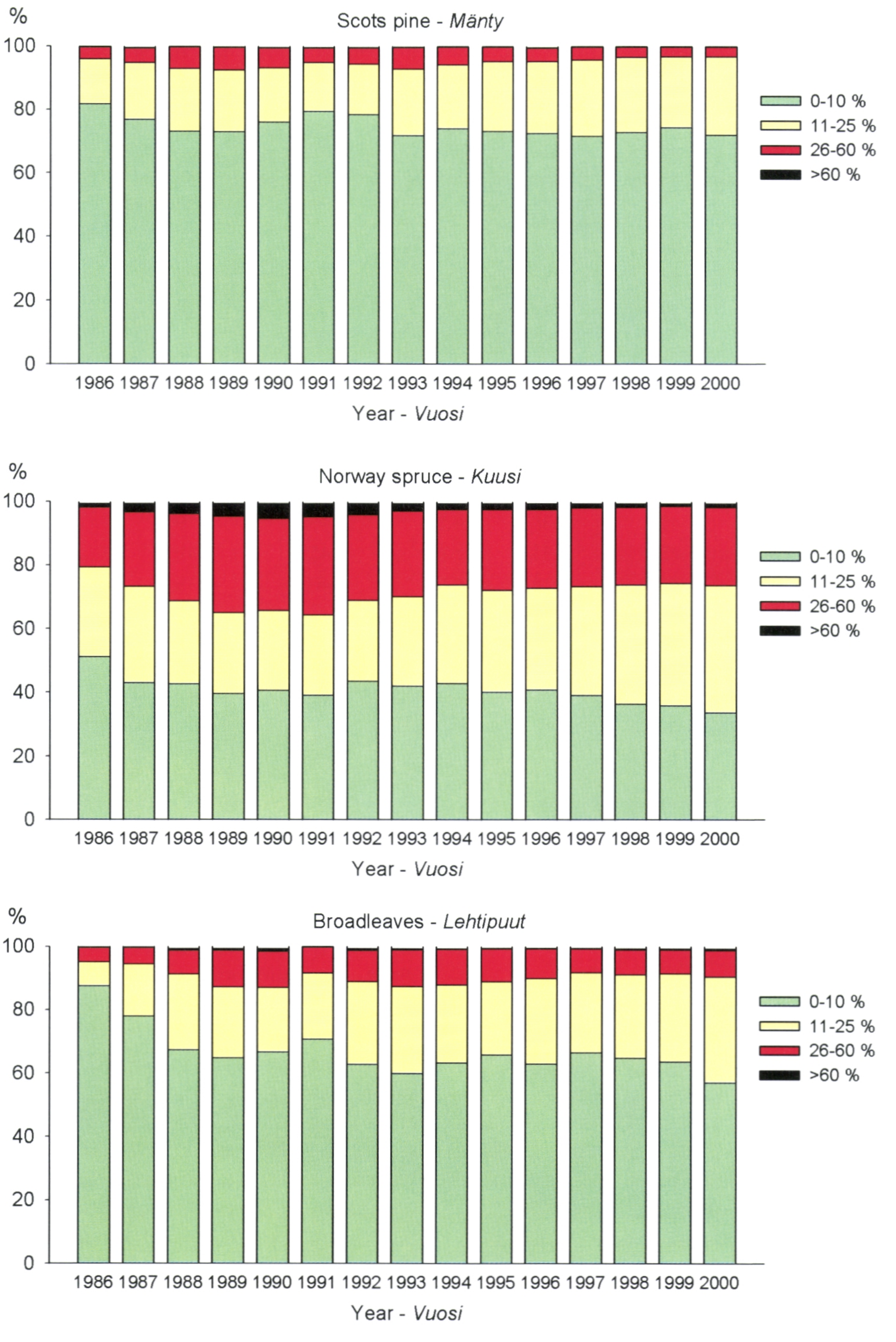

Figure 1. Defoliation frequency distribution for Scots pine, Norway spruce and broadleaves during 1986–2000.
Kuva 1. *Männyn, kuusen ja lehtipuiden harsuuntumisjakaumat kangasmetsissä 1986–2000.*

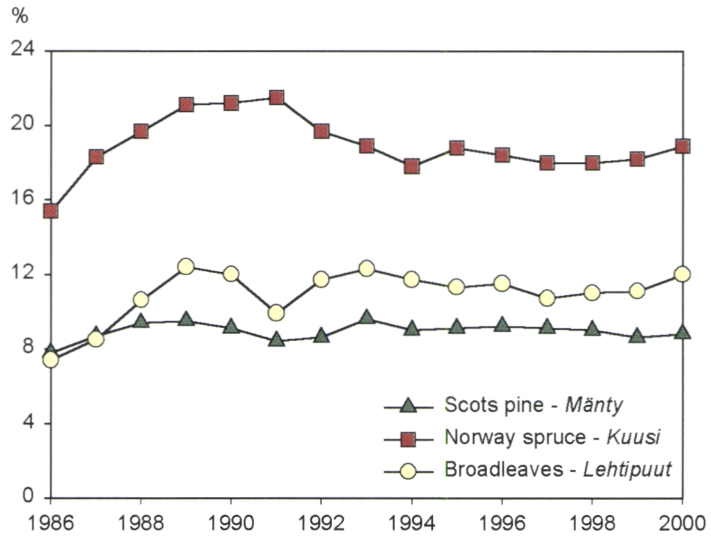

Figure 2. The average defoliation level of Scots pine, Norway spruce and broadleaves during 1986–2000.
Kuva 2. *Männyn, kuusen ja lehtipuiden keskimääräinen harsuuntumisaste vuosina 1986–2000.*

Table 2. Proportion (%) of trees in different defoliation classes in under 60-year-old and over 59-year-old stands in 2000.
Taulukko 2. *Puiden jakautuminen neljään eri harsuuntumisluokkaan alle ja yli 60-vuotiaissa metsiköissä.*

Defoliation class *Harsuuntumisluokka*	Scots pine *Mänty* < 60 yrs *< 60 v.*	 ≥ 60 yrs *≥ 60 v.*	Norway spruce *Kuusi* < 60 yrs *< 60 v.*	 ≥ 60 yrs *≥ 60 v.*	Broadleaves *Lehtipuut* < 60 yrs *< 60 v.*	 ≥ 60 yrs *≥ 60 v.*
0–10 %	92.3	55.3	72.2	17.1	73.0	39.2
11–25 %	6.9	39.2	21.9	47.5	24.3	43.2
26–60 %	0.5	4.8	5.3	32.7	2.3	15.2
> 60 %	0.1	0.6	0.2	2.4	0.1	1.9
Dead *Kuolleet*	0.2	0.2	0.4	0.2	0.3	0.5

and the modelled sulphur or nitrogen deposition at the national level in 2000 (deposition data for 1993 are based on the HILATAR model, Hongisto 1998).

The proportion of discoloured Scots pine decreased from 2.5 % in 1999 to 0.4 % in 2000, and that of Norway spruce increased correspondingly from 6 % to 8 %. The most frequent discoloration symptoms were needle tip/needle yellowing. Discoloration symptoms were mainly concentrated on needles older than two years. Discoloration was rare in broadleaves (0.4 % of trees) in 2000. There were no clear differences in the proportion of discoloured trees between under 60-year-old stands and older stands (Table 3). The most discoloured Norway spruce stands were mainly situated in South Finland (Fig. 4).

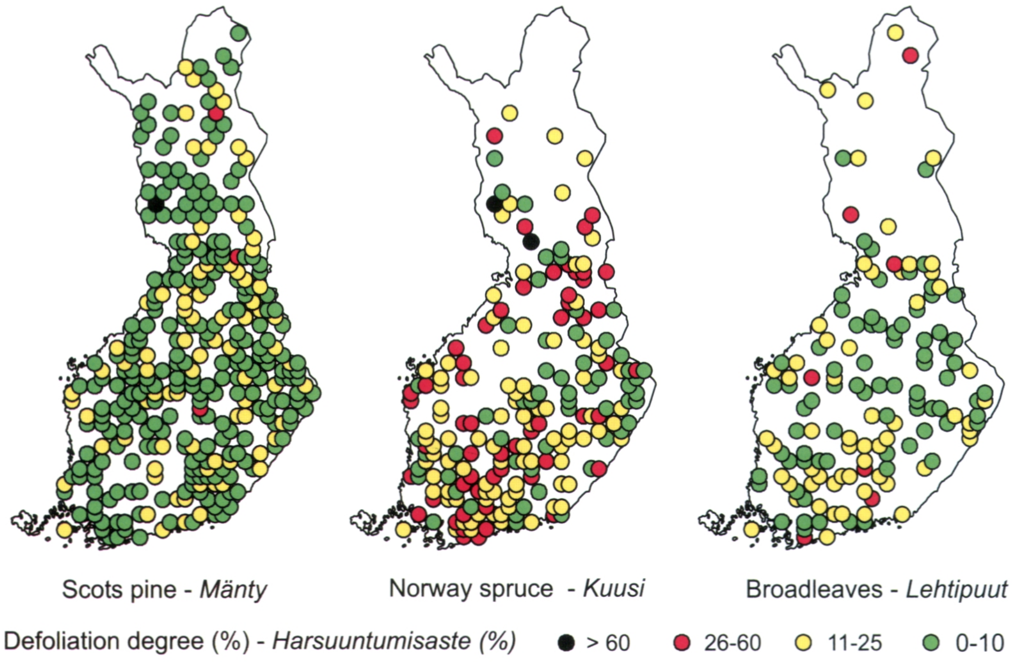

Figure 3. Average defoliation degree of Scots pine, Norway spruce and broadleaves in 2000. The colour of the circle indicates the plot-specific values (see map legend).
Kuva 3. *Männyn, kuusen ja lehtipuiden harsuuntumisen keskiarvot näytealoilla vuonna 2000. Pallon väri ilmaisee näytealakohtaisen arvon (kts. karttaseloste).*

Table 3. Proportion (%) of trees in different discoloration classes in under 60-year-old and over 59-year-old stands in 2000.
Taulukko 3. *Puiden jakautuminen neljään eri värioireluokkaan alle- ja yli 60-vuotiaissa metsiköissä.*

	Scots pine *Mänty*		Norway spruce *Kuusi*		Broadleaves *Lehtipuut*	
Discoloration class *Värioireluokka*	< 60 yrs *< 60 v.*	≥ 60 yrs *≥ 60 v.*	< 60 yrs *< 60 v.*	≥ 60 yrs *≥ 60 v.*	< 60 yrs *< 60 v.*	≥ 60 yrs *≥ 60 v.*
0–10 %	99.8	99.5	93.3	91.5	99.9	99.3
11–25 %	0.1	0.4	6.3	7.4	0.1	0.7
26–60 %	0.0	0.0	0.2	1.0	0.0	0.0
> 60 %	0.1	0.1	0.2	0.1	0.0	0.0

Altogether 37 % (35 % in 1999) of the Scots pines, 33 % (32 %) of the Norway spruces and 35 % (33 %) of the broadleaves had some kind of abiotic or biotic damage symptom (Fig. 5). Four percent of all the easily identifiable damage on Scots pines was classified as moderate or severe in 2000. The corresponding proportions for Norway spruce and broadleaves were 12 % (10 % in 1999) and 10 % (9 % in 1999), respectively. The most common biotic agents on Scots pine were insects (*Diprionidae, Tomicus* spp.), and on Norway spruce and broadleaves fungal pathogens.

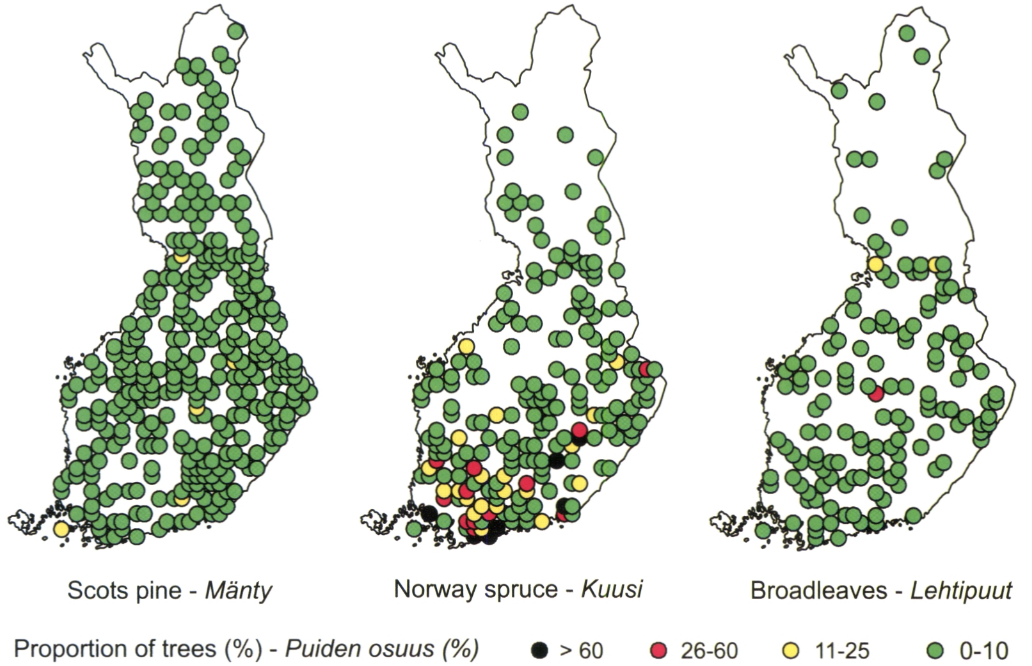

Figure 4. Proportion of discoloured Scots pines, Norway spruces and broadleaves in 2000. The colour of the circle indicates the plot specific values (see map legend).
Kuva 4. *Värioireellisten mäntyjen, kuusien ja lehtipuiden osuudet näytealoilla vuonna 2000. Pallon väri ilmaisee näytealakohtaisen arvon (kts. karttaseloste).*

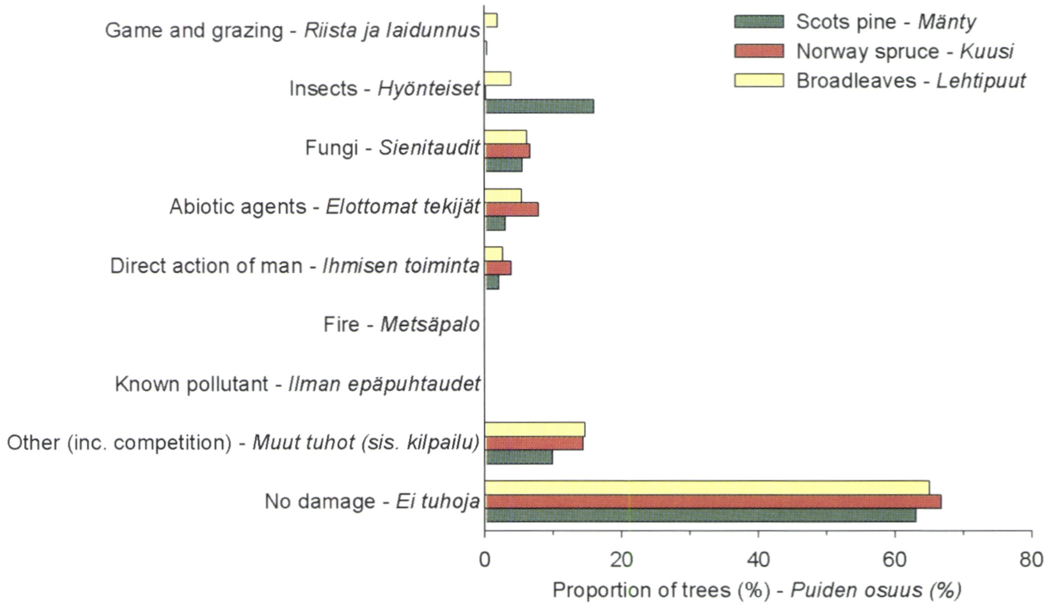

Figure 5. The proportion of trees in eight easily identifiable damage groups in 2000.
Kuva 5. *Puiden osuus kahdeksassa eri vaurio/tuho ryhmässä (ns. helposti tunnistettavat tuhot) vuonna 2000.*

Conclusions

A large number of natural factors, the most important of which 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 and 1997. Although the proportion of non-defoliated and slightly defoliated trees has varied in recent years, no essential changes have been observed in the proportion of moderately or severely defoliated trees, or average defoliation degree, of any of the tree species during the past few years.

In addition to natural factors, abiotic damaging agents such as snow, storms and summer drought (Lipponen et al. 2000) and biotic damaging agents e.g. an epidemic of Scleroderris pine canker (*Gremmeniella abietina*) (Nevalainen & Yli-Kojola 1990) or the rust fungi epidemic in 1998 (Lipponen et al. 1999) have had an influence on crown condition. Due to the wet summer, some rust fungi were rather common in 2000, especially *Chrysomyxa ledi* on spruce and *Melampsoridium betulinum* on birch. Insects, especially sawflies, have also caused forest damage in recent years (Lipponen et al. 2000). However, it appears that the peak in the mass outbreak of sawflies (especially pine sawfly, *Diprion pini*), which started in 1998, has now passed (Lipponen et. al in this report). The effects of this sawfly epidemic were not refelected in the results of the Level I assessment until 2000, when the frequency of trees with sawfly damage increased compared to that in the previous year (Lindgren 2000). Partly as a result of fungal diseases, there was a slight increase in the proportion of discoloured Norway spruce over 1999. In contrast to the summer 1999, which was very dry, discoloration was rare in Scots pine in 2000. No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 2000.

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

Intensiivisen seurannan tuloksia ICP metsäohjelma/ taso II havaintoaloilla

4.1 Crown condition on the intensive monitoring plots in 1999

Latvuskunto intensiivisen seurannan havaintoaloilla vuonna 1999

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Summary

The degree of defoliation, foliage discoloration and abiotic and biotic damage are recorded on 721 Scots pines and 800 Norway spruces growing on 27 Level II mineral soil plots. The average defoliation level of Norway spruce decreased slightly and that of Scots pine remained at the same level as in 1998. Due to the very dry summer the proportion of discoloured Scots pine and Norway spruce increased compared to the summer of 1998. 30 % of the discoloured Scots pines and 16 % of the discoloured Norway spruces also had sign of fungal infection.

Yhteenveto

Vuonna 1999 metsäekosysteemien intensiivisessä seurannassa (ICP metsäohjelma/taso II) oli mukana 721 mäntyä ja 800 kuusta, jotka kasvoivat kivennäismaakoealoilla. Kuusen keskimääräinen harsuuntumisaste väheni hieman, ja männyn pysyi samalla tasolla kuin edellisenä vuonna. Paikoin erittäin kuivan kesän seurauksena värioireellisten mäntyjen ja kuusien määrä lisääntyi vuoteen 1998 verrattuna. Noin 30 %:lla värioireellisista männyistä ja 16 %:lla kuusista oli myös sienitauteja.

Introduction

The 1999 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 four Scots pine plots on peatland. Defoliation, needle discoloration, and abiotic and biotic damage were assessed on 20 trees on each subplot, as well as on the 20 needle sampling trees. The number of assessed Scots pines was 991 (mineral soil) and 320 (peatland) and of Norway spruces 1140 (mineral soil). However, the results for trees used for needle sampling or trees growing on peatland are not included in this report. The results for 1999 are therefore based on 721 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 on 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. According to the comparison of defoliation levels between the observers and the check survey team, 93 % of the Scots pines and 91 % of the Norway spruces were assessed uniformly (± 5 % tolerance) (Table 1).

Results

In 1999, 68 % (73 % in 1998) of the Scots pines and 42 % (40 % in 1998) 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 were 72 % (71 % in 1998) and 35 % (36 % in 1998), respectively. There was an increase in the proportion of slightly defoliated Scots pine on the Level II plots (Fig. 1) but not for Norway spruce. The proportion of over 25 % defoliated Norway spruce decreased slightly compared to 1998, but for Scots pine it remained the same. There were no notable changes in the proportion of trees in any of the defoliation classes in Level I between 1998 and 1999 (Fig. 1). The average defoliation level of Scots pine (common sample trees) increased slightly and that of Norway spruce decreased over 1998 (Fig. 1). In contrast, there were no changes in the average defoliation level of pine or spruce in the Level I network (Fig. 1). For both tree species, the proportion of defoliated trees clearly increased with stand age on both the Level I and II plots (Fig. 2).

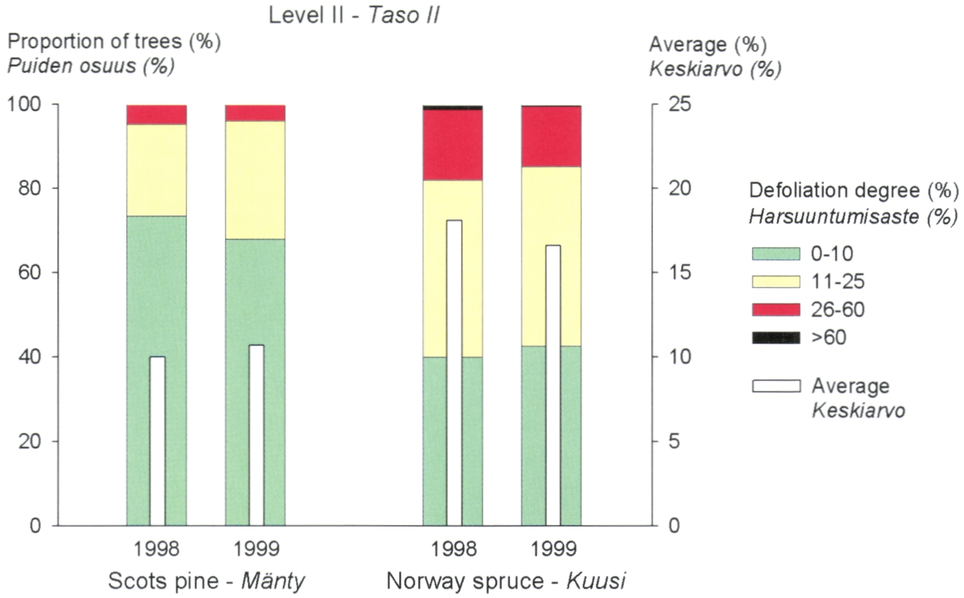
There was a clear decrease (more than 5 %) in the average defoliation degree on two Norway spruce sample plots (Oulanka_S, No. 7 and Oulanka_Sim, No. 21) compared to 1998 (Fig. 3). Almost every tree was suffering from a severe fungal (*Chrysomyxa* spp.) infection on both of the plots in 1997 and 1998, and the epidemic now seems to have died out. The change in the observer responsible for these plots may also cause variation between the years.

In 1999, 4.7 % (0.1 % in 1998) of the Scots pines and 17 % (7 % in 1998) of the Norway spruces were discoloured (the proportion of affected needles in the crown more than 10 %) (Table 2). The corresponding proportions for Level I were 2.7 % (0.2 % in 1998) and 6.5 % (4.5 % in 1998), respectively. The most abundant discoloration symptoms on Norway spruce at Level II were needle tip yellowing and apical yellowing (ca 60 % of discoloured trees) and overall yellowing (ca 40 %) of more than one-year old needles. 16 % of the discoloured spruces had a fungal infection. Overall yellowing of more than 2-year-old needles was the only discoloration symptom on Scots pine. 30 % of the discoloured Scots pines also had signs of fungal infection.

Altogether 24 % (24 % in 1998) of the Scots pines and 32 % (34 % in 1998) of the Norway spruces had some kind of damage symptom. However, about 2 % (2 % in 1998) of the

Table 1. Difference in the assessment of defoliation between the control team and individual observers in 1999. 0 = no difference, minus sign = observer's assessment was lower than that of the check survey team, plus sign = higher than that of the control team.
Taulukko 1. *Tarkastusryhmän ja arvioijien välinen ero harsuuntumisen arvioinnissa vuonna 1999. 0= ei eroa, – = arvioijien arvio alempi kuin kontrolliryhmän, + = arvioijien arvio korkeampi kuin kontrolliryhmän.*

Difference (%) *Ero*	Scots pine *Mänty* % of trees *% puista*	Norway spruce *Kuusi* % of trees *% puista*
– 15	1.0	0.0
– 10	1.0	0.9
– 5	20.0	17.3
0	43.0	53.6
+ 5	30.0	20.9
+ 10	4.0	5.5
+ 15	1.0	0.9
+ 25	0.0	0.9
Number of trees *Puiden lkm*	100	110



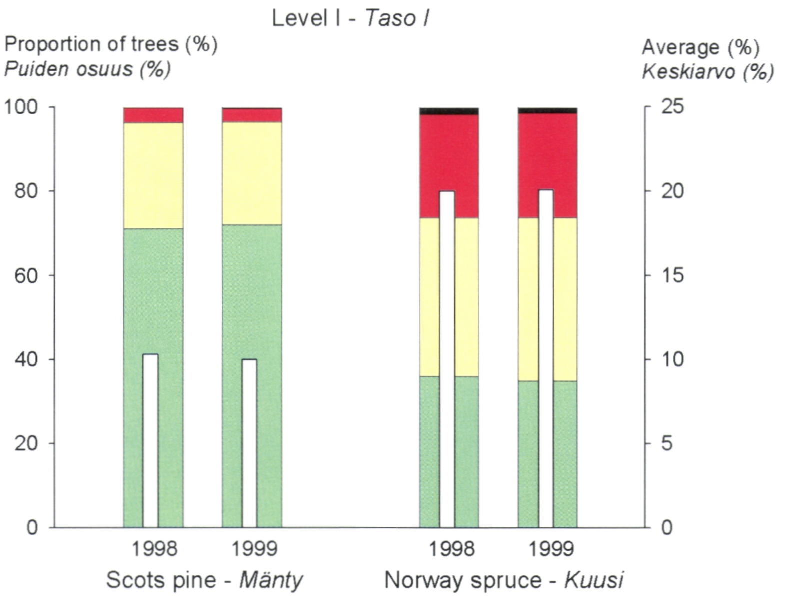


Figure 1. Defoliation frequency distribution and average defoliation degree (white column) for Scots pine and Norway spruce in 1998 and 1999 on Level II and Level I plots. The number of common sample trees on Level II is 719 for pine and 796 for spruce, and on Level I 3900 and 2629, respectively.

Kuva 1. *Männyn ja kuusen harsuuntumisjakauma vuosina 1998 ja 1999 taso II:n ja taso I:n näytealoilla. Vuosina 1998/1999 taso II:n yhteisten mäntyjen lukumäärä oli 719 ja kuusten 796. Vastaavat lukumäärät taso I:llä olivat 3900 ja 2629.*

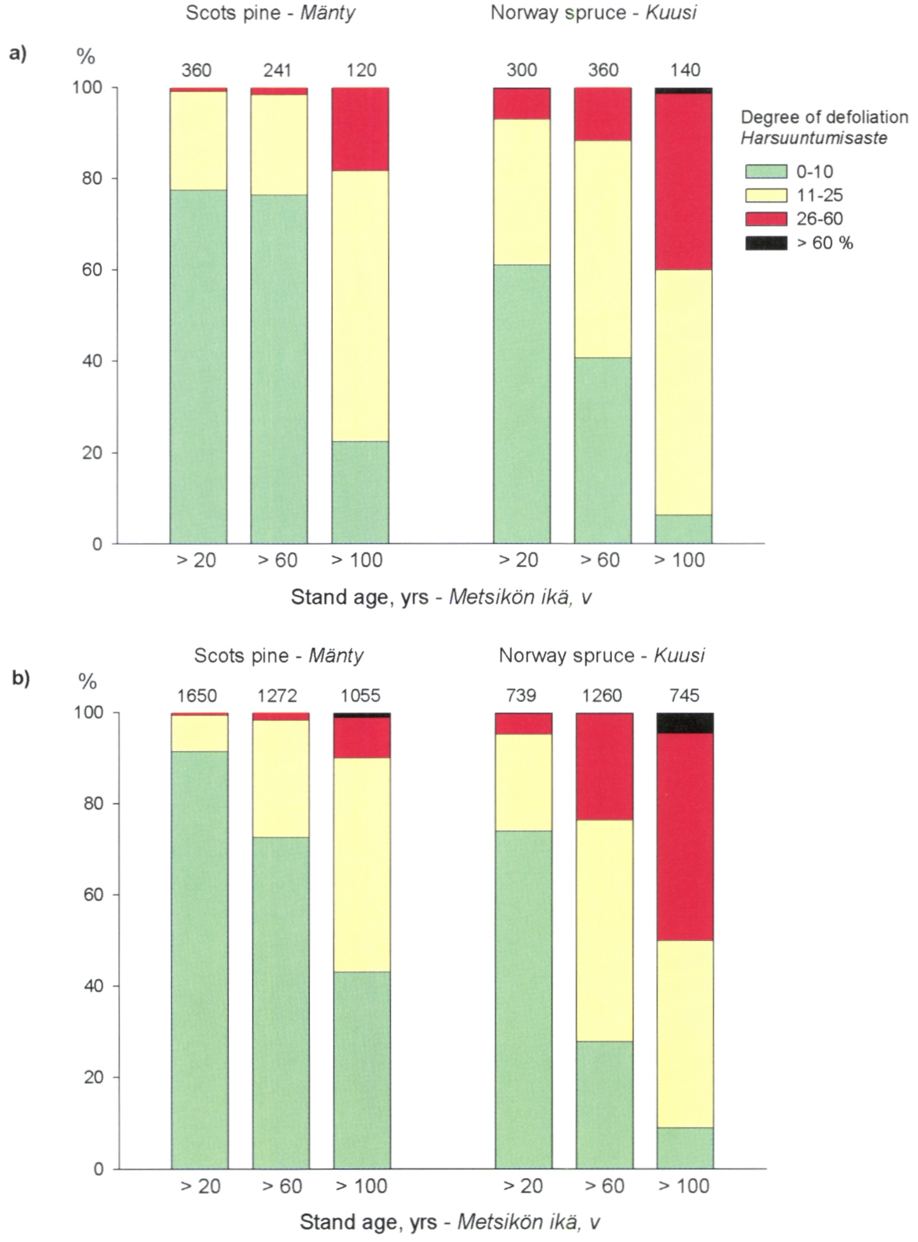
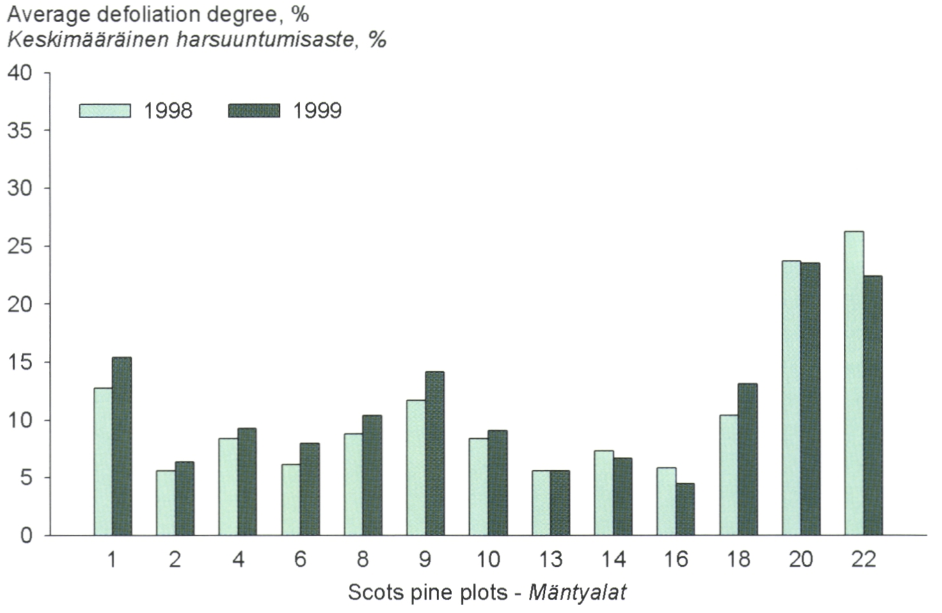


Figure 2. Defoliation frequency distribution for Scots pine and Norway spruce in three stand age classes on Level II (a) and Level I (b) plots in 1999. The number of trees is given above the column.

Kuva 2. *Männyn ja kuusen harsuuntumisjakaumat alle 60 vuotta, 61–100 vuotta ja yli 100 vuotta vanhoissa metsiköissä vuonna 1999. Kuva a = taso II ja kuva b = taso I. Puiden lukumäärä kussakin ryhmässä on ilmoitettu pylvään yläpuolella.*



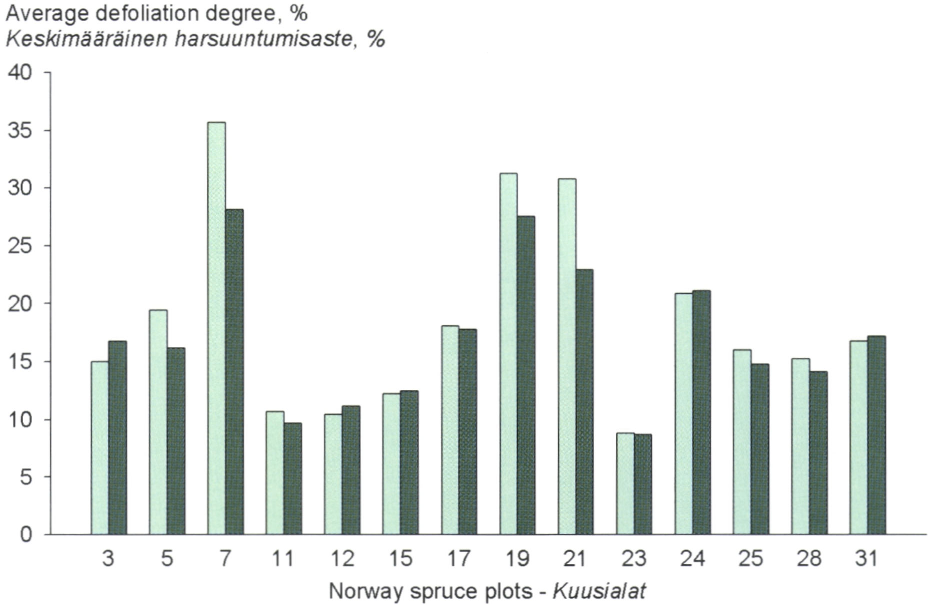


Figure 3. The plot-specific defoliation degree on Scots pine and Norway spruce in 1998 and 1999. The numbers refer to the monitoring plots (see p. 12, table 1 for plots).

Kuva 3. *Männyn ja kuusen keskimääräinen harsuuntuneisuus havaintoaloittain vuosina 1998 ja 1999. Kuvassa on esitetty havaintoalojen numerot (ks. s. 12, taulukko 1, havaintoalat).*

damage on Scots pine was classified as moderate or severe, and on spruce 9 % (13 % in 1998). Comparison of the frequencies of easily identifiable damage in 1999 (Fig. 4) with the results for 1997 (Lindgren 1999) showed that the proportion of undamaged trees has increased. This is due to the slight changes in the statistical handling of very slight damage (e.g. "slight competition", which was omitted in the 1998 and 1999 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 (*Chryso-*

Table 2. Proportion of discoloured trees in 1999. A tree is classified as discoloured when more than 10 % of the foliage is affected.
Taulukko 2. *Värioireellisten puiden osuus vuonna 1999. Puu luokitellaan värivikaiseksi, kun sen lehdistä tai neulasista yli 10 % on värioireellisia.*

		Proportion of trees (%) *Puiden osuus (%)*			
Species *Puulaji*	Number of trees *Puiden lkm*	0–10	11–25	26–60	> 60
Scots pine - *Mänty*	721	95.3	4.7	0.0	0.0
Norway spruce - *Kuusi*	800	83.7	14.9	1.2	0.3

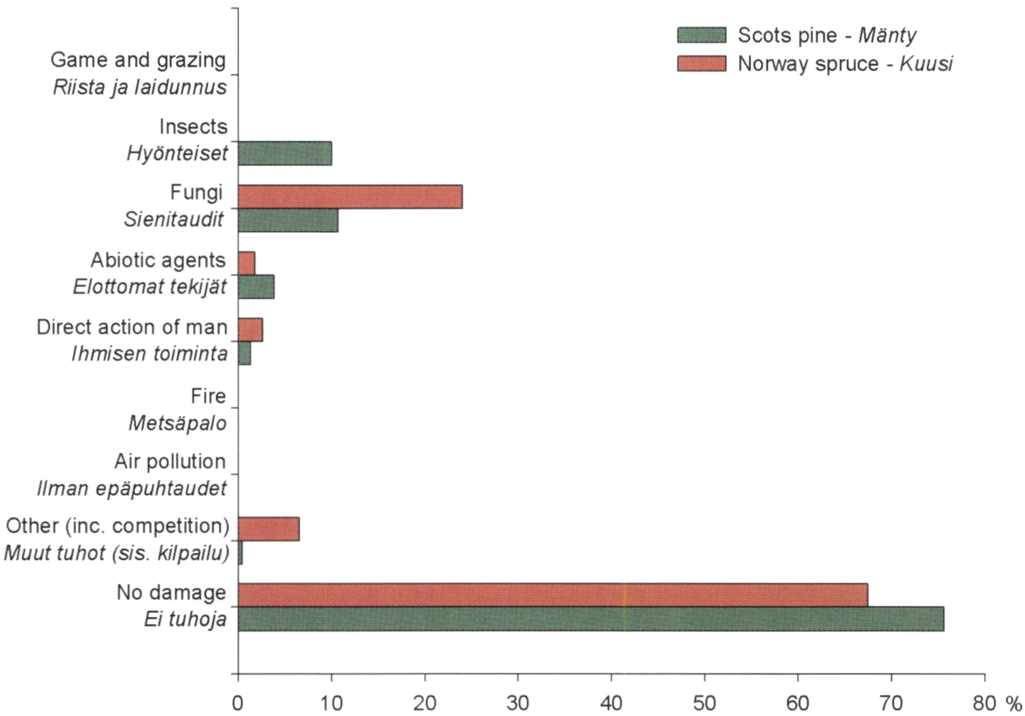


Figure 4. The proportion of trees in easily identifiable damage classes in 1999.
Kuva 4. *Puiden osuus kahdeksassa eri vaurio/tuho ryhmässä (ns. helposti tunnistettavat tuhot) vuonna 1999.*

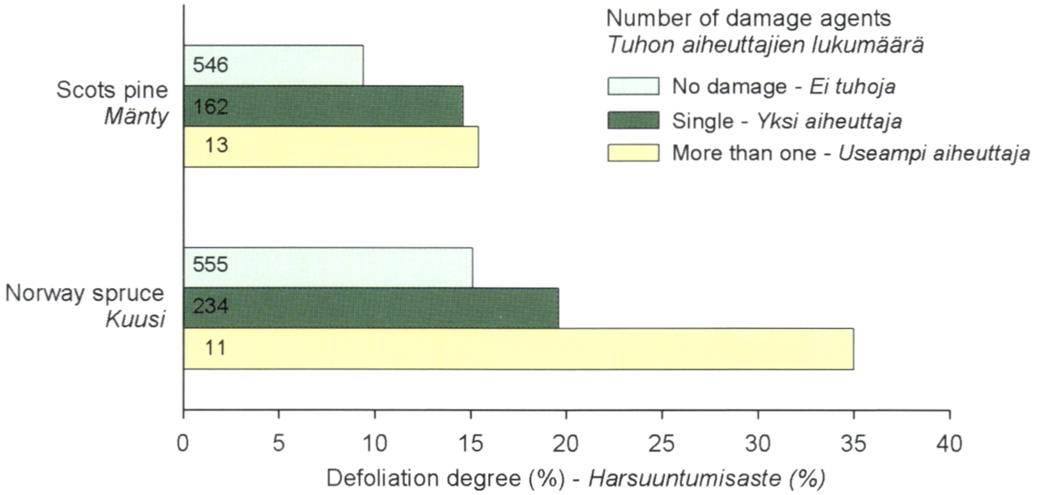


Figure 5. Defoliation degree of Scots pine and Norway spruce in relation to the number of damaging agents in 1998. Number of trees is given inside the column.
Kuva 5. *Männyn ja kuusen harsuuntumisaste suhteessa tuhojen määrään. Puiden lukumäärä kussakin ryhmässä on annettu pylvään sisällä.*

myxca spp.). According to the results, the defoliation degree was higher on trees that had one or more cause of damage (Fig. 5).

Conclusions

In general there were no marked changes in the defoliation level between 1998 and 1999 on the Level II plots. The average defoliation level of Norway spruce decreased slightly and that of Scots pine remained at the same level as in 1998. Compared to 1998, there was no change in the average defoliation level of pine or spruce on Level I. The proportion of over 25 % defoliated trees clearly increased with stand age on both Level II and Level I. The incidence of different damaging agents clearly 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 a slight variation in the defoliation level of the trees, e.g. a shift from non-defoliated trees to slight or slight to moderately defoliated trees, resulting in an increase in the defoliation level. Due to the very dry summer, the proportion of discoloured Scots pine and Norway spruce increased compared to summer 1998 (Lindgren 2000a). A parallel increase was also seen in the Level I results for 1999 (Lindgren 2000b).

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4.2 Understorey vegetation survey (ICP Forest/ Level II) in 1999

Aluskasvillisuuden kartoitus (ICP metsäohjelma/taso II) vuonna 1999

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Summary

Very small changes in the cover percentage of the understorey plant species were observed on six of the ICP Forest/Level II plots between the years 1998 and 1999. There were no significant differences between the assessment level of the two botanists carrying out the survey.

Yhteenveto

Aluskasvillisuuden lajien peittävyysprosenteissa havaittiin vain vähäisiä muutoksia kuudella ICP metsäohjelma/taso II koealalla vuosien 1998 ja 1999 välillä. Kahden kasvitieteilijän välillä ei ollut eroa peittävyyksien arviointitasossa.

Introduction

A complete vegetation survey of the 31 sample plots in the Level II monitoring network was carried out for the first time in 1998, and will be repeated every fifth year. The survey is also being repeated on 6 of the plots each year. In this report we analyse the change in the cover % of the understorey plant species on the six plots between 1998 and 1999.

The annual survey of understorey vegetation is carried out on three pine and three spruce sample stands representing the southern and northern boreal coniferous zones in Finland. The plots selected for the annual survey are: Pallasjärvi_P (No. 2, Empetrum-Myrtillus type), Pallasjärvi_S (No. 3, Hylocomium-Myrtillus type), Oulanka_S (No. 7, Hylocomium-Myrtillus type), Oulanka_P (No. 8, Hylocomium-Myrtillus type), Tammela_S (No. 12, Myrtillus type) and Tammela_P (No.13, Vaccinium type). One sub-plot (30 x 30 m) has been reserved only for vegetation monitoring in each plot.

Two botanists carried out the vegetation analysis in August 1999. A total of 16, permanently marked sample units (2 m^2 quadrats) were analysed on each sub-plot. Visual cover percentage 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 herbs, grasses and dwarf shrubs) and shrub layer (50–150 cm) were analysed. Plants growing on stones or on rotten wood were excluded. Cover % of litter, dead branches, fallen tree stems, stumps, exposed mineral soil and stones were also assessed. Field tests were carried out to check that the assessment level remained uniform between the two botanists. Samples of unknown plant species (mainly mosses and lichens) were later identified by specialists. A detailed description of the methods used has been given in Salemaa & Korpela (2000).

Table 1. The mean cover % of the field layer (the total of vascular plant species), the bottom layer (bryophytes and lichens), and their sum (all species), needle litter and decaying wood on the six vegetation plots during 1998–1999. Statistically significant differences (paired t-test) between the years are marked: *** = $p < 0.001$, ** = $p < 0.01$ and * = $p < 0.05$.

Taulukko 1. *Kenttäkerroksen (kaikki putkilokasvilajit), pohjakerroksen (sammalet ja jäkälät) ja niiden summan (kaikki lajit), neulaskarikkeen ja lahopuun keskimääräiset peittävyydet kuudella kasvillisuuden seuranta-alalla vuosina 1998 ja 1999. Tilastollisesti merkitsevät erot (parittainen t-testi) merkitty: *** = $p < 0.001$, ** = $p < 0.01$ and * = $p < 0.05$.*

Plot number	Year	Field layer	Bottom layer	Bryophytes Hepaticae	other	sum	Lichens Cladina	other	sum	All species	Needle litter	Decaying wood
Koealan no	*Vuosi*	*Kenttä-kerros*	*Pohja-kerros*	*Sammalet Hepaticae*	*muut*	*summa*	*Jäkälät Cladina*	*muut*	*summa*	*Kaikki lajit*	*Neulas-karike*	*Lahopuu*
2. Pallasjärvi_P	1998	45.4	49.4	3.0	32.5	35.5	10.0	3.9	13.9	94.8	51.0	6.6
	1999	43.1	60.6*	3.7	42.7*	46.4*	7.8	6.4	14.2	103.7	33.4**	9.1
3. Pallasjärvi_S	1998	70.2	87.7	3.0	84.3	87.3	0.1	0.3	0.4	157.8	6.7	4.4
	1999	58.0**	84.1	2.7	81.2	84.0	0.1	0.1*	0.2	142.1*	6.4	3.8
7. Oulanka_S	1998	72.1	88.0	3.3	84.6	88.0	0	0	0	160.0	4.7	2.1
	1999	68.8	90.8	3.0	87.8	90.8	0	0	0	159.6	1.5**	2.0
8. Oulanka_P	1998	83.3	82.6	0.2	82.3	82.5	0	0	0	165.8	23.9	6.9
	1999	79.8	87.4	0.5	86.8	87.4	0	0	0	167.2	9.9***	6.8
12. Tammela_S	1998	47.3	77.4	0	77.4	77.4	0	0	0	124.7	15.7	8.8
	1999	49.7	71.5	0	71.5	71.5	0	0	0	121.2	13.9	11.9
13. Tammela_P	1998	33.5	86.7	0	86.1	86.1	0.2	0.4	0.6	120.2	21.4	14.8
	1999	40.2**	81.6	0	80.9	80.9	0.3	0.3	0.6	121.8	19.8	16.2

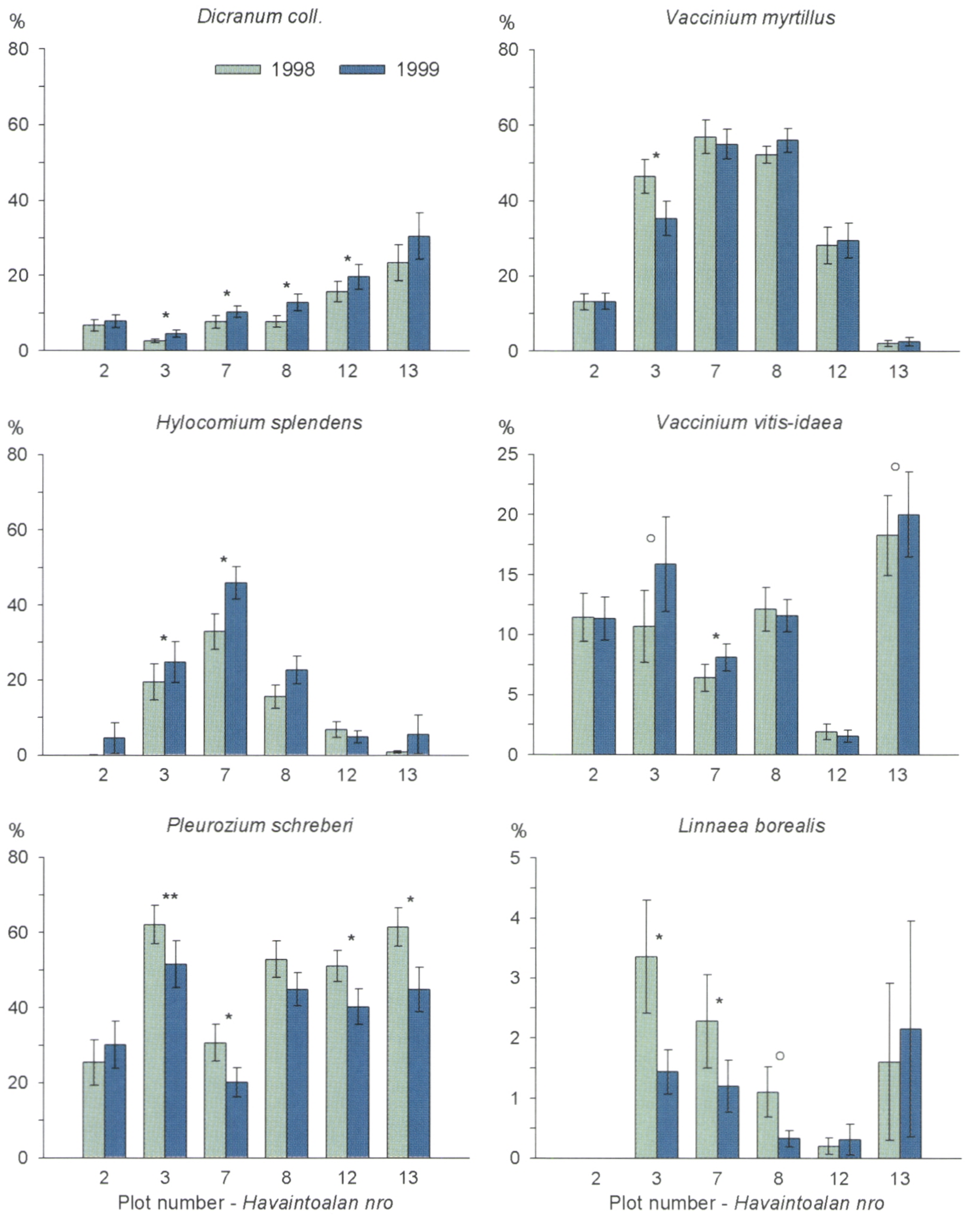

Figure 1. The change in the mean cover (%) of the most common bryophytes and vascular plant species on the six vegetation plots between 1998 and 1999. Statistical significances (paired t-test): o = $p < 0.10$, * = $p < 0.05$ (see p. 12 for plots).

Kuva 1. *Tavallisimpien sammal- ja putkilokasvilajien keskimääräisien peittävyyksien muutokset kuudella kasvillisuuden havaintoalalla vuosien 1998 ja 1999 välillä. Tilastolliset merkitsevyydet (parittainen t-testi): o = p < 0.10, * = p < 0.05 (ks. s. 12 havaintoalat).*

Results

The change in the total cover % of vascular plant species between 1998 and 1999 was relatively small (Table 1). The change in the total cover of vascular plant species was greatest at Pallasjärvi_S (No. 3): about 10 % units lower in 1999 than in 1998. This was mainly caused by the decrease in the cover of *Vaccinium myrtillus* (Fig. 1). In the case of other vascular plant species (e.g. *Vaccinium vitis-idaea* and *Linnaea borealis*), the absolute changes in the cover were less than 5 % units. Annual precipitation at Pallasjärvi_S (No. 3) was lower in 1999 (484 mm in througfall) than in 1998 (550 mm) (Lindroos et al. 2000), and this may have affected the shoot growth of *Vaccinium myrtillus* and contributed to the decreased coverage.

The change in the total cover % of bryophytes and lichens was also small during 1998–1999 (Table 1). Within the bryophytes group, however, there were changes in the relative abundances between the species. The proportion of *Hylocomium splendens* and *Dicranum* coll. increased, whereas the proportion of *Pleurozium schreberi* decreased on most of the plots (Fig. 1). The total cover of bryophytes was about 10 % units higher at Pallasjärvi_ P (No. 2) in 1999 than in 1998 (Table 1). During the same period the cover of needle litter decreased, which probably increased the amount of space available for species of the bottom layer (mosses and cup lichens).

Visual assessment of the cover percentage of the plant species is always susceptible to subjective errors (Vanha-Majamaa et al. 2000). Because the objective of monitoring forest vegetation is to produce information about changes in the abundance of plant species, it is important to keep the assessment level of the observers constant. According to the field tests, in which the two botanists assessed the same quadrats (one test quadrat per plot, n = 6) independently, there were no statistically significant differences in the assessment level between the botanists as regards either vascular plant species or bryophytes (Table 2).

Table 2. The similarity of the assessment levels of the two botanists in 1999, tested by paired t-tests. The number of test quadrats was 6.
Taulukko 2. *Kahden kasvitieteilijän arviointitasojen samanlaisuus vuonna 1999 tutkittuna parittaisilla t-testeillä. Testiruutujen lukumäärä oli 6.*

	Mean difference in the cover (%) *Peittävyyksien (%) keskimääräinen ero*	se	t	df	p
Vaccinium myrtillus	-1.60	2.11	-0.77	4	0.486
Vaccinium vitis-idaea	0.41	1.04	-2.25	5	0.704
Sum of vascular species - *Putkilokasvit yhteensä*	0.13	4.16	0.03	5	0.976
Dicranum coll.	0.08	1.19	0.07	5	0.947
Hylocomium splendens	0.17	4.36	0.04	5	0.971
Pleurozium schreberi	3.83	3.00	1.28	5	0.258
Sum of bryophytes - *Sammaleet yhteensä*	-0.50	2.03	-0.25	5	0.815

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4.3 Deposition on the forests and forest floor in 1999

Metsiin ja metsämaahan kohdistuva laskeuma vuonna 1999

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Summary

The deposition of acidifying compounds and base cations were monitored in open areas and within 8 Scots pine and 8 Norway spruce stands during 1999. The pine canopies increased the proton input to the forest floor, but the spruce canopies on many of the plots decreased the input. There was a clear decrease in sulphur deposition on the forest floor on moving from south to north. The threat posed to forest ecosystems in NE Finland by SO_2 emissions from the Nikel smelters, NW Russia, was still as low in 1999 as at the beginning of the 1990's. There was an increasing trend in the pH and a decreasing trend in SO_4-S deposition in stand throughfall in southern and central Finland during 1996–1999.

The decrease in the nitrogen flux as rain water passed down through the canopy indicated that the deposition level was, in general, relatively low in relation to the nitrogen requirements of the forest stands. Emissions from a local NH_3 point source were clearly reflected in the nitrogen fluxes in stand throughfall on the spruce plot in Uusikaarlepyy. The DON flux represented a significant part of the N flux in stand throughfall. The DOC fluxes in stand throughfall varied between 2400–8000 mg m^{-2} in 1999. The lowest fluxes were recorded on the plots in northern Finland.

Yhteenveto

Happamoittavien yhdisteiden ja emäskationien laskeumaa seurattiin 8 männikössä ja 8 kuusikossa sekä niiden viereisillä avoimilla paikoilla vuonna 1999. Männiköiden latvuskerros lisäsi protonilaskeumaa metsämaahan. Sen sijaan kuusikoiden latvukset vähensivät monilla aloilla protonilaskeumaa. Metsämaahan kohdistuva rikkilaskeuma väheni Etelä-Suomesta Pohjois-Suomeen. Kuolan niemimaalla sijaitsevan Nikelin SO_2 päästöt eivät uhanneet merkittävästi metsäekosysteemejä Koillis-Lapissa. Metsikkösadannan pH nousi ja SO_4-S-laskeuma väheni vuosina 1996–1999 etenkin Etelä- ja Keski-Suomen havaintoaloilla.

Typpilaskeuma oli yleisesti alhainen suhteessa metsiköiden käyttökelpoisen typen tarpeeseen. Tämä heijastui typpilaskeuman vähentymisenä sadeveden kulkiessa latvuskerroksen läpi. Paikalliset NH_3 päästöt heijastuivat selvästi metsikkösadannan typpikuormassa Uusikaarlepyyn kuusikossa. Liukoisen orgaanisen typen (DON) osuus metsikkösadannan typpilaskeumasta oli merkittävä. Liukoisen orgaanisen hiilen (DOC) määrä vaihteli metsikkösadannassa 2400–8000 mg m^{-2} vuonna 1999. Alhaisimmat laskeumat mitattiin Pohjois-Suomen aloilla.

Introduction

The deposition of acidifying compounds on the forest and forest floor has decreased considerably during the last two or three decades in Finland. Sulphur and nitrogen deposition was clearly lower in the late 1990's compared to the situation in the 1970's and 1980's (Lindroos et al. 1999). A decreasing trend in stand throughfall acidity and the proton (H^+) load, related to a decrease in SO_4 concentrations, has been reported for forested catchments in southern and central Finland during 1989–1997 (Ukonmaanaho et al. 1998, Lindroos et al. 2000a). A similar trend was also evident during 1996–1998 on the ICP Forests/ Level II monitoring plots (Lindroos et al. 2000b).

The primary aim of this report was to determine the deposition of acidifying compounds, base cations, chloride, dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) on the forests and forest floor on the ICP Forests/Level II monitoring plots in 1999. Such information is required when evaluating the effects of air pollution on forest ecosystems, which is one of the key aims of the ICP Forests monitoring programme. Information about DOC fluxes is needed in carbon cycling studies related to climatic change. The second aim was to compare the deposition of acidifying compounds in 1999 with corresponding results from the period 1996–1998. It is important to determine whether the earlier observed trends have continued in 1999.

Material and methods

Deposition samples were collected throughout 1999 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 during the winter and spring, and at 2-week intervals (bulked to give one sample per 4-week interval) during summer and autumn. There were 20 systematically located precipitation collectors (ø = 20 cm, h = 0.4 m) within the stand during the snow-free period, and 6 snow collectors (ø = 36 cm, h = 1.8 m) during wintertime. The corresponding number of collectors for the adjacent open area was 3 and 2, respectively. The samples were pre-treated and analysed according to the manual of the ICP Forests Programme.

Results and discussion

Precipitation, pH and proton deposition in 1999

Scots pine

The pine stand canopies intercepted, on the average, 17 % of the precipitation measured in the open area. The mean pH of stand throughfall on all the pine plots was lower than that of bulk deposition. This phenomenon is related to the acidifying effect of organic compounds and dry deposition leached from the canopies. The lowest stand throughfall pH values were recorded on the plots in southern Finland, and the highest in the north. The proton flux was higher in stand throughfall than that in bulk deposition in all the stands, and the fluxes in northern Finland were lower than those in the south (Fig. 1).

Norway spruce

The spruce stands intercepted, on the average, 23 % of the precipitation. In contrast to the pine stands, the pH values in both stand throughfall and bulk deposition were at a similar level. The effect of spruce canopies on the proton load reaching the forest floor was also different from that in the pine stands; the proton input to the forest floor in stand throughfall was lower on most of the plots than that in the open area.

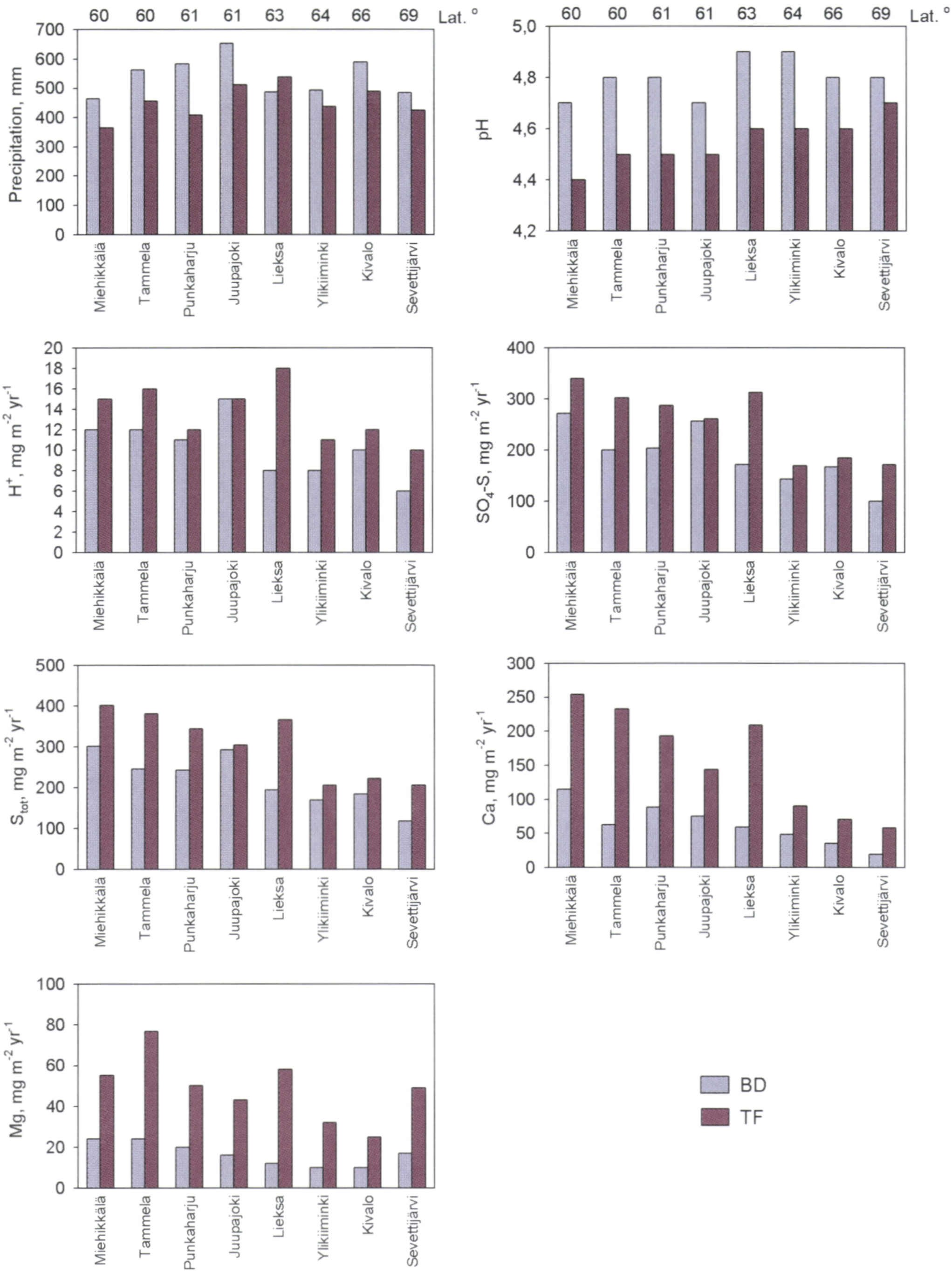

Figure 1. The amount of precipitation, mean pH and deposition of protons, sulphate, total sulphur, calcium and magnesium in bulk deposition (BD) and stand throughfall (TF) during 1999 in 8 Scots pine stands. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude, Lat.) of the plots is indicated in the upper part of the figure.
Kuva 1. *Sademäärä, keskimääräinen pH sekä protoni-, sulfaatti-, kokonaisrikki-, kalsium- ja magnesiumlaskeuma vapaassa sadannassa (BD) ja metsikkösadannassa (TF) 8 mäntyalalla vuonna 1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

There was an increasing S-N gradient in the pH and a decreasing S-N gradient in the proton load in stand throughfall throughout the country. A clear exception to this was the Uusikaarlepyy plot (No. 23) on the west coast of Finland, where the pH values were relatively high and proton deposition low due to the neutralising effect of NH_3 emissions from a nearby fur farm (Fig. 3).

Sulphur deposition in 1999

Scots pine

The SO_4-S deposition in stand throughfall was higher than that in bulk deposition, indicating the leaching of dry sulphate deposition from the pine canopies (e.g. Lindberg & Lovett 1992). Deposition decreased on moving from south to north. Dissolved organic sulphur (the difference between total S and SO_4-S) accounted for 13 % in bulk deposition and 16 % in stand throughfall of the total sulphur deposition (Fig. 1).

Marine-derived SO_4-S accounted for 2–6 % of the sulphate deposition in bulk deposition and 3–7 % in stand throughfall on the pine plots, excluding the northernmost plot, Sevettijärvi (No. 1). This plot is located at a distance of only about 50 km from the Arctic Ocean, and the proportion of marine-derived SO_4-S out of total sulphate deposition was therefore 10 % in bulk deposition and 13 % in stand throughfall. The Sevettijärvi plot is also located only about 70 km from the Cu-Ni smelter in Nikel, NW Russia, which is a significant emission source of sulphur dioxide. The sulphur load in bulk deposition and stand throughfall was, however, the lowest of all the pine sites. Open area deposition in 1999 was somewhat lower than the corresponding value during 1990–1993 in the same area (Anttila et al. 1995). In this respect, the threat to forest ecosystems in Sevettijärvi posed by the SO_2 emissions from the Nikel smelters had not increased in 1999 compared to the situation at the beginning of the 1990's.

Norway spruce

Sulphur deposition decreased on moving from south to north also on the spruce plots. SO_4-S deposition was higher in stand throughfall than that in bulk deposition. The highest SO_4-S deposition in stand throughfall was recorded on the Punkaharju plot (No. 17), nearly 600 mg m^{-2}. Organic sulphur accounted for 14 % in bulk deposition and 19 % in stand throughfall of the total sulphur deposition (Fig. 3).

Nitrogen deposition in 1999

Scots pine

In general, NO_3-N and NH_4-N deposition in throughfall was lower than that above the canopy layer, reflecting nitrogen uptake by the tree foliage, microflora and epiphytic lichens. The decrease in the nitrogen flux reaching the forest floor indicates that nitrogen deposition is relatively low in relation to the nitrogen requirements of the tree stands (Lindroos et al. 2000a). Deposition was clearly the lowest on the northernmost plot, Sevettijärvi (No. 1) (Fig. 2). The total N deposition in stand throughfall was low (< 15 kg ha^{-1} yr^{-1}) on all the pine plots compared to the deposition levels elsewhere in Europe (Forest... 2000).

The fluxes of dissolved organic nitrogen (DON) varied between 12–59 mg m^{-2} yr^{-1} in bulk deposition (mean 35 mg m^{-2} yr^{-1}), and 25–102 mg m^{-2} yr^{-1} in stand throughfall (mean 72 mg m^{-2} yr^{-1}). DON was calculated as the difference between total N and NO_3-N and NH_4-N deposition. The proportion of DON out of total N deposition was 12 % (variation 6–19 %) in bulk deposition and 26 % (22–31 %) in stand throughfall. The increase in DON values in stand throughfall compared to bulk deposition is related to the organic matter leaching from the tree canopies. The flux of DON represents a significant part of the N flux in stand throughfall.

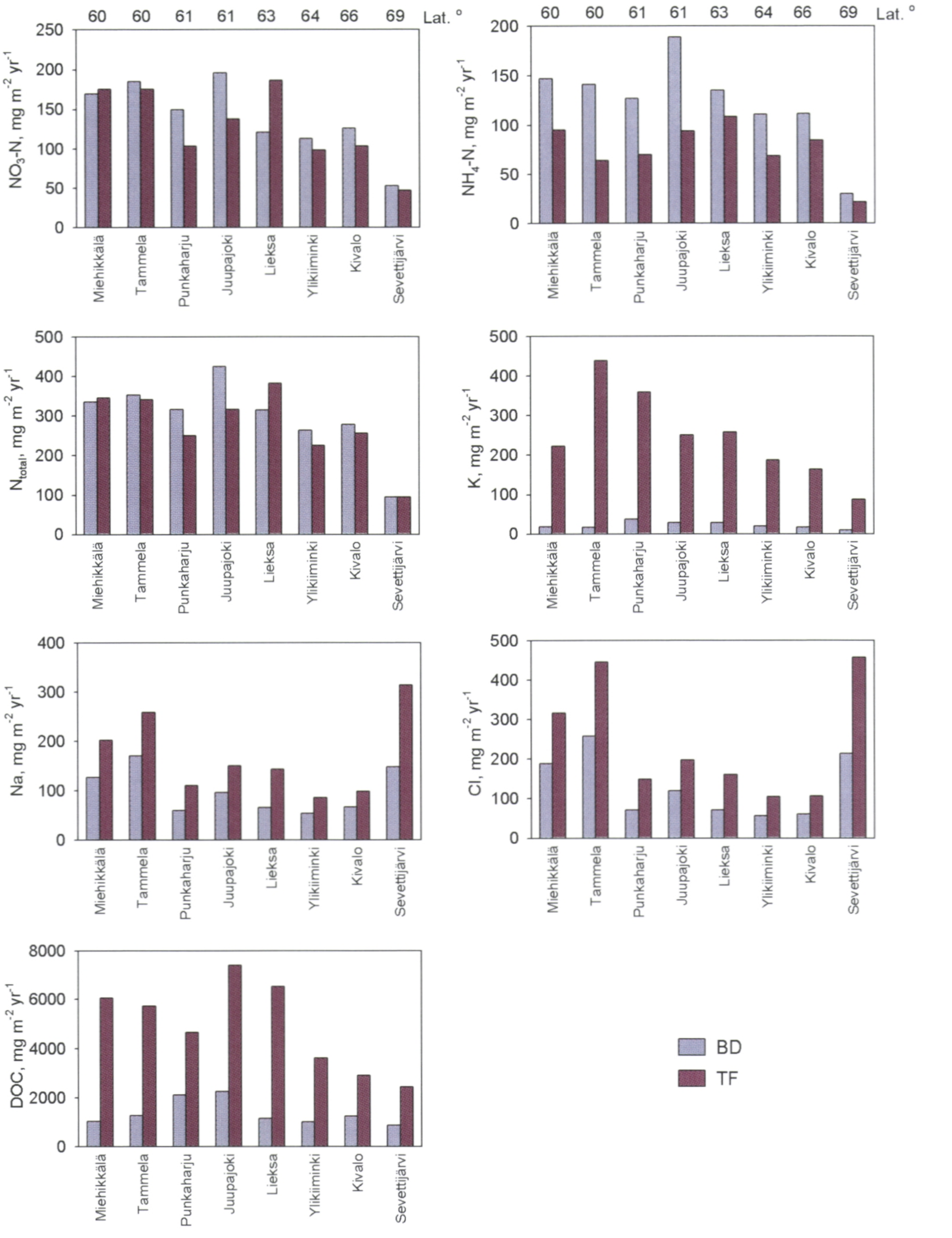

Figure 2. Deposition of nitrate, ammonium, total nitrogen, potassium, sodium, chloride and dissolved organic carbon in bulk deposition (BD) and stand throughfall (TF) during 1999 in 8 Scots pine stands. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude, Lat.) of the plots is indicated in the upper part of the figure.

Kuva 2. *Nitraatti-, ammonium-, kokonaistyppi-, kalium-, natrium-, kloridi- ja liukoisen orgaanisen hiilen laskeuma vapaassa sadannassa (BD) ja metsikkösadannassa (TF) 8 mäntyalalla vuonna 1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

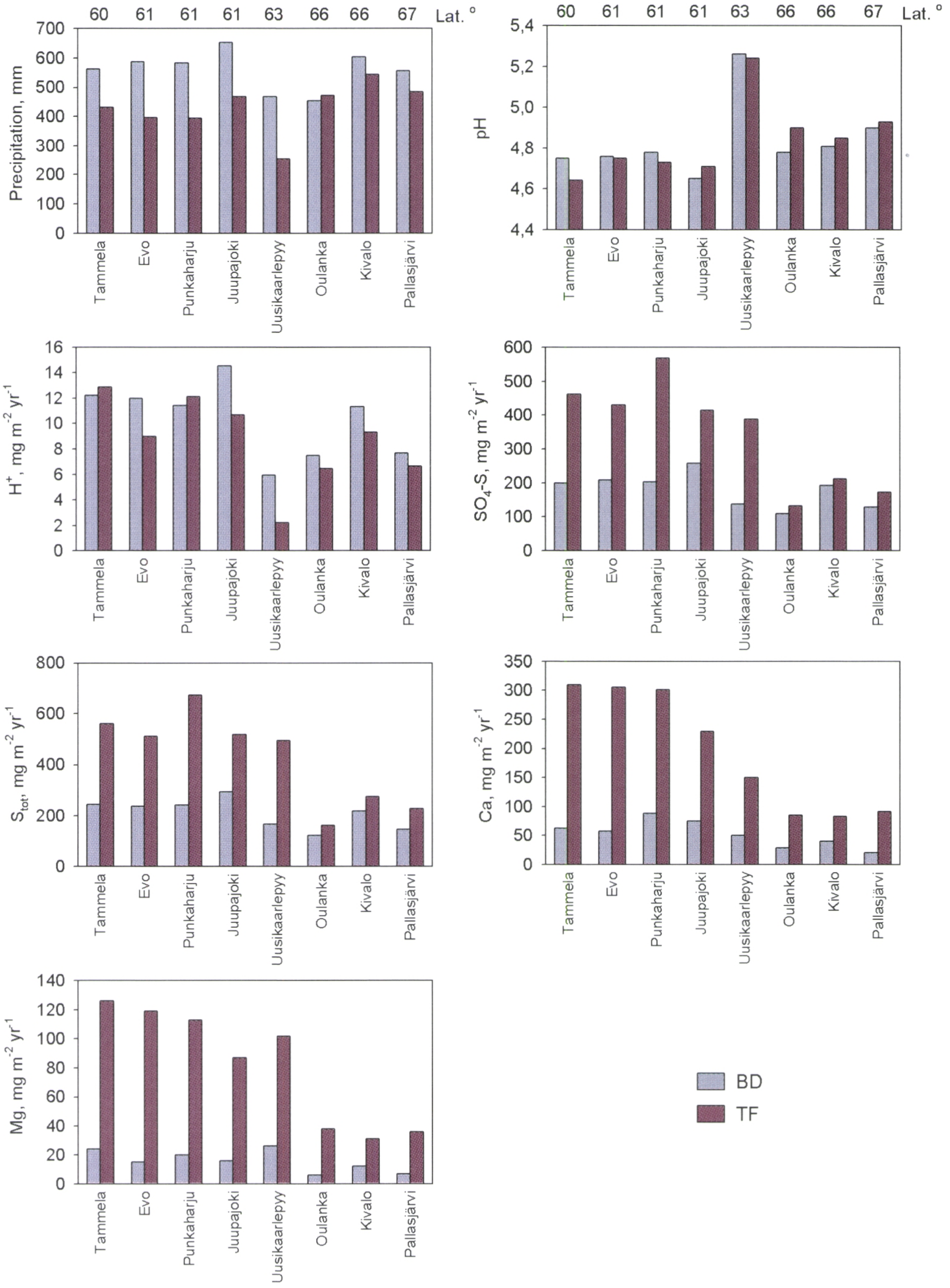

Figure 3. The amount of precipitation, mean pH and deposition of protons, sulphate, total sulphur, calcium and magnesium in bulk deposition (BD) and stand throughfall (TF) during 1999 in 8 Norway spruce stands. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude, Lat.) of the plots is indicated in the upper part of the figure.

Kuva 3. *Sademäärä, keskimääräinen pH sekä protoni-, sulfaatti-, kokonaisrikki-, kalsium- ja magnesiumlaskeuma vapaassa sadannassa (BD) ja metsikkösadannassa (TF) 8 kuusialalla vuonna 1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

Norway spruce

The total N deposition in stand throughfall was also low (< 15 kg ha^{-1} yr^{-1}) on all the spruce plots compared to the deposition levels elsewhere in Europe (Forest...2000). NO_3-N and NH_4-N deposition in throughfall were also lower than deposition above the canopy. The Uusikaarlepyy plot (No. 23) on the west coast was an interesting exception. This plot is located close to a point source of NH_3 (fur farm), and these emissions are clearly reflected in the nitrogen fluxes in stand throughfall. The NH_4-N load in stand throughfall was strongly elevated compared to the load in the open area, as well as to deposition in stand throughfall on the other plots. The NO_3-N load was also higher in stand throughfall than that in the open area (Fig. 4). However, this is most probably caused by nitrification (microbial conversion of NH_4 to NO_3) either on the needle surfaces in the tree crowns or in the precipitation collectors. Nitrification is promoted by low acidity and an input of NH_4 (Derome & Nieminen 1998).

The fluxes of dissolved organic nitrogen (DON) varied between 22–57 mg m^{-2} yr^{-1} in bulk deposition (mean 41 mg m^{-2} yr^{-1}) and 41–210 mg m^{-2} yr^{-1} in stand throughfall (mean 115 mg m^{-2} yr^{-1}). The proportion of DON out of total N deposition was 14 % (variation 8–19 %) in bulk deposition and 42 % (30–52 %) in stand throughfall. Thus, the DON flux represents a significant and even larger component of the N flux in stand throughfall in spruce stands than in pine stands.

Deposition of base cations and chloride in 1999

Scots pine

The Ca, Mg, K, Na and Cl loads in throughfall were increased by leaching and wash-off processes in the tree canopies. There were clear decreasing S-N gradients in these ions when the plot at Sevettijärvi (No. 1) was excluded. The vicinity of the Arctic Ocean was reflected as elevated Mg, Na and Cl loads in stand throughfall and bulk deposition on this plot (Figs. 1 and 2).

Norway spruce

Nutrient leaching and wash-off of dry deposition accumulated in the spruce canopies increased the Ca, Mg, K, Na and Cl fluxes in stand throughfall compared to deposition in the open area. There were also clear decreasing S-N gradients for these ions (Figs. 3 and 4).

DOC fluxes in 1999

Scots pine

The DOC fluxes in stand throughfall varied between 2400–7400 mg m^{-2} on the pine plots in 1999. The corresponding range during 1996–1998 was 1500–6500 mg m^{-2} yr^{-1} (Lindroos et al. 1999). The highest fluxes in 1999 were recorded on the plots in southern and central Finland (Fig. 2).

Norway spruce

The DOC fluxes in stand throughfall varied between 2600–8000 mg m^{-2} on the spruce plots in 1999. The corresponding range during 1996–1998 was 2200–15400 mg m^{-2} yr^{-1} (Lindroos et al. 1999). The lowest fluxes in 1999 were recorded on the plots in northern Finland (Fig. 4).

Time trends of acidifying components in throughfall on pine and spruce stands

There was an increasing trend in the pH of stand thoughfall on most of the pine and spruce plots in southern and central Finland from 1996–1999. The SO_4-S deposition on the forest floor decreased from 1996–1999 on plots located between latitudes 60–61° N (Figs. 5 and 6). The decreasing trend in stand

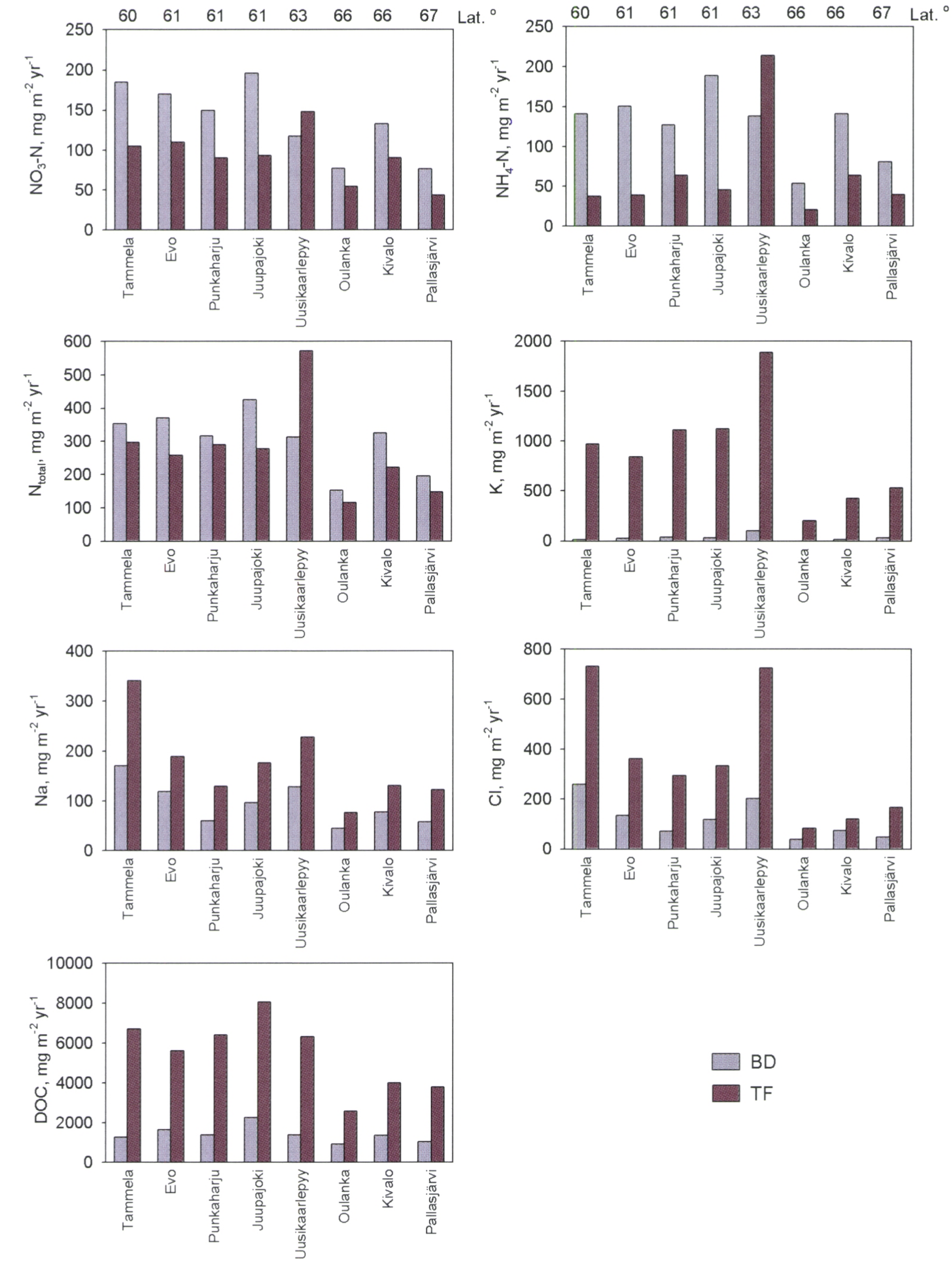

Figure 4. Deposition of nitrate, ammonium, total nitrogen, potassium, sodium, chloride and dissolved organic carbon in bulk deposition (BD) and stand throughfall (TF) during 1999 in 8 Norway spruce stands. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude, Lat.) of the plots is indicated in the upper part of the figure.
Kuva 4. *Nitraatti-, ammonium-, kokonaistyppi-, kalium-, natrium-, kloridi- ja liukoisen orgaanisen hiilen laskeuma vapaassa sadannassa (BD) ja metsikkösadannassa (TF) 8 kuusialalla vuonna 1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

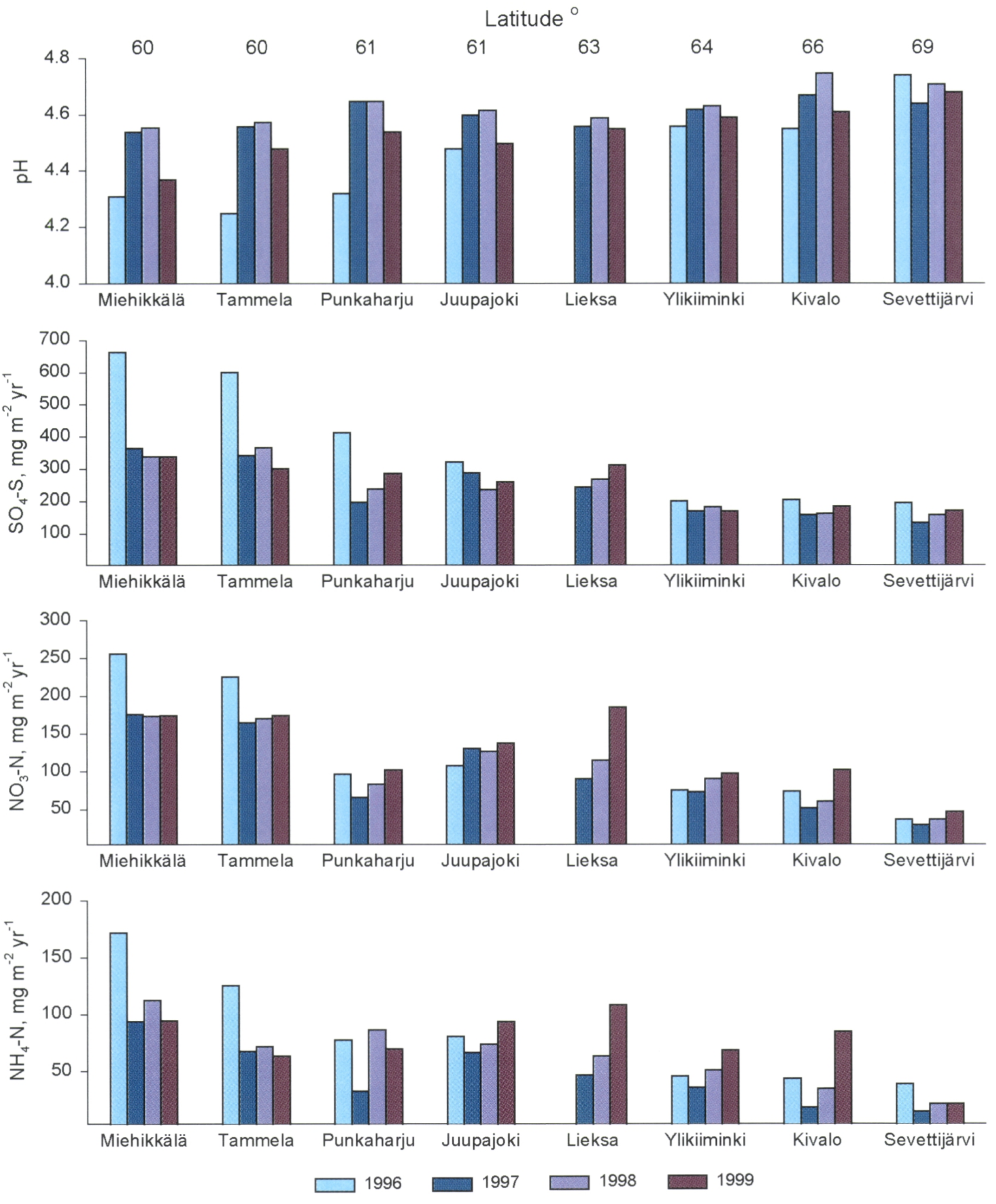

Figure 5. Mean pH and deposition of sulphate, nitrate and ammonium in stand throughfall in 8 Scots pine stands during 1996–1999. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude) of the plots is indicated in the upper part of the figure.

Kuva 5. *Keskimääräinen pH sekä sulfaatti-, nitraatti- ja ammoniumlaskeuma metsikkösadannassa 8 mäntyalalla vuosina 1996–1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

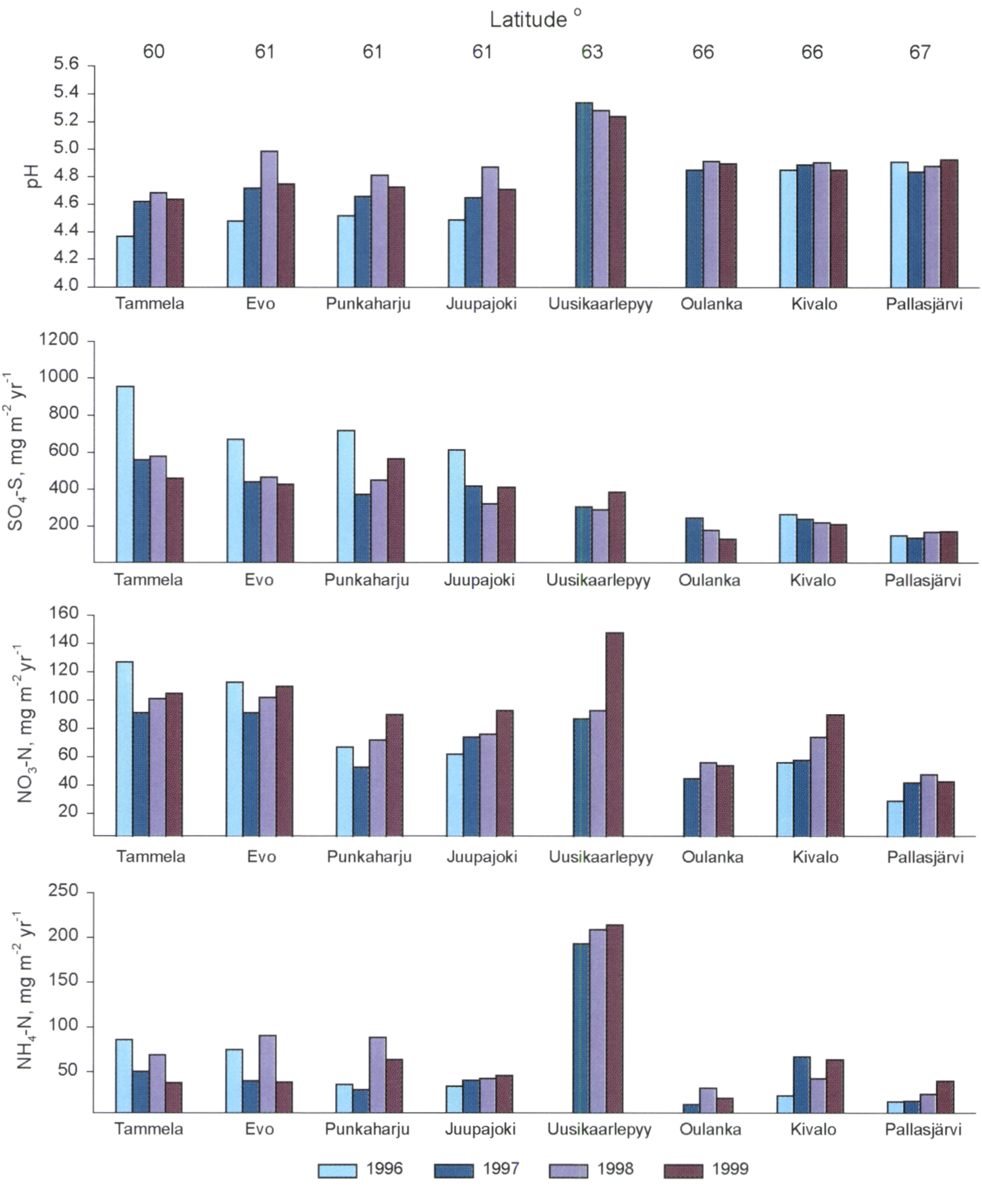

Figure 6. Mean pH and deposition of sulphate, nitrate and ammonium in stand throughfall in 8 Norway spruce stands during 1996–1999. The plots are arranged from left to right to correspond to the S-N gradient through Finland. Location (latitude) of the plots is indicated in the upper part of the figure.

Kuva 6. *Keskimääräinen pH sekä sulfaatti-, nitraatti- ja ammoniumlaskeuma metsikkösadannassa 8 kuusialalla vuosina 1996–1999. Havaintoalat on järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. Havaintoalan sijainti (leveysaste) on ilmaistu kuvan yläreunassa.*

throughfall acidity and proton flux has been related to the decrease in SO_4 concentrations and fluxes in several studies (e.g. Ukonmaanaho et al. 1998, Lindroos et al. 2000a).

In general, no clear time trends were detected in NO_3-N and NH_4-N deposition in stand throughfall. However, the nitrogen load decreased at the two southernmost pine plots from 1996–1999 (Figs. 5 and 6).

The loads of acidifying compounds in throughfall indicated that the time trends observed in earlier years also continued in 1999 (Lindroos et al. 2000b).

Conclusions

The effect of spruce canopies on the proton load as rain water passed down through the canopy layer was different from that in pine stands; the pine canopies increased the proton input to the forest floor, but the spruce canopies on many of the plots decreased the input.

Sulphur deposition to the forest floor decreased on moving from south to north in 1999.

The threat posed to forest ecosystems in NE Finland (e.g. at Sevettijärvi) by SO_2 emissions from the Nikel smelters, NW Russia, was still as low in 1999 as at the beginning of the 1990's.

There was an increasing trend in the pH and a decreasing trend in SO_4-S deposition in stand throughfall in southern and central Finland from 1996–1999.

The decrease in the nitrogen flux as rain water passed down through the canopy indicated that the deposition level was, in general, relatively low in relation to the nitrogen requirements of the forest stands.

Emissions from a local NH_3 point source were clearly reflected in the nitrogen fluxes in stand throughfall on the spruce plot in W Finland.

The DON flux represented a significant part of the N flux in stand throughfall.

The DOC fluxes in stand throughfall varied between 2400–8000 mg m^{-2} in 1999. The lowest fluxes were recorded on the plots in northern Finland.

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4.4 Soil solution – an indicator of nutrient availability, soil acidification, and soil-forming processes

Maavesi – maaperän ravinteisuuden, happamoitumisen ja maannosprosessien indikaattori

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Summary

The article contains a short review of soil solution sampling techniques. The main results of the 1998 and 1999 ICP Forests/Level II soil solution monitoring programme are presented, and differences in the soil solution composition obtained using tension and zero-tension lysimeters are tentatively explained.

There were considerable differences between the pH and concentrations of SO_4-S, NH_4-N, NO_3-N, Mg and K in soil solution sampled with tension and zero-tension lysimeters at the majority of the 10 monitoring plots covered in this report. The differences were primarily due to the fact that the soil solution sampled by the two techniques is not the same. The soil solution sampled by tension lysimeters provides information about nutrient uptake by the vegetation, and about soil buffering and neutralization processes. The soil solution sampled by zero-tension lysimeters provides, in turn, information about the movement of ions between the soil horizons, as well as the situation in the soil prior to e.g. buffering. For this reason, the calculation of ion fluxes in the soil should be restricted to ion concentrations obtained using zero-tension lysimeters, combined with measured water flux data calibrated using e.g. hydrological models. This is especially important because the ions of greatest interest in flux studies are in fact mainly those showing the greatest differences between the lysimeter types.

Yhteenveto

Artikkelissa kuvataan lyhyesti maaveden keräystekniikat sekä esitetään maavesiseurannan (ICP metsäohjelma/taso II) tärkeimmät tulokset vuosilta 1998 ja 1999. Lisäksi kuvataan maaveden koostumuksen eroja alipaine- ja vajovesilysimetrimenetelmien välillä.

Maaveden pH:ssa sekä SO_4-S-, NH_4-N-, NO_3-N-, Mg- ja K-pitoisuuksissa oli huomattavia eroja alipaine- ja vajovesilysimetreillä kerättyjen näytteiden välillä suurimmalla osalla kymmenestä havaintoalasta. Eri menetelmät keräävät maaveden eri fraktioita, mikä selittää maaveden koostumuksen eroja. Alipainelysimetreillä kerätty maavesi heijastaa kasvillisuuden ravinteiden ottoa ja maaperän puskuri- ja neutraloitumisprosesseja. Vajovesilysimetreillä kerätty maavesi kuvaa ionien kulkeutumista maannoshorisonttien välillä ja tilannetta esimerkiksi ennen puskuroitumista. Tämän

vuoksi ionivirtojen laskemisessa olisi hyvä käyttää ionipitoisuuksia vajovesilysimetrien näytteistä yhdistettynä mitattuihin vesimääriin, jotka on kalibroitu esimerkiksi hydrologisilla malleilla. Ainetasetutkimuksissa tärkeiden ionien pitoisuuksissa näyttäisi olevan suurimmat erot eri lysimetrityyppien välillä.

Soil solution sampling techniques

The soil solution (also called soil water) plays an important role in the nutrition and growth of trees because it is the medium through which tree roots receive mineral nutrients derived from deposition, from the leaching of both dead and living biomass in the tree crown, from mineralisation processes in the organic layer, and from the weathering of minerals in the mineral soil. In addition to being important from the point of view of plant nutrition, the composition of the soil solution also provides information about buffering and neutralization processes in the soil. Soil water sampling is being used to an ever-increasing extent for monitoring the effects of air pollution and other stress factors on soil properties. Three sampling techniques are available for this purpose:

- Tension lysimetry
- Zero-tension lysimetry
- Centrifugation of soil samples (centrifuge drainage)

Tension lysimetry is the technique most widely used in solution monitoring. Tension lysimeters are mainly based on three types of material: ceramic (P80), Prenart teflon/super-quartz, and Aluoxide (Fig. 1).

Tension lysimetry utilises vacuum pumps to draw soil solution, via capillary connections, into the lysimeter. The vacuum is also used to lift the soil solution samples up into collection vessels located at or close to the ground surface. In theory, the P80 and Prenart type lysimeters can be installed at almost any depth. However, their use in the organic layer is restricted because they are relatively long (6–8 cm) and it is also usually difficult to maintain capillary contact with the humus material during dry periods. The problem with length can be avoided to some extent by inserting them at an angle (but not horizontally). Aluoxide plate lysimeters can usually only be installed close to the soil surface because insertion at greater depths results in considerable disturbance to the soil profile, with subsequent changes in the physical and hydrological properties of the soil.

Zero-tension lysimeters are mainly of two types: plate and funnel lysimeters (Fig. 2).

The installation of zero-tension lysimeters in stony soils can be difficult. Plate lysimeters can be easily installed under the organic layer

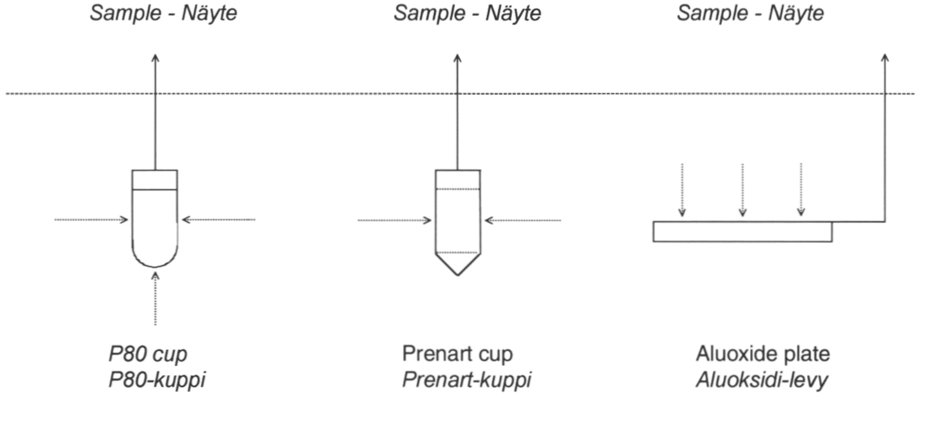

Figure 1. Examples of the different types of material and construction of tension lysimeters.
Kuva 1. *Esimerkkejä erityyppisistä alipaineimulysimetrien materiaaleista ja rakenteista.*

on any type of soil, but successful installation in the mineral soil in e.g. till soils can be extremely problematic and cause considerable changes in the overlying soil (e.g. aeration and hydrological changes caused by trench excavation). Funnel lysimeters have been successfully installed using special large-diameter soil augers on relatively stony soils down to depths of 40 cm even, but the roots leading into the overlying soil profile are always cut during installation. This means that soil water quality will not necessarily reflect the normal situation until the roots have grown back into the soil core. There is also frequently a flush of DOC and macronutrients in the soil water following installation owing to the cessation of nutrient uptake by the roots and an increase in nutrient mineralization.

The centrifuge drainage method is a relatively new technique. In this method, fresh soil samples (intact cores or mixed composite samples) are centrifuged at high speed in two-piece cups (Fig. 3). The soil solution from the soil sample in the upper cup is carried, as a result of centrifugal forces, down into the lower cup. This method is an intermediate form between traditional soil sampling and lysimetry, and its use is restricted by the same limitations associated with soil sampling.

A number of reviews and comparison studies have been carried out on the different techniques used to obtain samples of soil solution (Raulund-Rasmussen 1989, Zabowski & Ugolini 1990, de Vries et al. 1995, Giesler et al. 1996, Lawrence & David 1996, Ludwig et al. 1999, Nissinen et al. 2000).

The three procedures differ considerably with respect to the soil solution fraction sampled, the effects of sampling on the site, as well as the extent to which they provide information about temporal and spatial variation in the properties of the soil solution. The different soil solution fractions sampled by the three techniques are shown in Fig. 4.

Of the three methods, zero-tension lysimetry is the only one which samples a clearly definable fraction of the soil water, i.e. free-flowing water that percolates down through the soil when the field capacity is exceeded. Even so, there are drawbacks to this method because zero-tension lysimeters do not necessarily collect, for technical reasons, all of the free-flowing water at the sampling point, and the volume of water collected/surface area of the collector is therefore not always equal to the water flux at the sampling point. The situation is made even more complicated by the fact that the transport of ions and organic material between and within horizons as a result of capillary flow can occur upwards, downwards, or laterally.

Tension lysimetry samples a relatively broad fraction of the soil water. Soil water samples are obtained by this technique only

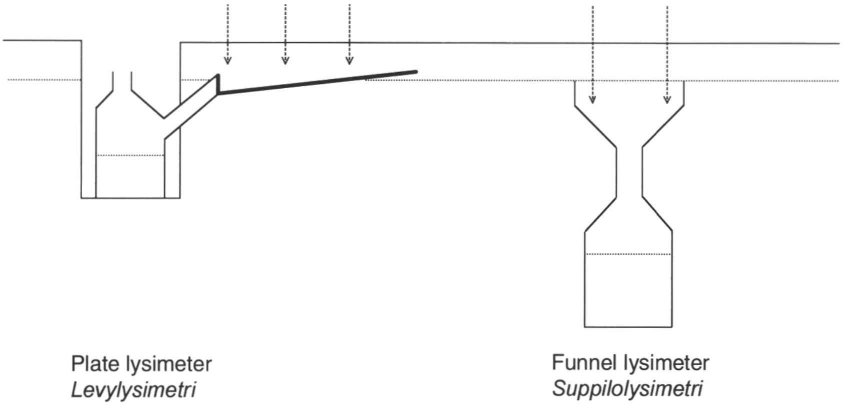

Figure 2. Examples of different types of zero-tension lysimeter.
Kuva 2. *Esimerkkejä erityyppisistä vajovesilysimetreistä.*

when the magnitude of the negative pressure (vacuum) applied exceeds that of the hydraulic forces holding the water in the soil. Tension lysimetry obviously also samples free-flowing water and groundwater or perched water when it is present.

Centrifuge drainage involves the centrifugation of fresh soil samples at high speeds in order to separate the soil solution from the solid material. This method removes a high proportion of the water in soil samples, but part of this water is so strongly adsorbed that is not normally available for plants. Furthermore, it is a time-consuming technique that suffers from the same drawbacks as soil sampling, e.g. it is a destructive technique, and cannot readily be used at the same site for frequently repeated sampling.

There are important differences between the chemical composition of soil water obtained by the different techniques. The percolation water obtained using zero-tension lysimeters is the soil water fraction that is primarily involved in soil formation processes, e.g. the transport of ions down the soil profile, from one horizon to another in the podzolisation process. In contrast, the chemical composition of soil water obtained using tension lysimeters usually represents the soil solution trapped in micropores, i.e. the medium where nutrient uptake by the roots occurs, as well as buffering and neutralization processes. The two sampling techniques are therefore in many cases complementary to each other.

The results presented in this report are restricted to continuous soil solution monitoring carried out at the same sampling points using tension and zero-tension lysimeters.

Material and methods

Soil solution samples are collected at 2- to 4-week-intervals during the snowfree period on 16 of the Level II monitoring plots. The results presented in this report represent soil solution collected during 1998 and 1999 from 10 of the plots which represent even-aged Scots pine and Norway spruce stands. The soil type on all of the plots is podzolic; most of the pine plots are located on sorted glacifluvial material, and the spruce plots on till soils.

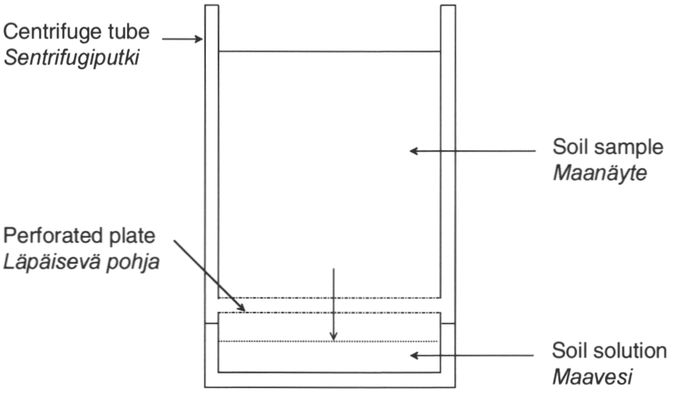

Figure 3. Cross-section of the 2-piece centrifuge tube used for extracting soil solution from soil samples by the centrifuge drainage method.
Kuva 3. *Läpileikkaus kaksiosaisesta sentrifugiputkesta, jota käytetään sentrifugointimenetelmässä erottamaan maavesi maanäytteestä.*

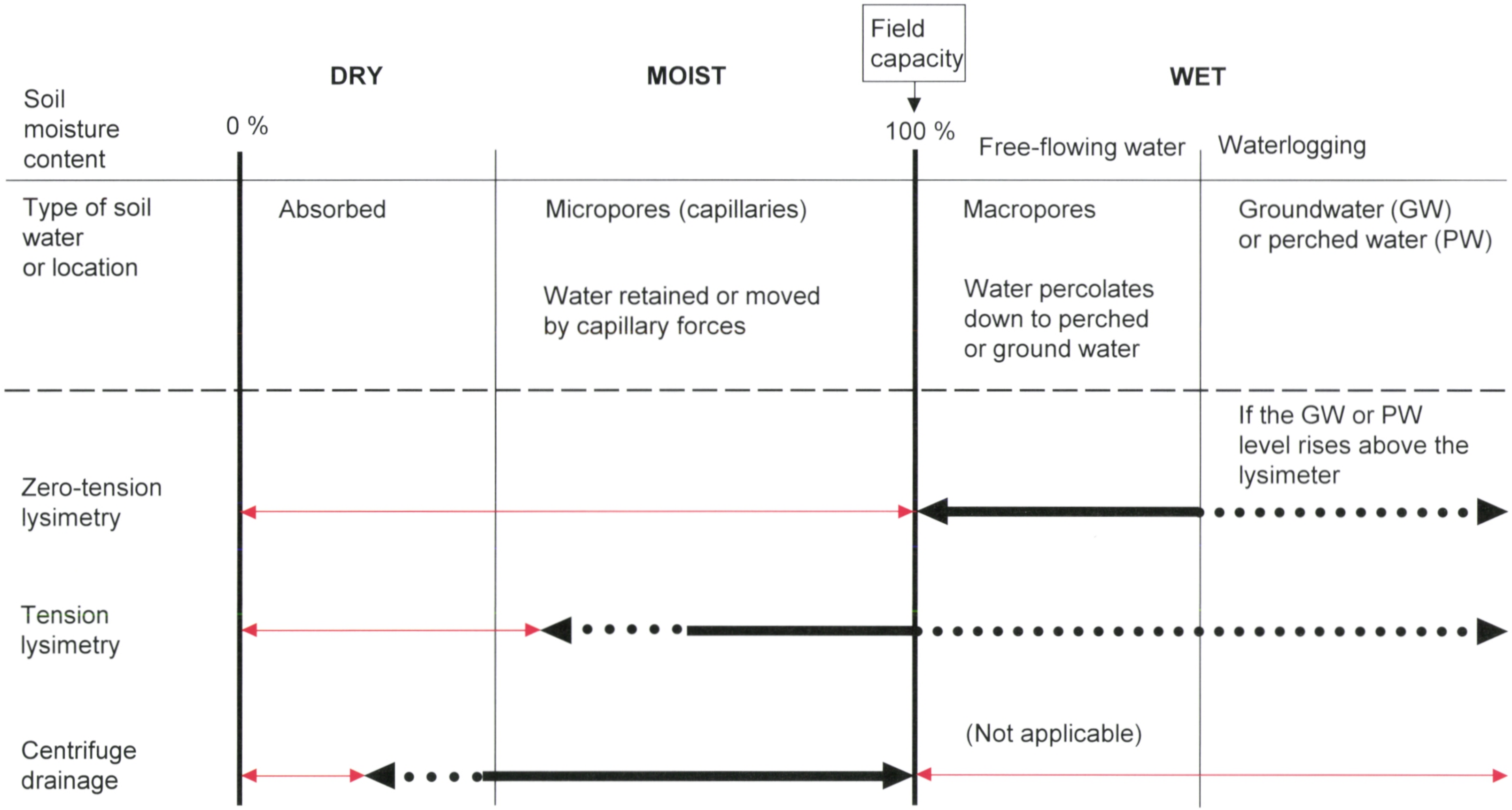

Figure 4. The soil water fractions sampled by zero-tension lysimetry, tension lysimetry and centrifuge drainage (thick black lines). Thethin red lines indicate the fractions that cannot be sampled. The actual fractions sampled by tension lysimetry can vary depending on the size of the vacuum applied and the moisture content of the soil during sampling (dotted lines). Similarly the amount of adsorbed water sampled by centrifuge drainage depends on the magnitude of the centrifugal force applied.

Kuva 4. *Vajovesilysimetreillä, alipainelysimetreillä ja sentrifugimenetelmällä kerättävät maavesifraktiot (paksu musta viiva). Ohut punainen viiva osoittaa fraktiot, joita ei voida kerätä. Alipainelysimetreillä kerättävät maavesifraktiot voivat vaihdella alipaineen määrästäja maaperän kosteudesta riippuen (katkoviiva). Sentrifugimenetelmällä saatava sitoutunut vesimäärä riippuu sentrifugivoiman suuruudesta.*

Percolation (free-flowing) water zero-tension lysimeters (funnel type, ø 20 cm) were installed at depths of 20 and 40 cm from the ground surface in 1997. Installation and construction of this type of lysimeter are described in detail in Derome et al. (1991). There were 5 lysimeters at each depth, the lysimeters being located systematically on the plot. Tension lysimeters (P80 porcelain cups) were installed at depths of 20 and 40 cm from the ground surface in 1997. There were 6 lysimeters at each depth.

The samples were pre-treated and analysed according to the manual of the ICP Forests Programme (Manual.... 1998). The soil solution parameters measured were pH, the Ca, Mg, K, NH_4-N, NO_3-N, 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, Mg, K and Al by ICP-AES. SO_4, NH_4 and NO_3 were determined on unconserved samples by ion chromatography.

Results and discussion

The mean values of the parameters for soil solution samples obtained by tension lysimetery and by zero-tension lysimetry differed considerably on the individual plots (Figs. 5–7, Table 1). A number of the parameters (e.g. Al, Ca/Al ratio, SO_4-S and Ca at 20 cm, and Al, Ca/Al ratio, NH_4-N, Ca and K at 40 cm) showed no clear trends attributable to the type of lysimetry used. In contrast, soil solution collected with tension lysimeters was significantly less acidic (higher pH) on all the plots (except for plot No. 17 at Punkaharju) at depths of both 20 and 40 cm (Fig. 5). There were also relatively clear trends for NH_4-N, NO_3-N, Mg and K at 20 cm, and SO_4-S, NO_3-N and Mg at 40 cm (Figs. 6–7).

These trends can be explained on the basis of the type of soil solution sampled, as well as on the behaviour of the specific ions.

The reason for the lower pH of the percolation water collected by zero-tension lysimeters is that it contains considerable amounts of acidic material leached from the overlying organic layer, as well as the input of protons from deposition and canopy-leaching processes. The pH of soil solution collected with tension lysimeters represents, correspondingly, the end result of buffering and neutralization processes in the soil. These results clearly demonstrate that the buffering capacity of the soil in the 10 stands is fully capable of withstanding the load of acidifying compounds to which these soils have been, and are currently, subjected.

The higher SO_4-S concentrations in soil solution sampled at 40 cm depth using zero-tension lysimeters in the majority of the plots are due either to the so-called "concentration" of conservative anions (Cl^- and to some extent SO_4^{2-}) with increasing depth, or to the fact that SO_4^{2-} plays an increasingly important role as an accompanying anion as the proportion of inorganic anions decreases with increasing soil depth. The amount of water percolating down through the soil profile decreases with increasing depth owing to the uptake of water by the trees and ground vegetation (evapotranspiration), as well as direct evaporation from the ground surface. As there is almost no uptake of Cl^-, and only minimum uptake of SO_4^{2-} by the vegetation, this means that the concentrations of these anions will increase with increasing soil depth. The movement of ions down the soil profile is governed by the physical law that there must always be equal amounts of cations and anions in the soil solution. Podzolic soils normally contain considerably higher concentrations of inorganic cations (e.g. Ca^{2+}, Mg^{2+}, K^+, Al^{3+}) than anions (e.g. Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}), the remaining anions being the organic anions formed through the dissociation of weak organic acids. These organic anions have a low mobility in the soil, and hence play an important role in reducing the leaching of the major cations (e.g. Ca^{2+}, Mg^{2+}, Al^{3+}) down into the mineral soil, and eventually into the groundwater. However, the input of SO_4^{2-} ions in acidifying deposition

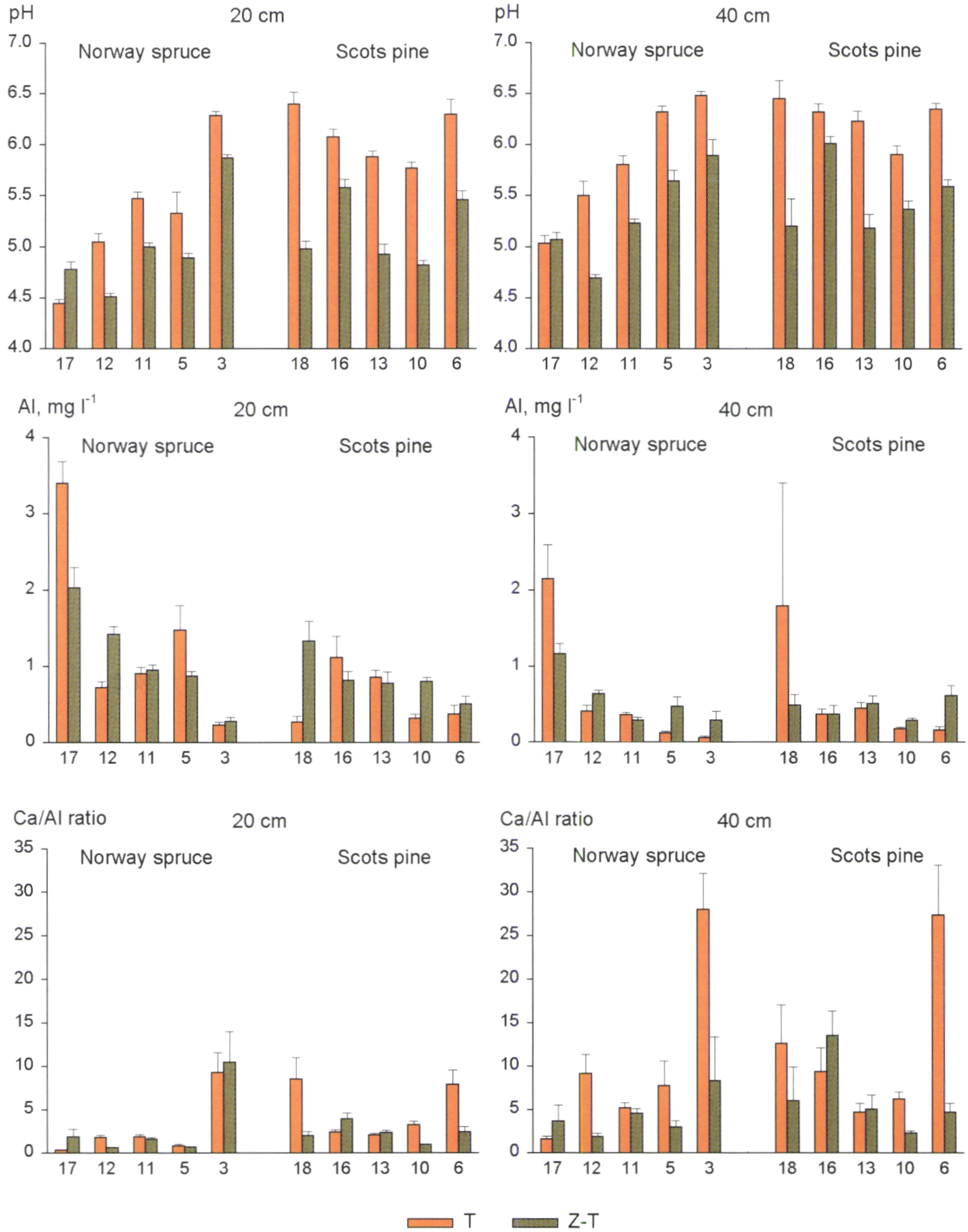

Figure 5. Mean pH, Al concentration and molar Ca/Al ratio in soil solution collected at depths of 20 and 40 cm using tension (T) and zero-tension lysimeters (Z-T) in Norway spruce and Scots pine stands during the snowfree season in 1998 and 1999. The numbers refer to the monitoring plots, which are arranged in order from south to north.

Kuva 5. *Maaveden keskimääräinen pH, Al-pitoisuus ja Ca/Al-moolisuhde 20 ja 40 cm:n syvyyksillä. Näytteet on kerätty alipainelysimetreillä (T) ja vajovesilysimetreillä (Z-T) kuusi- ja mäntyaloilta lumettomana aikana 1998 ja 1999. Kuvassa on esitetty havaintoalojen numerot. Havaintoalat on järjestetty etelästä pohjoiseen.*

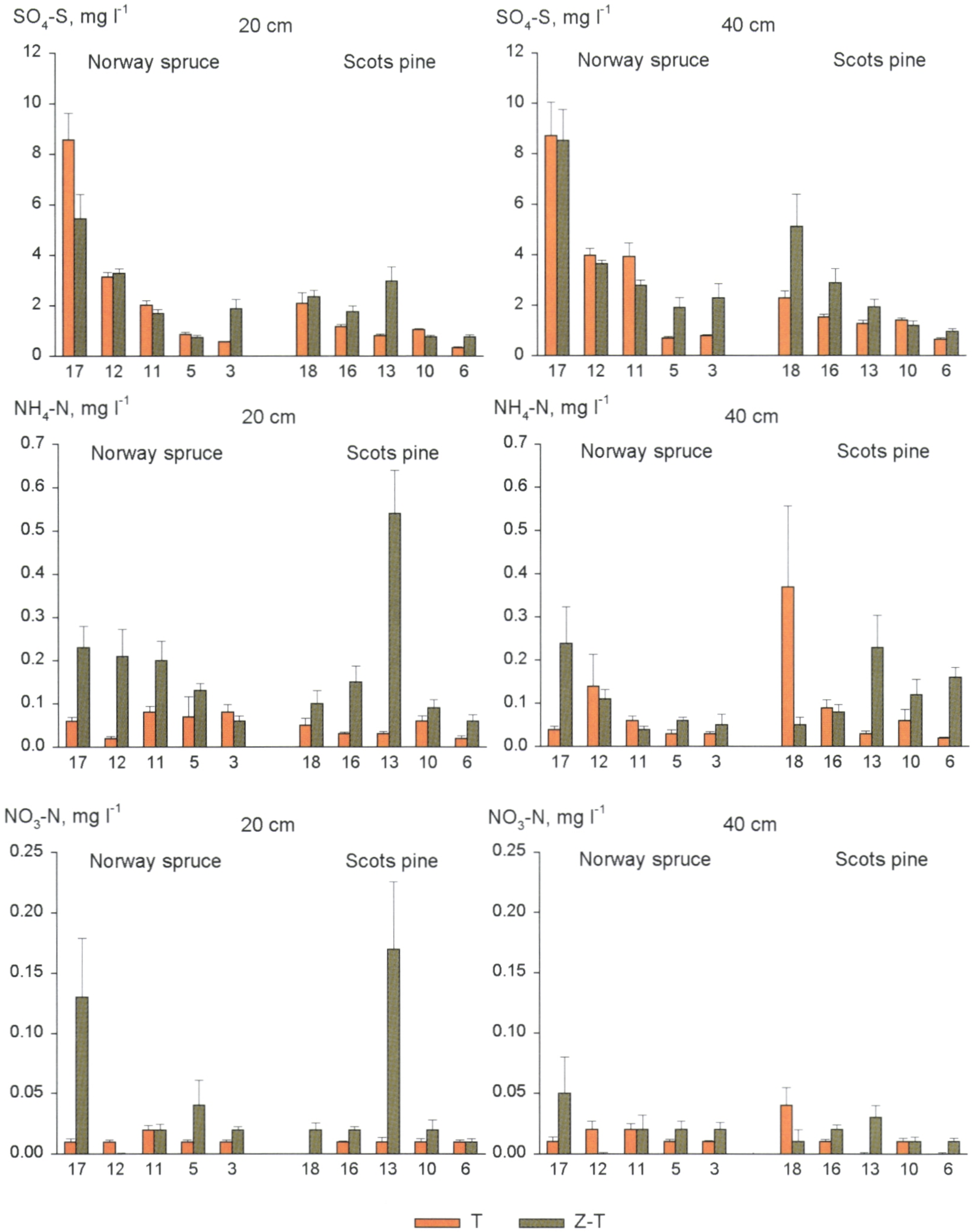

Figure 6. Mean SO_4-S, NH_4-N and NO_3-N concentrations in soil solution collected at depths of 20 and 40 cm using tension (T) and zero-tension lysimeters (Z-T) in Norway spruce and Scots pine stands during the snowfree season in 1998 and 1999. The numbers refer to the monitoring plots, which are arranged in order from south to north.

Kuva 6. *Maaveden keskimääräinen SO_4-S-, NH_4-N- ja NO_3-N-pitoisuus 20 ja 40 cm:n syvyyksillä. Näytteet on kerätty alipainelysimetreillä (T) ja vajovesilysimetreillä (Z-T) kuusi- ja mäntyaloilta lumettomana aikana 1998 ja 1999. Kuvassa on esitetty havaintoalojen numerot. Havaintoalat on järjestetty etelästä pohjoiseen.*

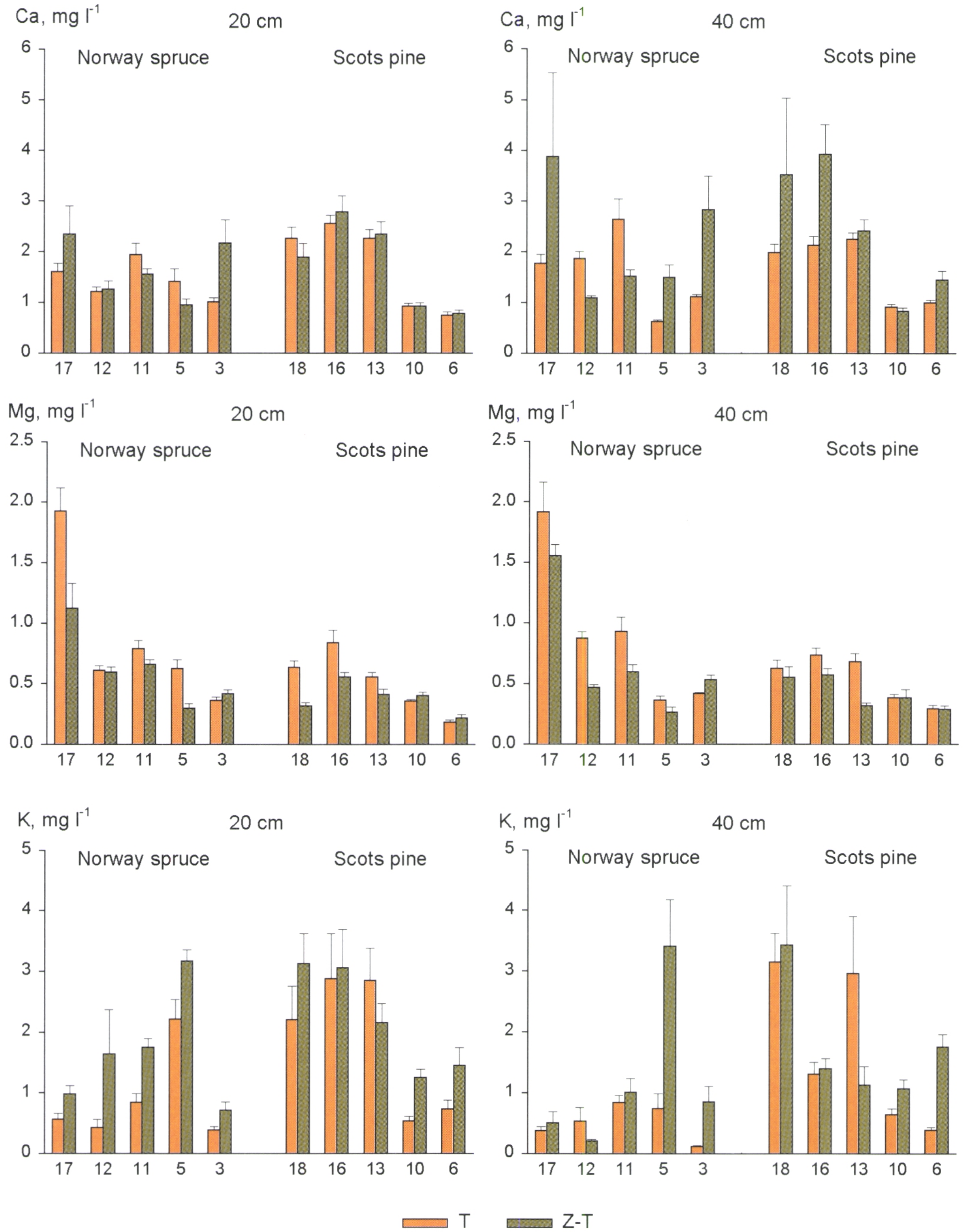

Figure 7. Mean Ca, Mg and K concentrations in soil solution collected at depths of 20 and 40 cm using tension (T) and zero-tension lysimeters (Z-T) in Norway spruce and Scots pine stands during the snowfree season in 1998 and 1999. The numbers refer to the monitoring plots, which are arranged in order from south to north.

Kuva 7. *Maaveden keskimääräinen Ca-, Mg- ja K-pitoisuus 20 ja 40 cm:n syvyyksillä. Näytteet on kerätty alipainelysimetreillä (T) ja vajovesilysimetreillä (Z-T) kuusi- ja mäntyaloilta lumettomana aikana 1998 ja 1999. Kuvassa on esitetty havaintoalojen numerot. Havaintoalat on järjestetty etelästä pohjoiseen.*

Table 1. Number of plots (maximum 10) with a significant difference between soil solution obtained using tension lysimetry (T) and zero-tension lysimetry (Z-T). T>Z-T = the mean value for tension lysimeter samples was greater than that for zero-tension lysimeters, T<Z-T = the mean value for tension lysimeter samples was smaller than that for zero-tension lysimeters. Sets with more than 5 plots are marked in bold.
Taulukko 1. *Havaintoalojen jakauma (maksimi 10 havaintoalaa) perustuen merkitsevään eroon maaveden koostumuksessa alipainelysimetrien (T) ja vajovesilysimetrien (Z-T) välillä. T>Z-T = Alipainelysimetrien näytteiden keskiarvo oli korkeampi kuin vajovesilysimetreillä kerätyissä näytteissä. T<Z-T = Alipainelysimetrien näytteiden keskiarvo oli matalampi kuin vajovesilysimetreillä kerätyissä näytteissä. Havaintoalaryhmät, joissa on enemmän kuin viisi havaintoalaa, on vahvennettu.*

Parameter - *Tunnus*	No of plots – *Havaintoalojen lukumäärä* 20 cm T>Z-T	20 cm T<Z-T	No of plots – *Havaintoalojen lukumäärä* 40 cm T>Z-T	40 cm T<Z-T
pH	**9**	1	**9**	0
Al	2	3	2	5
Ca/Al	4	2	5	1
SO_4-S	4	4	1	**6**
NH_4-N	0	**8**	1	5
NO_3-N	1	**7**	2	**6**
Ca	2	2	2	5
Mg	**6**	0	**6**	1
K	0	**7**	2	4

during the past few decades means that forest soils now contain higher concentrations of the more mobile SO_4^{2-} ion, which readily moves down deeper into the mineral soil.

The lower NH_4-N and NO_3-N concentrations in soil solution sampled at both 20 and 40 cm depth using tension lysimeters in the majority of the plots (Fig. 6) are due to the efficient uptake of these nitrogen compounds by plant roots and soil micro-organisms. Coniferous forest soils are usually deficient in nitrogen in a plant-available form (NH_4^+, NO_3^-), and the residence time in the soil of NO_3 especially is usually relatively short. The concentrations of both NH_4 and NO_3 in the soil solution sampled with both types of lysimeter were extremely low, and the low concentrations of NO_3 in percolation water at a depth of 40 cm is a clear indicator that nitrogen deposition on the forest floor on these plots has not accumulated to such a level that it would have caused nitrogen saturation.

Magnesium is known to play an important role in buffering processes in the soil, and the higher Mg concentrations in soil solution obtained with tension lysimeters at both 20 and 40 cm compared to the corresponding concentrations in percolation water suggests that this is a result of the displacement of Mg^{2+} ions from cation exchange sites by protons (H^+). This conclusion is supported by the higher pH of the soil solution obtained using tension lysimeters (Fig. 7). There is also an input of Mg from weathering processes in the mineral soil.

Potassium is an extremely mobile cation in the soil, and it has a low affinity for cation exchange sites. Despite this, a number of studies in podzolic soils under conifers have shown that K concentrations in percolation water decrease strongly with increasing depth, presumably due to efficient uptake of K by the tree roots and mycorrhizas. The higher K concentrations in the percolation water compared to those in the soil solution obtained with tension lysimeters (Fig. 7) supports this conclusion.

There are a number of factors associated with the type of lysimeter that can also have a considerable effect on the results of soil solution sampling. These factors have undoubtedly contributed to the considerable variation in the magnitude and polarity (i.e. positive or negative) of the differences between the individual plots:

1) Zero-tension lysimeters only provide samples when the water-holding capacity of the soil is exceeded, i.e. when the soil is relatively wet. This means that, compared to the situation with tension lysimeters, the soil solution will be relatively diluted, especially during the period following snowmelt. Furthermore, soil solution samples will be obtained with tension lysimeters during periods when no percolation water is obtained, and therefore the sampling periods will, in many cases, be different.

2) The greatest drawback to the use of tension lysimeters is that they sample water from a volume of soil that varies according to the suction pressure applied, the moisture content of the soil, and the soil texture (i.e. pore size). On sites with an intermittently high perched water or ground water table, tension lysimeters may frequently sample perched or ground water. Furthermore, as the thickness of the soil layer from which the soil solution is sampled varies, the sampling depth will not be at all precise. This is the greatest obstacle to using ion concentrations obtained with tension lysimeters for calculating ion fluxes in the soil.

Conclusions

There were considerable differences between the pH and concentrations of SO_4-S, NH_4-N, NO_3-N, Mg and K in soil solution sampled with tension and zero-tension lysimeters at the majority of the 10 monitoring plots covered in this report. The differences were primarily due to the fact that the soil solution sampled by the two techniques is not the same. The soil solution sampled by tension lysimeters provides information about nutrient uptake by the vegetation, and about soil buffering and neutralization processes. The soil solution sampled by zero-tension lysimeters provides, in turn, information about the movement of ions between the soil horizons, as well as the situation in the soil prior to e.g. buffering. For this reason, the calculation of ion fluxes in the soil should be restricted to ion concentrations obtained using zero-tension lysimeters, combined with measured water flux data calibrated using e.g. hydrological models. This is especially important because the ions of greatest interest in flux studies are in fact mainly those showing the greatest differences between the lysimeter types.

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4.5 Phenological observations

Fenologiset havainnot

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Summary

Phenology is the study of annual recurring phenomena in the life cycle of an organism. Knowledge about the timing and the duration of certain life cycle events provides valuable information about the condition of trees and the effects of climate fluctuations and changes on them. Since 2000 phenology has been included in the ICP Forests/Level II programme on an optional basis. Phenological observations are made at two levels, an extensive one at the plot level and an intensive one the individual tree level. The results of intensive phenological assessments made on three Norway spruce plots in Finland during 2000 are presented. A system using digital cameras was also developed.

Yhteenveto

Fenologia pyrkii kuvaamaan kasvien elämänkierron vuosittain toistuvia ilmiöitä. Havainnot ilmiöiden ajankohdasta ja kestosta tuottavat arvokasta tietoa ilmaston vaihteluiden ja muutosten vaikutuksista puiden kuntoon. Fenologiset havainnot ovat vuodesta 2000 lähtien kuuluneet ICP metsäohjelma/taso II:n valinnaisiin ohjelmiin. Fenologiset havainnot on tehty sekä havaintoalan että yksittäisen puun tasolla. Tässä raportissa esitetyt tulokset ovat kolmesta suomalaisesta havaintokuusikosta vuodelta 2000. Lisäksi kehitettiin digitaalikamerajärjestelmän käyttöä fenologisten havaintojen teossa.

Introduction

Phenology is the study of annually recurring phenomena in the life cycle of an organism (life cycle events). For forest trees, the most relevant phenological events are budburst in spring, flowering, leaf or needle coloration, shedding during autumn and the development of frost hardiness during winter. Temperature is known to be the most important trigger for these events, although photoperiod, precipitation and the nutritional status of the tree also affect the timing of the events. Genetic properties also have a strong effect on phenology (Flint 1974, Beuker 1994). Many studies have shown that the geographical origin (provenance) of trees also affects the timing of phenological events, because trees are adapted to the climate in which they grow (ecotypes).

Phenology is of the greatest importance in the temperate and boreal regions where the summer (favourable for growth) alternates with the unfavourable winter period. In other regions seasonal drought periods may be unfavourable for growth. This means that trees have to synchronise their active and dormant periods with the cycle of the seasons in order to optimise growth while, at the same time, minimising the risk of damage by e.g. frost or drought.

Phenological observations on the Level II plots

In the Level II monitoring programme phenology is defined as the observation and recording of biotic and abiotic (damaging) events, as well as the yearly development stages of the trees. Its aim is to provide additional and complementary information on the status and development of the condition of forest trees throughout the year.

Because the timing of the phenological events is so strongly depending on climatic events, climate change will affect the adaptation of trees to their local climate (Beuker 1994, Kramer 1995). This is why phenology is an important tool for observing the effects of climate warming on forest trees. The political desire to place more emphasis on the effects of climate warming was one of the reasons why phenology has been included in the ICP Forests programme. Long term phenological observations will help to determine the course of the annual development stages of the trees on the Level II plots. This can then be used to explain possible changes in the timing of phenological phases (starting time, length of period and magnitude) in relation to environmental factors of natural and/or anthropogenic origin.

Knowledge about the timing and duration of certain life cycle events also provides valuable information about the condition of trees. Extreme weather effects, such as late spring frosts during or shortly after flushing that cause damage to the new shoots, will also affect the condition of the foliage during the rest of the growing period. When analysed in combination with other data obtained from the Level II plots, such as meteorological, deposition, crown condition and increment, phenology provides additional background information about possible causes to the crown condition assessments that are carried out annually on each plot, as well as to the growth assessments carried out only every five years.

There are two levels of phenological observation in the Level II programme. The extensive observations, at plot level, consist of those biotic and abiotic (damaging) events and phenological phenomena which are observed during cursory examination of the plot and its buffer zone. Overall observation of the plots is made at regular intervals. The observations can be made by field staff visiting the plot for other reasons, such as the collection of deposition and soil water samples or litterfall samples. These rough assessments provide additional information about what is happening on the plot. This information can be used to explain the results of other assessments such as crown condition. The data are, however, not sufficient for detailed analyses and modelling of phenological events. For these purposes, intensive monitoring at the individual tree level consists of more detailed observations on the condition of selected trees. These observations are made at more frequent intervals, especially during critical phases. For example, in the boreal zone observations have to be made every second day at least during bud burst in order to assess the exact timing of the event. Because of the qualitative nature of the intensive assessments, a high degree of comparability between the plots can only be reached through training of the field staff.

The manual for phenological observations on Level II plots was prepared during a series of meetings of the Expert Panel on Phenology:

September 21–23. 1997, Punkaharju, Finland
January 15–18. 1998, Firenze, Italy
February 11–13. 1999, Prague, The Czech Republic

The manual was published in November 1999, and since the year 2000 phenological observations have been an official part of the ICP Forests/Level II programme. At the moment, however, both levels are optional. The reason for this is that further expansion of the programme is difficult to implement in many of the participating countries. The intensive monitoring especially requires regular visits to the plots, up to several times a week during critical periods. Because many of the plots are situated far from stations with trained staff, and often difficult to reach, intensive observations of this sort are not possible without additional funding.

Assessments during 2000

Intensive phenological observations were made during 2000 at 3 Level II plots: Pallasjärvi_S, No. 3; Kivalo_S, No. 5; and Solböle_Spro, No. 28. Norway spruce is the dominant species on each plot, and flushing was the event assessed. A one-day training event was organised at Solböle for the field staff on May 22. Unfortunately a period of warm weather resulted in almost complete flushing on the Solböle plot by that time. A comparison between the plots for the timing of flushing can be seen in Fig. 1. On each plot 10 trees were assessed, except for plot 17 where only 3 trees were observed using digital cameras. Flushing clearly occurred earlier in the southern part of Finland than in the north. This is in agreement with earlier studies (e.g. Beuker 1994). Figure 2 shows the variation between individual trees on plots No. 3 and 5.

Digital cameras

The possibilities of carrying out intensive phenological monitoring are limited by the fact that many Level II plots are at remote sites, and are often rather inaccessible. In addition, it also takes a considerable amount of time for trained field staff to carry out the work. Therefor a remote system that could make observations at a high frequency would be of considerable assistance. Digital cameras seem to be the most suitable tool for this purpose. At the Norway spruce Level II plot Punkaharju_S, No. 17 in Eastern Finland three digital surveillance cameras were installed on the weather tower immediately outside the plot (Fig. 3). Because the aim was to develop a usable system, each camera was set at a different angle or zooming rate. The cameras were connected to a computer (Fig. 4) which was programmed to save one picture from each camera at a certain time each day.

The findings after one season are that digital cameras are very suitable for assessing phenological events. The timing of flushing and flowering could be assessed satisfactory from the pictures. However, the technique needs to be further refined. Due to the rather unsatisfactory sharpness of the pictures, assessments could only be made on closely zoomed pictures (compare Figs. 5 and 6). This means that only one or two trees can be included in one picture frame. Several cameras would be needed to obtain an overview of the whole plot. In the manual it is recommended that between 10 and 20 trees should normally be used for the intensive phenological assessments. A camera that could rotate and take pictures in different directions may be the solution. Furthermore, the cameras used in the trial could not respond sufficiently to the changing light conditions in the open forest. In the future the cameras will be connected to a (mobile) telephone network in order to enable immediate analysis of the pictures from the different plots by the same person. The inclusion of colour scales to enable the assessment of changes in foliage colouring, and metric graduations to enable growth rate assessments, will also be considered.

Acknowledgements

I would like to thank Thomas Lindblad, Aarno Nova and Eveliina Rauhala for making the phenological assessments in the field, Esko Oksa, Sakari Silvenoinen and Matti Tolvanen for their help with the installation of the cameras.

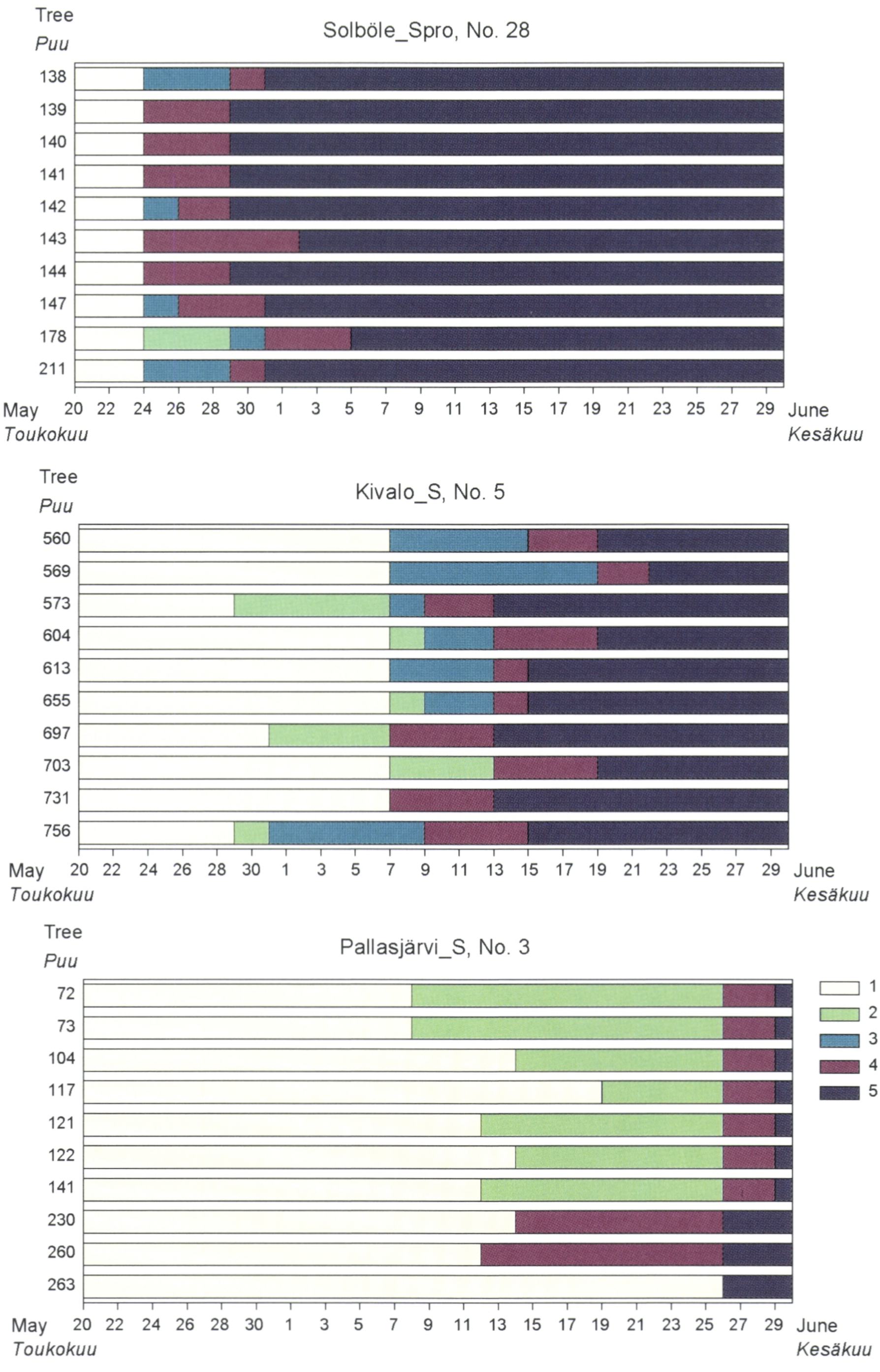

Figure 1. Flushing development during spring 2000 at three Level II plots. The extend of the flushing was scored in five grades: 1 = not present, 2 = infrequent, 3 = common, 4 = abundant and 5 = completed.

Kuva 1. *Silmunpuhkeamisen kehitys keväällä 2000 kolmella intensiivisen seurannan (taso II) havaintoalalla. Kehitys jaetaan 5 luokkaan: 1 = kaikki silmut levossa, 2 = joitain silmuja auennut, 3 = suuri osa silmuista auennut, 4 = lähes kaikki silmut auenneet ja 5 = kaikki silmut auenneet.*

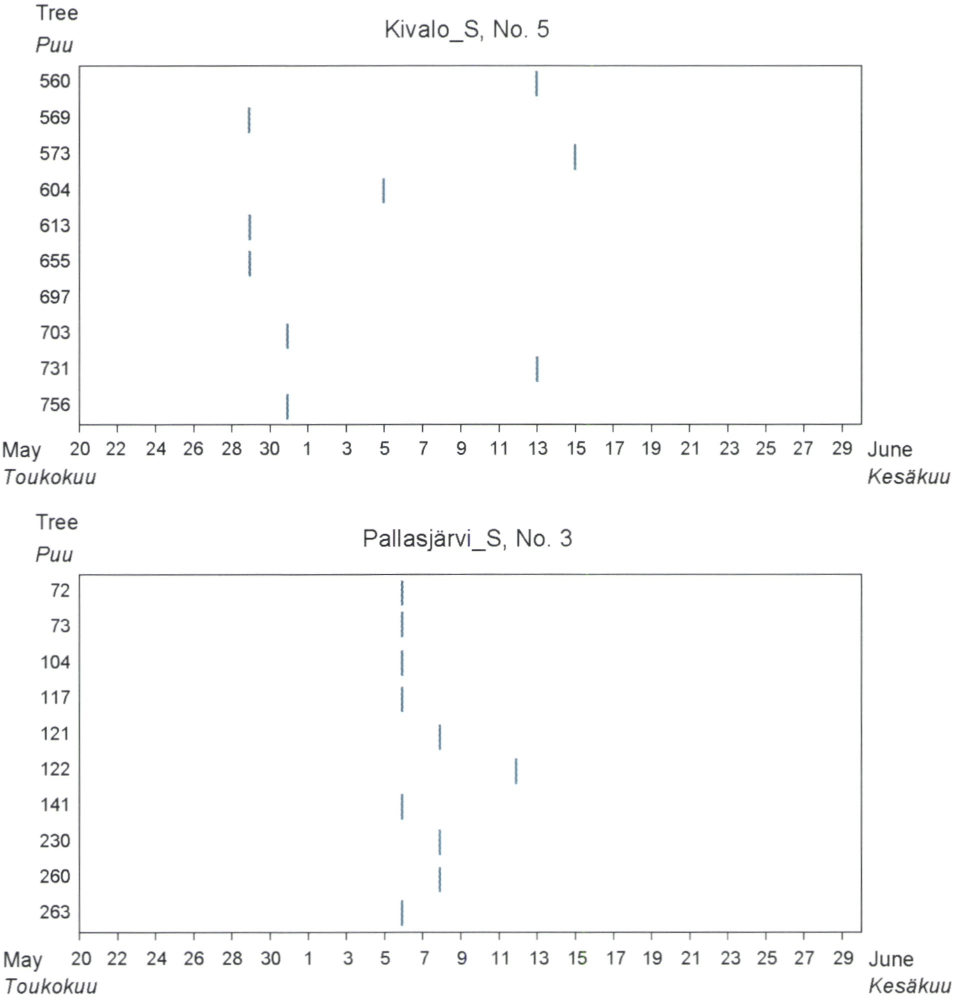

Figure 2. Starting date of flowering during spring 2000 at two Level II plots.
Kuva 2. *Kukinnan alkamisajankohta keväällä 2000 kahdella intensiivisen seurannan (taso II) havaintoalalla.*

Figure 3. A digital camera attached to the weather tower at plot Punkaharju_S No. 17. (Photo: Egbert Beuker).
Kuva 3. *Säätorniin asennettu digitaalikamera havaintoalalla Punkaharju_S nro 17. (Kuva: Egbert Beuker).*

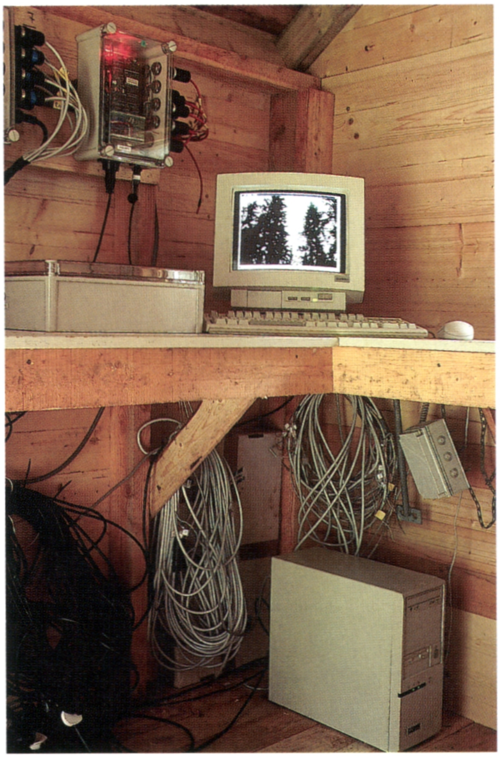

Figure 4. The PC saving the images from the digital cameras. (Photo: Egbert Beuker).
Kuva 4. *Digitaalikameran ottamien kuvien tallentamiseen käytetty tietokone. (Kuva: Egbert Beuker).*

Figure 5. Image from one of the cameras with a wide angle setting. (Photo: Egbert Beuker).
Kuva 5. *Digitaalikameran ottama laajakulmakuva. (Kuva: Egbert Beuker).*

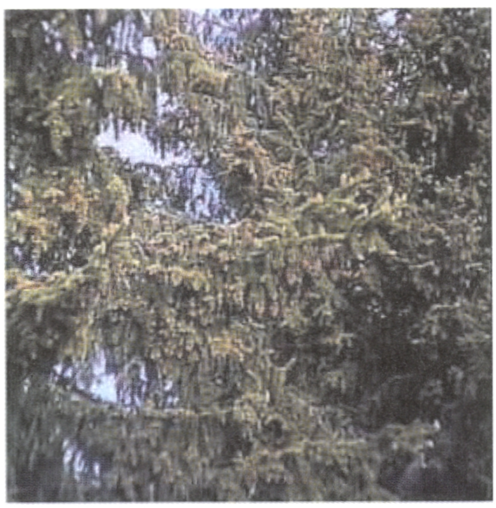

Figure 6. Image from one of the cameras with a zoom setting. (Photo: Egbert Beuker).
Kuva 6. *Digitaalikameran ottama lähikuva. (Kuva: Egbert Beuker).*

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5 Variation in throughfall in relation to funnel size, collection period, field arrangement and number of collectors

Metsikkösadannan määrän ja laadun vaihtelu suhteessa keräimen kokoon, keräysajanjaksoon, koejärjestelyyn maastossa ja keräinten lukumäärään

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Summary

The effects of funnel size, collection period, arrangement (layout) of collectors, and number of collectors needed to achieve defined levels of precision and accuracy are described for throughfall at a Norway spruce stand located in southern Finland. The size of the funnels used corresponded to those used in the EC-UN/ECE ICP Forests/Level II throughfall programme. Results indicated that: 1) throughfall deposition loads significantly varied with the type of funnel used, 2) monthly concentration values tended to increase with the length of the collection period, 3) 15 collectors would allow for most of the ICP Forests mandatory throughfall parameters to be determined within 15–20 % of the true mean weekly value at Kasiniemi with a confidence level of 95 %, and 4) if the stand were uniform (single species and random stem distribution), sampling with either a systematic or random design would give similar results.

Yhteenveto

Tutkimuksen tarkoituksena oli tutkia keräimen koon, keräysajanjakson ja koejärjestelyn vaikutusta metsikkösadannan ravinteiden määrään ja laskeumaan (accuracy) sekä optimoida paras mahdollinen keräinten lukumäärä luotettavan tuloksen saamiseksi (precision). Tutkimuskoeala sijaitsi kuusivaltaisessa metsikössä Etelä-Suomessa. Käytettyjen suppiloiden koko vastasi EC-UN/ECE ICP metsäohjelma/taso II metsikkösadanta ohjelmassa käytettyjen keräinten kokoa. Tulokset osoittivat, että 1) metsikkösadantalaskeuma vaihteli merkitsevästi käytetyn keräimen mukaan, 2) pisimmän keräysjakson (4 viikkoa) maastossa olleen näytteen kuukausipitoisuus oli korkeampi kuin lyhyemmän ajanjakson olleiden, 3) 15 keräimen käyttäminen antoi 95 % merkitsevyystasolla 15–20 % marginaalin sisällä oikean pitoisuus keskiarvon useimmille ICP metsäohjelma/taso II ohjelman ns. pakollisille mitattaville tunnuksille ja 4) keräinten järjestyksellä maastossa ei ollut merkittävää vaikutusta mitattuihin pitoisuuksiin homogeenisessä kuusimetsikössä.

Introduction

The effects of funnel size, collection period, arrangement (layout) of collectors, and number of collectors needed to achieve defined levels of precision and accuracy are generally unknown within the EC-ICP Forest/Level II throughfall programme. We carried out a study to address these issues in a Norway spruce stand located in southern Finland (Starr & Ukonmaanaho 2000). Although the results are specific to the particular stand and deposition conditions, the principles involved are generally applicable.

Material and methods

The Kasiniemi study stand

The 64-year-old Norway spruce (*Picea abies*) stand at Kasiniemi (61° 25' 29" N, 24° 55' 24" E, 135 m a.s.l.) was selected because it was in the vicinity of the institute's Vesijako Research Area (accessibility and availability of field technician for sampling) and because of reduced variability due to uniform stand structure (i.e. dominance of a single species, trees of similar size and uniform stocking density).

The stand had volume (over-bark) of 340 m^3 ha^{-1} (98 % Norway spruce), with 467 stems ha^{-1} and a mean breast height diameter (dbh) of 27.5 cm (Fig. 1). The canopy cover (vertical canopy projection per unit of ground area) was 57 %. Although the stand was relatively uniform in terms of tree size and stocking, there were some gaps in the canopy where snags, the result of snow damage, had been removed or had fallen to the ground. These gaps were avoided in locating the throughfall collectors.

Figure 1. Photograph of the Norway spruce study stand at Kasiniemi. (Photo: Liisa Ukonmaanaho).
Kuva 1. *Kasiniemessä sijaitseva kuusikkokoeala. (Kuva: Liisa Ukonmaanaho).*

The mean annual temperature during 1989–98 (measured at the nearby Hattula, Leteensuo meteorological station) was 4.8 °C and annual precipitation 593 mm. The corresponding values for 1998, the year in which the study was carried out, were 4.2 °C and 662 mm. The year 1998 was noticeably wetter than average, the annual precipitation in the area being 12 % higher than the 1989–98 average. During the sampling period (June–October 1998), rainfall was 25 % greater than the 1989–98 average. Out of the 18-week study period, only one week was without rainfall.

Experimental design and funnels types

The position, height, dbh and canopy projection of every tree in an area approximately 70 x 130 m in what was considered the most uniform part of the stand and as far from the forest road as possible was measured using standard procedures.

A 10 x 10 m grid was placed over the resulting tree map such that 72 intersections forming a 60 x 110 m block all fell on a spot not occupied by a tree stem. The block of 72 points was then divided into four equal sized sub-blocks of 18 points. The positions of these intersections were located in the field and 16 in each sub-block, the least affected by a gap or proximity of Scots pine (5) or birch (4) trees were selected as locations for the throughfall collectors.

We studied four different types of throughfall funnel collector. All the funnels were made of polyethylene plastic but differed in diameter, whether there was a rim or not, and funnel slope

Table 1. Characteristics of the funnels types used in study.
Taulukko 1. *Tutkimuksessa käytettyjen metsikkösadantakeräinten ominaisuudet.*

Funnel *Suppilo*	Diameter, cm *Läpimitta, cm*	Collection area, cm^2 *Keräys pinta-ala, cm^2*	Rim height, cm *Reunan korkeus, cm*	Funnel slope, ° *Suppilon kaltevuus, °*
Type 1[a] *Tyyppi 1[a]*	20	308	2	45
Type 2[b] *Tyyppi 2[b]*	20	308	0	45
Type 3 *Tyyppi 3*	14	154	0	64
Type 4 *Tyyppi 4*	9	64	0	64

[a] used in the Finnish UN-ECE ICP Integrated Monitoring programme (Ukonmaanaho & Starr 1995).
Käytetään Ympäristön yhdennetty seuranta (YYS) ohjelmassa Suomessa (Ukonmaanaho & Starr 1995)
[b] used in the Finnish ICP Forests/Level II programme (Lindroos et al. 1999).
Käytetään ICP metsäohjelma/taso II ohjelmassa Suomessa (Lindroos et al. 1999)

(Table 1, Fig. 2). The three particular diameter sizes were chosen because they are those generally used in the ICP Forests/Level II programme (EC-UN/ECE 1998).

A funnel type was randomly allocated to 16 selected sample points in each of four sub-blocks (described below). To ensure sufficient sample for analysis two of type 4 funnels were used at each sampling station; the throughfall from them being bulked and subsequently treated as a single sample. Thus, there were 16 replicates of each type of funnel, giving a total of 64 sampling stations in the experiment.

Sampling procedure

The network of funnels was set out in May 1998 and sampling started on 1st June. Samples were collected weekly. There was no rainfall during the 14th week of the study (31.8.–7.9.). Each funnel was held at 1.5 m above ground level in a black PVC tube supported by a wooden post. The neck of each funnel was fitted with a plastic mesh to prevent litter from entering the sample, reducing contamination of the sample (Ukonmaanaho & Starr 2001). The funnel drained into a plastic bag fitted inside the PVC support tube. Upon collection, the weight of each sample was recorded (±1 g) and placed in a styrene box kept cool with freezing blocks and transported to the laboratory within one day. The funnels and sieve mesh in the funnel were rinsed with distilled-deionised water and a new plastic bag installed ready for the next sampling period. All the funnels and sample bottles had been acid-washed and rinsed in distilled-deionised water several times before use.

Figure 2. Photograph showing the four types of throughfall funnel collector used. Clockwise from the top left: type 1, type 2, type 3 and type 4 (see Table 1). The ruler in the foreground is 30 cm in length. (Photo: Michael Starr).
Kuva 2. *Tutkimuksessa käytetyt 4 metsikkösadantakeräin tyyppiä, myötäpäivään vasemmalta ylhäältä, tyyppi 1, 2, 3, 4 (kts. taulukko 1). Kuvassa oleva viivoitin on 30 cm pitkä. (Kuva: Michael Starr).*

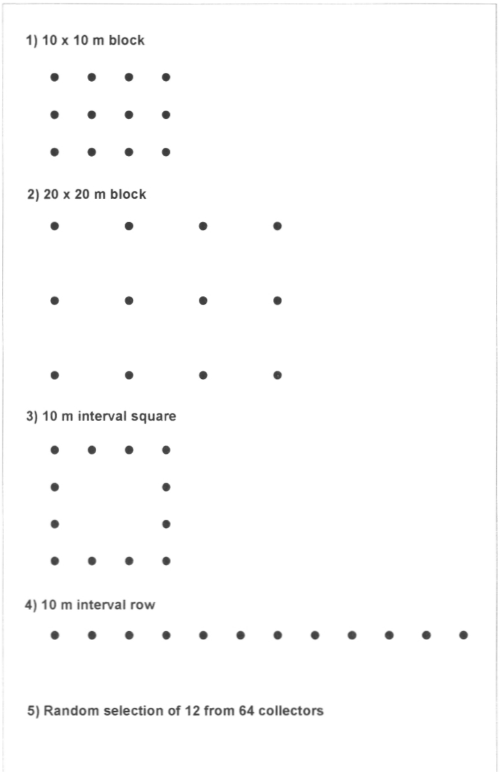

Figure 3. Spatial arrangements (layouts) of throughfall collectors tested in this study.
Kuva 3. *Tutkimuksessa käytetyt metsikkösadantakeräinten koejärjestykset.*

In order to determine if the length of the collection period had an effect on monthly deposition values we collected throughfall using type 1 funnels after one, two and four weeks and compared calculated monthly values. Two additional type 1 funnels were installed close to one of the original type 1 funnels described above in each of the four sub-blocks. Selection of which type 1 funnel in each sub-block where to locate the two additional collectors was random. The two additional type 1 funnels were located within 1 m of the original and each other. One of the additional collectors was emptied every 2nd week and the other every 4th week. On the occasion of the 4th week, the collector that had been used to collect the two fortnightly samples became the collector for the following monthly collection and the collector that had been used to collect the monthly sample became the collector for the two fortnightly samples. Otherwise the samples were treated in the same way as above.

To determine if the spatial arrangement of collectors had an effect on throughfall, we tested if throughfall quality differed among five different layouts of collectors. The five layouts studied were: a block at two different spacing, a square, a row, and random from the entire network (Fig. 3). For each layout we selected three sets of data from the entire network of collectors regardless of funnel type for each week and calculated the weekly mean concentration values. The locations of each layout of funnels were random within the entire network of collectors. If a location resulted in a data set having < 11 funnels present (less than 12 was possible because of the gaps in the network) it was rejected and another location for the layout chosen at random. Using this procedure, we consider variability related to funnel type, spatial pattern in tree stems, and seasonality were randomised thereby allowing us to test for differences related to the spatial arrangement of collectors.

Chemical analysis

Upon arrival at the laboratory, the samples were placed in a cold room (+4 °C). Prior to analysis the samples were filtered through a 0.45 μm membrane filter. Sub-samples were analysed as follows: Ca, Mg, K, Na (inductively coupled plasma mass spectrometry), SO_4^{2-}, Cl^-, NO_3^- (ion chromatography), total N and NH_4^+ (flow injection analysis), DOC (dissolved organic carbon) (Shimadzu TOC-5000 analyser), and pH (electrode and meter). These determinants are the mandatory parameters in the ICP Forests deposition programme (Manual on... 1998).

Results and discussion

Differences between funnel types

The weekly throughfall amounts and deposition loads according to each of the four

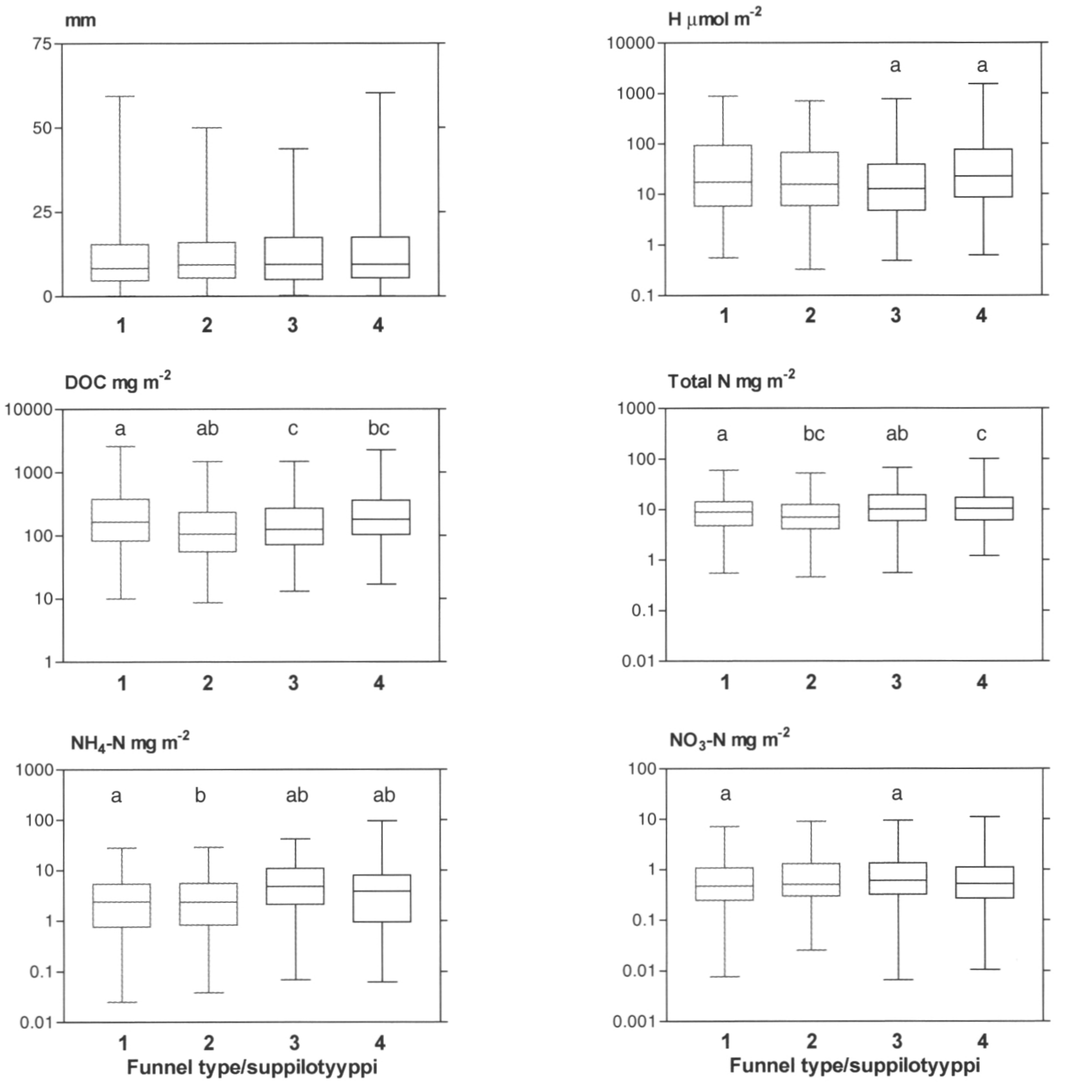

Figure 4. Box and whiskers plots describing the weekly throughfall amounts and deposition loads during the study period by funnel type. The box extends from the 25th percentile to the 75th percentile, with a line at the median (the 50th percentile). The whiskers extend above and below the box to show the highest and lowest values. Medians that are significantly different ($p < 0.05$; Dunn's multiple comparison test) are indicated by the same letter above the boxes. Notice use of logarithmic scale on Y-axis.

Kuva 4. *Viikottainen metsikkösadantamäärä ja -laskeuma tutkimusajanjaksolla keräintyypeittäin 'Box and whiskers' jakaumana esitettynä. Kuvasta on nähtävissä aineiston alakvartiili (25 %) ja yläkvartiili (75 %), keskiviiva osoittaa mediaanin (50 %). Pystysuora jana osoittaa korkeimmat ja alhaisimmat arvot. Merkitsevästi erilaiset mediaanit (p < 0.05; Dunnettin testi) on merkitty samalla kirjaimella. Huomaa logaritminen asteikko y-akselilla.*

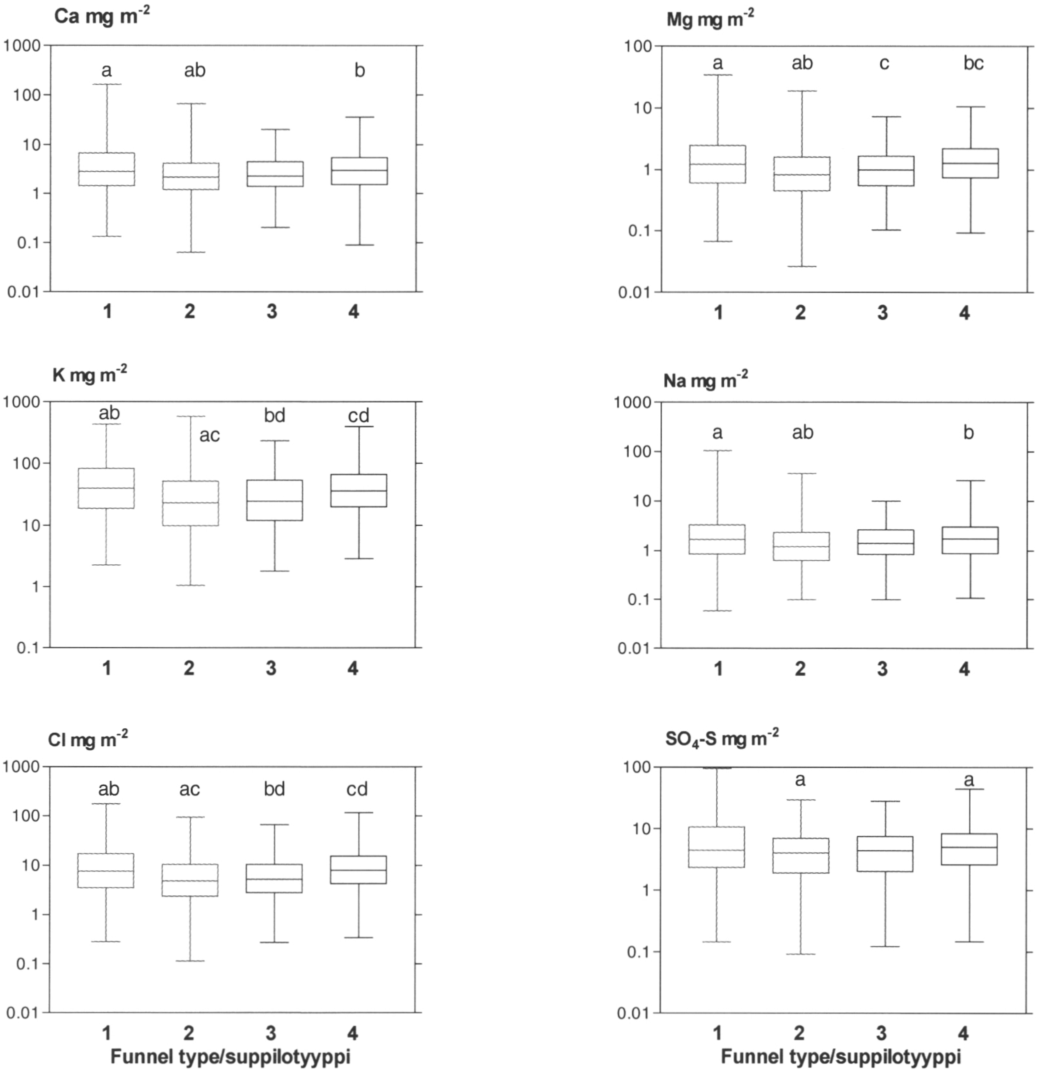

Figure 4. Continues
Kuva 4. *Jatkuu*

funnel types are described in Figure 4. It is seen that the deposition loads for each constituent are positively skewed and that they vary over 2–3 orders of magnitude.

Kruskal-Wallis one-way analysis of variance tests showed that there were significant ($p < 0.019$) differences in the median deposition loads but not in the amount of water collected ($p = 0.224$) among the funnel types. Except for nitrogen (total, NH_4-N and NO_3-N), deposition loads tended to be higher with funnel types 1 and 4. Funnel types significantly different from each other are also indicated in Figure 4.

As the funnel type had no significant effect on the amount of throughfall collected, the differences in deposition loads must be due to differences in concentrations. If the concentrations in wet deposition were the same for each type of funnel, the differences in throughfall concentrations would be due to differences in the amount of dry deposition collected; funnel types 1 and 4 tending to collect more than the other two funnel types. If the increased amount of dry deposition collected by funnel type 1 is related to the presence of the rim then it is unclear why funnel type 4 should also collect more. Having the smallest diameter, funnel type 4 has a greater edge/area ratio compared to the other funnels. This may have caused more turbulence and increased capture of dry deposition.

An alternative, and perhaps more plausible, explanation for the observed variation in concentrations among funnel types is the accumulation of litterfall in the funnel and the subsequent leaching of constituents (Ukonmaanaho & Starr 2001). Leaching from litterfall fallen into the funnels would be proportionally greater for the smaller throughfall sample volumes collected with funnel type 4.

Effect of collection period on monthly deposition values

The calculated monthly throughfall amount and deposition loads based on data of the different collection periods (i.e. sum of 4 weekly samples, sum of 2 fortnightly samples, and the actual four week sample) are presented in Table 2. The mean ($n = 4$) values for H^+ loads decreased and that for all other constituents increased with the length of the collection period. This would indicate a neutralising effect on acidity (decomposition of organic acids, loss of carbonic acid) and a concentrating effect on other solutes due to evaporation, both of which would increase with time. However, the mean amount of throughfall was similar for all three collection periods and therefore other processes must be involved. We suggest that leaching from litterfall trapped in the collectors between collection times was the cause. It was observed that the samples collected over the 4-week period were coloured compared to those collected over shorter periods, indicating that changes had taken place.

We had expected to observe increasing evaporation losses in throughfall amount with increasing collection period resulting in corresponding increases in concentrations. The study period was exceptionally wet and this may explain why there were no differences in throughfall amount among the three collector periods used. Evaporation and the resulting concentration of solutes may occur in more normal rainfall years and for those sites with high potential evaporation losses during the summer.

Accuracy and precision: number of collectors required

The number of collectors needed for the sample mean to be within a certain interval of the true mean (percentage value of the mean) with a confidence level of 95 % is presented for each constituent in Fig. 5. The number of collectors needed presented in Fig 5. are the average of the weekly values. The numbers required vary with constituent, with inorganic N forms requiring the most and DOC the least. The number of collectors required to be within 5 % of the mean are impractical but substantially drop if being within 10 % of the mean is an acceptable level of accuracy.

Table 2. Mean (and standard deviation) of monthly throughfall amounts and deposition loads (mg m^{-2}) calculated using data from different collection periods (n = 4).
Taulukko 2. *Metsikkösadannan määrän ja laskeuman (mg m^{2}) keskiarvo (ja keskihajonta) kolmella eri keräysjaksolla (n = 4).*

Parameter *Tunnus*	Sum of 4 weekly values (4 x 1) *Neljän viikko näytteen summa (4 x 1)*		Sum of fortnightly values (2 x 2) *Kahden kahdenviikon näytteen summa (2 x 2)*		After 4 weeks (1 x 4) *Neljänviikon näyte (1 x 4)*	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
mm	42.7	(25.30)	43.5	(25.02)	45.3	(30.78)
H^+, µmol m^{-2}	751.7	(614.43)	326.0	(448.39)	187.8	(238.96)
DOC	513.4	(293.44)	630.2	(404.98)	625.7	(312.66)
N	29.5	(14.80)	45.5	(22.13)	57.0	(36.15)
NH_4-N	11.7	(9.28)	24.9	(13.90)	32.6	(27.80)
NO_3-N	3.4	(1.50)	3.5	(2.31)	4.4	(2.76)
Ca	10.2	(4.06)	12.1	(6.14)	12.9	(4.96)
Mg	3.7	(1.76)	5.1	(2.58)	5.9	(2.55)
K	132.5	(72.72)	181.3	(91.55)	188.8	(92.01)
Na	5.2	(1.96)	7.5	(4.56)	7.0	(2.43)
Cl	31.3	(22.95)	37.8	(22.61)	37.0	(23.74)
SO_4-S	16.5	(5.96)	23.1	(10.14)	22.8	(10.18)

The ICP Forests manual (Manual on... 1998) states that 10–15 collectors per stand are necessary to cover the variability in throughfall parameters. Using 15 collectors in the Kasiniemi stand would allow the mean weekly values for throughfall amount and deposition loads of all constituents except Mg, Na and inorganic forms of N to be calculated within 15 % of the true mean. This implies that at least a 15 % change in these parameters is required before it could be considered to be statistically significant. For Mg, Na and inorganic forms of N, using 15 collectors would result in a mean value being within 20 % of the true mean value.

Effect of layout of collectors

The mean weekly amount of throughfall and concentration of the various constituents according to the five layouts of funnels are presented in Table 3. The mean values are very similar to each other across all five layouts and we found no statistically significant effect of spatial arrangement on any of the variables. The layout of collectors was thus less important than the size of funnel, duration of collection period and the number of collectors used – at least in this relatively uniform stand. Furthermore, the coefficients of variation (Table 3) showed that the variation was also similar for each layout of collectors. This is a measure of how successful we were in choosing a stand of uniform structure – no difference between the spatial patterns would be expected in a single species stand with a random distribution of stems.

Conclusions and recommendations

Median throughfall deposition loads significantly varied with the type of funnel used. The differences were due to differences in concentrations and not throughfall amount. Differences in the collection of dry deposition and/or leaching of litterfall in the collector were implicated. Within the ICP Forests programme

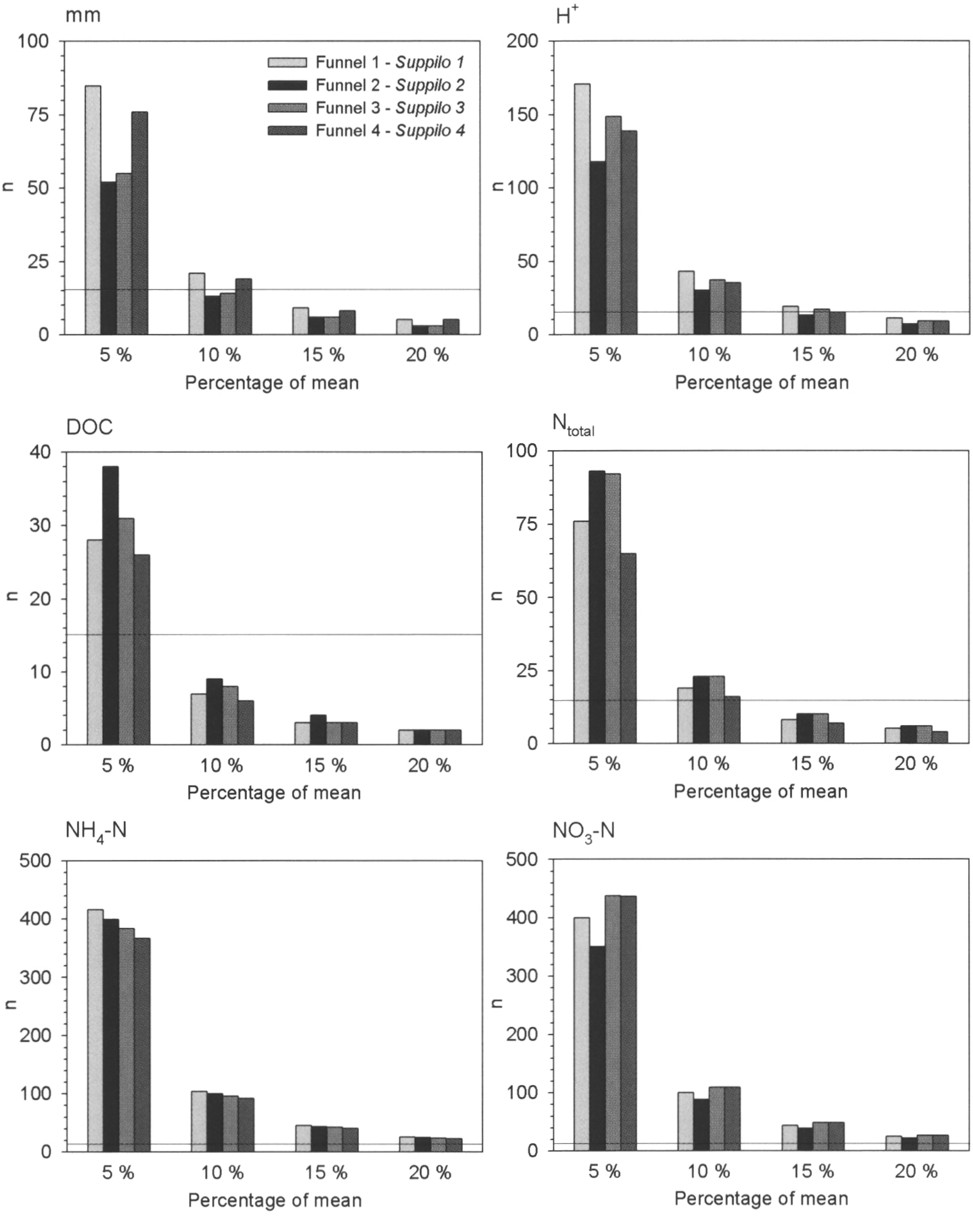

Figure 5. *Number (n) of collectors required for mean values to be within 5 %, 10 %, 15 % and 20 % of the true mean with a confidence level of 95 %. Values are the mean of the weekly values during the study period. The solid grid-line indicates 15 funnels; the number of collectors mentioned in the ICP Forests Manual as being required for a 50 x 50 m plot.* $n = (t_{0.05} \times cv/c)^2$, *where* $t_{0.05}$ *is the Student's t value at the required level of confidence, cv is the coefficient of variation as a percentage, and c is the desired confidence interval as a percentage of the mean (Kimmins 1973).*
Kuva 5. *Keräinten lukumäärä (n) joka vaaditaan, että havaintojen keskiarvo on 95 % luotettavuustasolla 5 %, 10 %, 15 % ja 20 % sisällä aineiston todellisesta keskiarvosta. Arvot ovat viikottaisten arvojen keskiarvoja koko tutkimusjaksolta. Yhtenäinen viiva 15 suppilon kohdalla osoittaa suppilomäärän, joka on ICP Forests manuaalin mukainen suositus 50 x 50 m koealalle.* $n = (t_{0.05} \cdot cv/c)^2$, *missä* $t_{0.05}$ *on Studentin t-arvo vaaditulla luotettavuustasolla, cv on variaatiokerroin prosentteina (kuinka monta prosenttia keskihajonta on otoksen keskiarvosta) ja c on haluttu keskiarvon luotettavuusväli prosentteina (Kimmins 1973).*

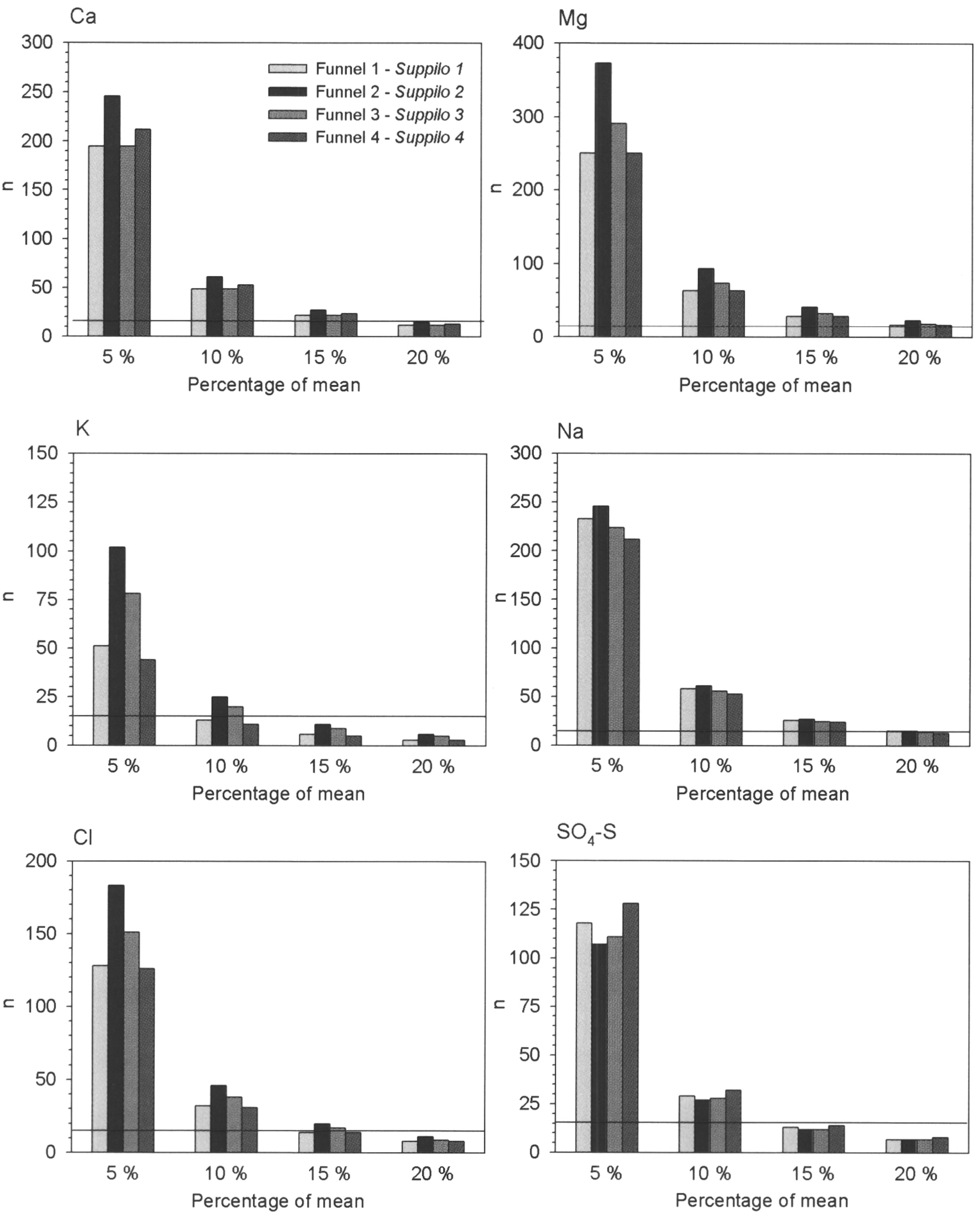

Figure 5. Continues
Kuva 5. *Jatkuu*

Table 3. Mean (coefficient of variation, %) throughfall amount and concentration of constituents according to different spatial arrangements of collectors (see Fig. 3).
Taulukko 3. *Metsikkösadannan määrä ja pitoisuuden keskiarvo (variaatiokerroin, %) erilaissa koejärjestelyissä (kts. kuva 3).*

Parameter *Tunnus*	Arrangement of collectors – *Keräinten koejärjestys*									
	Block – *Lohko* 10 m x 10 m		Block – *Lohko* 20 m x 20 m		Square – *Neliö*		Row – *Linja*		Random *Satunnainen*	
mm	12	(75)	12	(72)	12	(72)	12	(72)	12	(69)
H	6.30	(162)	7.30	(155)	7.58	(152)	7.13	(160)	8.36	(172)
DOC	19.81	(40)	20.03	(47)	19.78	(55)	18.26	(43)	19.48	(60)
N_{total}	1.16	(35)	1.20	(49)	1.19	(49)	1.14	(39)	1.18	(39)
NH_4-N	0.49	(71)	0.41	(73)	0.42	(77)	0.48	(75)	0.48	(68)
NO_3-N	0.58	(131)	0.57	(137)	0.58	(131)	0.59	(129)	0.58	(138)
Ca	0.50	(47)	0.48	(48)	0.49	(53)	0.44	(44)	0.46	(55)
Mg	0.19	(49)	0.19	(48)	0.19	(56)	0.17	(46)	0.18	(57)
K	5.35	(50)	5.05	(47)	5.06	(55)	4.73	(46)	4.95	(50)
Na	0.25	(34)	0.24	(36)	0.24	(44)	0.23	(34)	0.24	(48)
Cl	1.32	(66)	1.27	(64)	1.30	(73)	1.19	(60)	1.26	(68)
SO_4-S	2.24	(58)	2.22	(57)	2.22	(61)	2.11	(58)	2.18	(61)

the use of the same type of funnel or calibration with a reference funnel is recommended.

Monthly concentration values tended to increase with the length of the collection period (sum of 4 weekly samples, sum of two fortnightly samples, and a 4 week period). The length of the collection period had no effect on the monthly amounts of throughfall, which may due to the exceptionally high rainfall during the study period. We had expected to observe increasing losses in throughfall amount with collection period because of evaporation losses. This may still be the case in more normal rainfall years and for those sites with high evaporation. The leaching of litterfall trapped in the collector is a probable cause of the change in sample chemistry. It is recommended to use a short collection period and sum the values to make a monthly value rather than collecting a monthly sample in the field. It is also recommended to remove any litterfall that collects in the throughfall collector as soon as possible so as to reduce leaching inputs.

The use of 15 collectors would allow for most of the ICP Forests mandatory throughfall parameters to be determined within 15–20 % of the true mean weekly value at Kasiniemi with a confidence level of 95 %. The number of collectors required to achieve a similar level of accuracy and precision for inorganic forms of N are not practical and it may be worth changing the status of these parameters to optional.

The ICP Forests manual allows for systematic or random siting of collectors in the stand. If the stand were uniform (single species and random stem distribution), sampling with either a systematic or random design would give similar results. However, if the stand is not uniform, then differences in throughfall parameters related to the spatial arrangement of collectors may occur. The ICP Forests manual also allows for placement under trees only (tree-wise). This procedure would bias the throughfall towards canopy drip and is not recommended.

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6 Biotic and abiotic forest damage in 2000

Metsätuhot vuonna 2000

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Summary

The needle damage caused by larvae of the pine sawfly (*Diprion pini*) in Satakunta (area 4 in Fig. 1), and in the mass outbreak area stretching from Pohjois-Karjala (12) via Pohjois-Savo (11) and Keski-Suomi (13) to Pohjanmaa (14, 16, 17) and the southern parts of Kainuu (18), in summer 2000 was clearly lighter than that during the previous summer. The population density was reduced by a number of natural factors, and it appears that the outbreak that started in summer 1998 has now passed its peak. The exceptionally warm and dry summer in 1999 prevented the spread of many serious fungal diseases (e.g. scleroderris canker (*Gremmeniella abietina*) and lophodermella needle cast (*Lophodermella sulcigena*), and no extensive epidemics developed during summer 2000. However, the most common epidemic fungal diseases were rusts, especially chrysomyxa needle cast (*Chrysomyxa ledi*) and birch rust (*Melampsoridium betulinum*), which benefited from the wet summer.

The cause of the growth disturbances in the crowns of Norway spruce in Pohjois-Savo (11), especially in areas earlier subjected to shifting agriculture and grazing, has now been confirmed as depressed levels of plant-available boron. The contribution of fungi and insects to the disturbance has proved to be insignificant. However, more studies will have to be carried out on this problem. There were no reports of the death of individual or groups of spruces in other parts of the country, corresponding to those that occurred in a number of years in the middle of the 1990's, although the incidence of dead standing trees was expected to increase as a result of the dry summer in 1999.

Forest was felled by trombis at the end of June in Häme (5) and Pirkanmaa (6) especially. Local tornadoes also occurred in the middle of July in northern Finland. The vole populations were low throughout the country apart from in Metsä-Lappi (southern and central parts of area 19) and northern Kainuu (18). The 2000 defoliation survey did not indicate any major changes in forest condition in Finland.

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

Yhteenveto

Pilkkumäntypistiäisen toukkien aiheuttamat neulastuhot Satakunnassa (alue 4, kuva 1) ja Pohjois-Karjalasta (12) Pohjois-Savon (11) ja Keski-Suomen (13) kautta Pohjanmaalle (14, 16, 17) ja Kainuun (18) eteläosiin ulottuvalla joukkoesiintymäalueella jäivät kesällä 2000 selvästi edellisvuotista vähäisemmiksi. Kantaa alensivat erilaiset luontaiset tekijät ja näyttää siltä, että vuonna 1998 alkaneen esiintymän huippu olisi jo ohitettu. Poikkeuksellisen lämpimän ja vähäsateisen kesän 1999 seurauksena monien merkityksellisinä pidettyjen sienitautien esim. männynversosurman ja

männynharmaakaristeen leviämismahdollisuudet heikkenivät siinä määrin, että laaja-alaisia epidemioita ei päässyt kehittymään kesän 2000 aikana. Epideemisistä sienitaudeista yleisiä olivat kuitenkin kesän sateisuudesta hyötyneet ruosteet, erityisesti kuusensuopursuruoste ja koivunruoste.

Pohjois-Savossa (11) varsinkin aiemmin kasketuilla ja laidunnetuilla alueilla todettujen kuusen latvojen kasvuhäiriöiden pääasialliseksi syyksi on varmistumassa boorin puute. Sienten ja hyönteisten osuus häiriössä on todettu vähäiseksi. Yksittäisten kuusten tai kuusiryhmien kuolemisesta muualla Suomessa ei tehty ilmoituksia vastaavassa määrin kuin muutamana vuonna 1990-luvun puolivälissä, vaikka kesän 1999 kuivuuden seurauksena pystyynkuivumisen odotettiin lisääntyvän.

Kesäkuun lopun trombit kaatoivat metsää varsinkin Hämeessä (5) ja Pirkanmaalla (6). Paikallisia pyörremyrskyjä riehui heinäkuun puolivälissä myös Pohjois-Suomessa. Myyräkannat olivat niukat koko maassa Metsä-Lappia (alueen 19 etelä- ja keskiosat) ja Pohjois-Kainuuta (18) lukuunottamatta.

Raportti perustuu Metsäntutkimuslaitoksen tutkijoiden maastokäynneillä tekemiin tuhohavaintoihin sekä metsäammattilaisilta ja metsänomistajilta saatuihin, tutkijoiden näytemäärityksin varmistamiin, tietoihin metsätuhojen esiintymisestä.

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

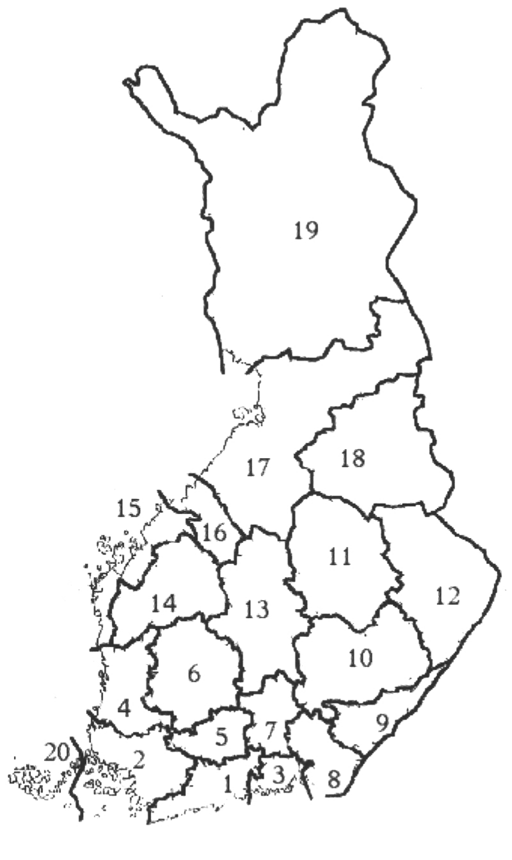

Figure 1. The provinces of Finland.
Kuva 1. *Suomen maakunnat.*

Fungal diseases

There were a few reports of the occurrence of epidemic fungal diseases in summer 2000. Only rust fungi, which benefited from the relatively wet summer and in some areas almost everyday occurrence of rain, developed into extensive epidemics during the summer. However, the epidemic was not as serious as the previous one in summer 1998. Although rust fungi do not cause tree death, frequently recurring extensive epidemics may result in a reduction in total growth.

The most common rust diseases were chrysomyxa needle cast (*Chrysomyxa ledi*) and birch rust (*Melampsoridium betulinum*). Downy birch (*Betula pubescens*) suffered from birch rust infections in late summer throughout the country. Chrysomyxa needle cast occurred widely in the central and northern parts of the country, especially in Lapland (19). An exceptionally high number of cases of pine twisting rust (*Melampsora pinitorqua*) were reported on Scots pine seedlings, especially in seedling stands where aspen (*Populus tremula*) suckers had not been cleared. *Melampsoridium hiratsukanum* rust, which infects alder (*Alnus*) and which was reported in the Baltic countries in 1997, appears to have spread into Finland through southern Finland and Pohjanmaa (14, 15, 16) already up to Kainuu (18).

The thunderstorms at the beginning of July damaged relatively fragile birch seedlings immediately after being transferred from plastic greenhouses into the open in a number of seedling nurseries. Birch seedlings became infected by stem lesions and cankers causing *Godronia multispora.*

Insect damage

The needle damage caused by larvae of the pine sawfly (*Diprion pini*) in pine stands remained light, or at the most moderate, during summer 2000. The stands looked denser and well recovered when the trees that were seriously defoliated during previous years produced new shoots and needles. In some localities the forest owners were astonished by the sudden drop in the pest population and the good recovery of the pines.

According to prognosis studies, there were three main reasons for the low number of pine sawfly larvae: 1) large proportion of the cocoons that overwintered in the ground were destroyed by parasitic insects, diseases or small mammals (shrews, voles, mice), 2) only a few healthy cocoons emerged during the summer into adult, reproducing sawflies, most of the cocoons remaining in prolonged diapause for a year or even longer, and 3) the populations were effectively reduced by egg parasitoids which destroyed most (60–90 %) of the eggs laid in the needles during the first half of summer. Parasitized eggs produce only parasitoids, and no sawfly larvae.

Preparations were made to control pine sawflies at Lestijärvi (16), but the work had to be called off owing to the restrictions set by the environmental authorities. Owing to the high degree of egg parasitism (35–90 %), severe damage and mortality of trees were avoided at Lestijärvi and the more threatened areas at Kaavi and Ilomantsi (11, 12). There were no reports of any new major outbreaks. However, the development of the pest population should still be monitored.

Small, local outbreaks of the larvae of the European pine sawfly (*Neodiprion sertifer*) were reported mainly in Savo (10). Density of the pupae of the bordered white moth (*Bupalus piniarius*) was higher than normal in many localities, although not in alarming numbers. Norway spruce and larch were defoliated in some localities by larvae of spruce and larch sawflies (*Pristiphora* spp.).

Larvae of the northern winter moth (*Operophtera fagata*) and the winter moth (*O. brumata*) again defoliated birches, although less severely than during the previous year. The spear-marked black moth (*Rheumaptera hastata*) occurred in large numbers in parts of Pohjois-Karjala (12), Pohjois-Savo (11), Kainuu (18) and Pohjois-Pohjanmaa (17). The larvae, which live between leaves that have been webbed together, completely defoliated valuable transplants of *Betula pendula*, and aroused considerable concern. In addition to birch, the larvae also feed on willows (*Salix* spp.) and currants (*Ribes* spp.). The last outbreak occurred over a decade ago.

Mass outbreaks of the vapourer (*Orgyia antiqua*) were reported in the region extending from Pohjois- Karjala (12) to Keski-Suomi (13). The hairy larvae, decorated with colourful tufts, are polyphagous and completely defoliated e.g. bilberries (*Vaccinium myrtillus*) and many shrubs over large areas.

The pine weevil (*Hylobius abietis*) caused serious damage in conifer plantations, especially pine, in some localities throughout the country.

Damage caused by moose and deer

The amount of damage caused by cervids in young stands has increased compared to the previous year. On the basis of the estimates made by the Forestry Centres, a total of about FIM 25 million will be paid in compensation for damage during 2000.

Moose (*Alces alces*) damage increased mainly in the eastern parts of the country, because damage declined in some areas of the western coast. Damage continued in the forest areas naturally favoured by moose, although a considerable amount of new damage obviously also occurred elsewhere due to the higher population density. Damage prediction has proved to be difficult because moose browsing is often reported in summer ranges where artificial regeneration of deciduous tree species is common. Such damage was expected to continue because of insufficient culling of the population in previous year.

White-tailed deer (*Odocoileus virginianus*) had increased in the southern parts of the country, thus increasing the risk of damage in the youngest deciduous and pine seedling stands. The population of roe deer (*Capreolus capreolus*) continued to increase, mainly in those areas where the moose and deer populations are already relatively high.

The probable effects of the record-breaking warm and wet autumn on forest damage

According to the Finnish Meteorological Institute, the temperature conditions during summer 2000 were close to the average throughout the country. Precipitation in many of the regions was also close to average. However, rainy days occurred more often than the average, and subsequently there were relatively few sunny days. High precipitation was recorded in western Uusimaa (1), Häme (5), Päijät-Häme (7), Pohjois-Karjala (12), Pohjois-Pohjanmaa (17) and western Lapland (19). The number of hot days (> 25 °C) in July in northern Finland was high, the greatest number occurring in Lapland. The weather was humid as well as hot.

After the wet summer, September was record-breakingly sunny especially in the south-western parts of the country. The sun shone for almost as many hours as in July and August although the days had already shortened. The nights were also clear and the night temperatures dropped below the average. In some areas the number of nights with frost in September was double the average. Precipitation in September was only about one half the average throughout almost the whole country.

The weather conditions in September favoured the onset of dormancy in trees. However, a record-breaking warm spell started at the beginning of October and continued throughout the country for more than three weeks. In Lapland the weather was the warmest for more than a century. The warm period was interrupted by heavy falls of snow. In Lapland there was a shift from completely abnormal summer temperatures to full winter during October. The thick snow cover in some areas melted as the temperature again rose at the end of October, and the warm period continued through November up until the middle of December throughout almost the whole country. The minimum daily temperatures were also record-breakingly high.

The exceptionally warm and humid period during October-November may be reflected in the forest damage situation in summer 2001, e.g. an increase in damage caused mainly by epidemic fungal diseases, especially Schleroderris canker (*Gremmeniella abietina*) and lophodermium needle cast (*Lophodermium seditiosum*). The autumn weather is not expected to increase the amount of insect damage caused e.g. by the pine sawfly (*Diprion pini*).

According to reports, the weather conditions in autumn 2000 have clearly increased the visibility of an epiphytic lichen (*Hypogymnia physodes*) on spruce especially. The thick growth of lichen on the needles reduces the assimilating needle surface and may thus result in growth losses. The weakened trees are also more susceptible to a range of secondary damaging agents.

7 Forest damage observed in the 9th National Forest Inventory in South Finland 1996–2000

Valtakunnan metsien 9. inventoinnissa vuosina 1996–2000 havaitut tuhot Etelä-Suomessa

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Summary

The 9th National Forest Inventory has now covered the whole of the southern half of Finland. The field teams recorded damage affecting the vitality or quality of the growing stock on 17 % of the forest land area of southern Finland, and slight damage on 23 % of the area. The causal agent of one third of the damage cases could not be identified. Most of the identified forms of damage were caused by fungi, primarily root rot caused by *Heterobasidion parviporum*. Root rot damage was most frequent in the southernmost part of Finland and in areas along the cost. Another common group was damage caused by abiotic factors (wind, snow, climatic factors, soil, harvesting damage etc.). The frequency of abiotic damage was highest on the Åland Islands and in the eastern parts of Finland. The third most common damage group was that caused by vertebrates, mainly moose and deer.

Yhteenveto

Valtakunnan metsien 9. inventointi tehtiin Etelä-Suomessa vuosina 1996–2000. Inventoinnissa havaittiin metsikön laatua alentavia tuhoja 17 %:lla metsämaan alasta. Tämän lisäksi 23 %:lla metsämaan alasta havaittiin lieviä tuhoja, jotka eivät ole vaikuttaneet metsikön laatuun. Kolmannekselle tuhoista ei ole maastossa voitu tunnistaa aiheuttajaa. Tunnistetuista tuhoista yleisimpiä olivat sienten aiheuttamat tuhot, näistä suuri osa on maannousemasienen aiheuttamaa tyvilahoa. Lahottajasienten tuhoja havaittiin eniten eteläisimmässä Suomessa ja meren rannikon läheisyydessä. Toiseksi yleisin ryhmä tuhoja on abioottiset tuhot, joihin on luettu mm. tuulen, lumen, muiden ilmastotekijöiden, maaperätekijöiden ja puunkorjuun aiheuttamat tuhot. Abioottisia tuhoja esiintyi useimmin Ahvenanmaalla ja itäisessä Suomessa. Kolmanneksi yleisin tuhojen ryhmä on selkärankaisten, lähinnä hirvieläinten, aiheuttamat tuhot.

Introduction

The forest resources of Finland have been monitored at intervals of about 10 years by the National Forest Inventory (NFI) since the 1920's. The most recent complete inventory (8th NFI) was started in 1986 and finished in 1994. The 9th NFI was started in 1996 and has now covered the whole of the southern half of Finland.

The main purpose of the NFIs has been to estimate the volume and growth of the growing stock and the cutting potential. Additional aims have become more and more important in recent years. The monitoring of forest damage was introduced in the 7th NFI, and further developed in the 8th and 9th NFIs.

From the very beginning the NFI's have been sample-based inventories. In the 9th NFI, the sampling units are systematically located clusters of sample plots. In the southernmost parts of the country, the spacing of the clusters plots is 6 km. Each cluster consists of 15 sample plots. In the central parts of the country, the spacing of clusters is 7 km, each cluster comprising 18 sample plots. A large number of variables describing the site and growing stock of the stand on each sample plot are recorded. These variables include a description of all forms of visible damage.

Occurrence of damage according to causal agent

Table 1 shows the area of forest land where forest damage was observed in the 9th NFI in South Finland. The damage is classified by the causal agent (if identified) and severity of the damage. The total area of forest land (forest with a growing potential greater than 1 $m^3 ha^{-1} yr^{-1}$) in southern Finland is 11.17 mill. ha. Damage was observed on 40 % of the forest land (4.42 mill. ha). Most (57 %) of the damage was slight, i.e. damage with no significant effect on the silvicultural condition or technical quality of the growing stock. The total area of noticeable, serious and complete damage was 1.90 mill ha (17 % of the forest land area). These forms of damage have decreased the value or vitality of the growing stock to some extent at least.

The causal agent could not be identified in one third of the damage cases. Most of the identified forms of damage were caused by fungi. The total area with fungal damage was 1.06 mill. ha (ca. 10 % of the forest land area). The most common forms of fungal damage were root rot caused by *Heterobasidion parviporum* (1.8 % of the forest land area), other types of rot damage (1.7 %) and Scleroderris canker (2.9 %). Damage caused by root rot damage was, on the average, more serious than the other types of damage – only 40 % of the root rot damage caused by *Heterobasidion parviporum* was classified as slight damage.

Abiotic damage was observed on 0.67 mill. ha (6 % of the forest land area). Abiotic forms of damage were mainly caused by wind and snow. Wind damage especially was in most cases slight – 73 % of the damage was classified as slight, and only 27 % of this type of damage affected the value or vitality of the growing stock.

Damage caused by vertebrates (primarily cervids, i.e moose and deer) was observed on 0.39 mill. ha (3.5 % of the forest land area). The area of forest where moose and deer damage was recorded was 0.36 mill. ha. Almost 50 % of the moose and deer damage was classified as slight damage with no noticeable effect on the value or vitality of the growing stock.

Geographic distribution of the damage

The geographic distribution of all types of damage and of some selected forms of damage are presented in Figure 1. The colours in the maps indicate the proportion (%) of plots with damage out of the total number of plots on forest land. Only noticeable, serious and complete damage are included in the figure. Slight damage was excluded from this analysis.

The damage frequency was highest near the coast and especially on the Åland Islands. Damage appears to be more frequent in the northernmost parts of the southern half of Finland (northern part of the North Savo district) and in the eastern parts than in the central parts of the country.

Figure 1 also shows that most of the forest damage on the Åland Islands was abiotic. Wind affects the growth pattern of trees on the relatively small islands, resulting in bending of the main trunk. Abiotic damage was also relatively frequent in the eastern parts of southern Finland. In this area, most of the abiotic damage is related to the nutrient status of the soil. Damage caused by moose and deer (mainly deer) was another relatively frequent

Table 1. The area of forest damage by severity class and causal agent. 9[th] NFI, southern half of Finland.
Taulukko 1. *Tuhojen ala tuhon asteen ja aiheuttajan mukaan. VMI9 Etelä-Suomi.*

	Severity class - *Tuhon aste*									
	Slight *Lievä*		Noticeable *Todettava*		Serious *Vakava*		Complete *Täydellinen*		Total *Yhteensä*	
	km²	%	km²	%	km²	%	km²	%	km²	%
Abiotic damage - *Abioottiset tuhot*	3458	51.9	2657	39.8	490	7.3	63	0.9	6668	100.0
Wind - *Tuuli*	1027	73.1	322	22.9	47	3.3	9	0.6	1405	100.0
Snow - *Lumi*	1053	68.8	442	28.9	31	2.0	3	0.2	1530	100.0
Frost - *Halla, pakkanen*	323	48.7	294	44.3	40	6.0	6	0.9	663	100.0
Other climatic factors - *Muu ilmasto*	142	47.3	125	41.7	30	10.0	3	1.0	300	100.0
Forest fire - *Metsäpalot*	4	13.3	20	66.7	6	20.0	0	0.0	30	100.0
Soil factor - *Maaperätekijät*	909	33.2	1454	53.0	336	12.3	43	1.6	2741	100.0
Human activities - *Ihmisen toiminta*	2450	56.2	1781	40.8	127	2.9	6	0.1	4363	100.0
Timber harvesting - *Puunkorjuu*	921	80.0	227	19.7	3	0.3	0	0.0	1151	100.0
Air pollution - *Ilman saasteet*	9	64.3	6	42.9	0	0.0	0	0.0	14	100.0
Other human activity - *Muu ihmisen toiminta*	1521	47.6	1547	48.4	124	3.9	6	0.2	3198	100.0
Animals - *Eläintuhot*	2977	56.0	1899	35.7	348	6.5	94	1.8	5318	100.0
Vole - *Myyrä*	37	44.0	28	33.3	20	23.8	0	0.0	84	100.0
Moose - *Hirvieläimet*	1740	47.8	1523	41.8	302	8.3	77	2.1	3642	100.0
Other vertebrate - *Muut selkärankaiset*	58	39.2	52	35.1	21	14.2	17	11.5	148	100.0
Bark beetles - *Ytimennävertäjät*	310	78.5	86	21.8	0	0.0	0	0.0	395	100.0
Pine weevil - *Tukkimiehentäi*	3	16.7	13	72.2	3	16.7	0	0.0	18	100.0
Pine sawfly - *Mäntypistiäiset*	692	88.0	91	11.6	3	0.4	0	0.0	786	100.0
Other needle-damaging insect - *Muut neulastuholaiset*	14	70.0	6	30.0	0	0.0	0	0.0	20	100.0
Spruce bark beetle - *Kirjanpainaja*	3	42.9	4	57.1	0	0.0	0	0.0	7	100.0
Other identified insect - *Muu tunnistettu hyönteinen*	37	54.4	31	45.6	0	0.0	0	0.0	68	100.0
Unidentified insects - *Tunnistamaton hyönteinen*	84	56.4	65	43.6	0	0.0	0	0.0	149	100.0
Fungi - *Sienituhot*	6302	59.4	3640	34.3	616	5.8	59	0.6	10618	100.0
Annosum root rot - *Juurikääpä*	818	40.4	1046	51.6	147	7.3	17	0.8	2027	100.0
Other rot fungus - *Muu lahottajasieni*	642	34.4	982	52.6	212	11.4	31	1.7	1867	100.0
Scleroderris canker - *Versosurma*	2559	78.1	639	19.5	68	2.1	9	0.3	3275	100.0
Pine branch twist - *Männynversoruoste*	528	44.6	485	40.9	169	14.3	3	0.3	1185	100.0
Blister rust - *Tervasroso*	1131	75.5	359	24.0	8	0.5	0	0.0	1498	100.0
Other rust fungus - *Muu ruostesieni*	190	95.5	9	4.5	0	0.0	0	0.0	199	100.0
Pine needle-cast fungus - *Karistesieni*	273	91.3	23	7.7	3	1.0	0	0.0	299	100.0
Other identified fungus - *Muu tunnistettu sieni*	24	46.2	26	50.0	3	5.8	0	0.0	52	100.0
Unidentified fungus - *Tunnistamaton sieni*	137	64.0	72	33.6	6	2.8	0	0.0	214	100.0
Competition - *Kilpailu*	1354	53.0	1105	43.2	83	3.2	14	0.5	2556	100.0
Unidentified - *Tunnistamaton*	8720	59.3	5579	37.9	380	2.6	33	0.2	14711	100.0
Total - *Yhteensä*	25263	57.1	16660	37.7	2044	4.6	268	0.6	44235	100.0
No damage - *Ei tuhoja*	0	0.0	0	0.0	0	0.0	0	0.0	67463	
Total - *Yhteensä*	25263	22.6	16660	14.9	2044	1.8	268	0.2	111698	

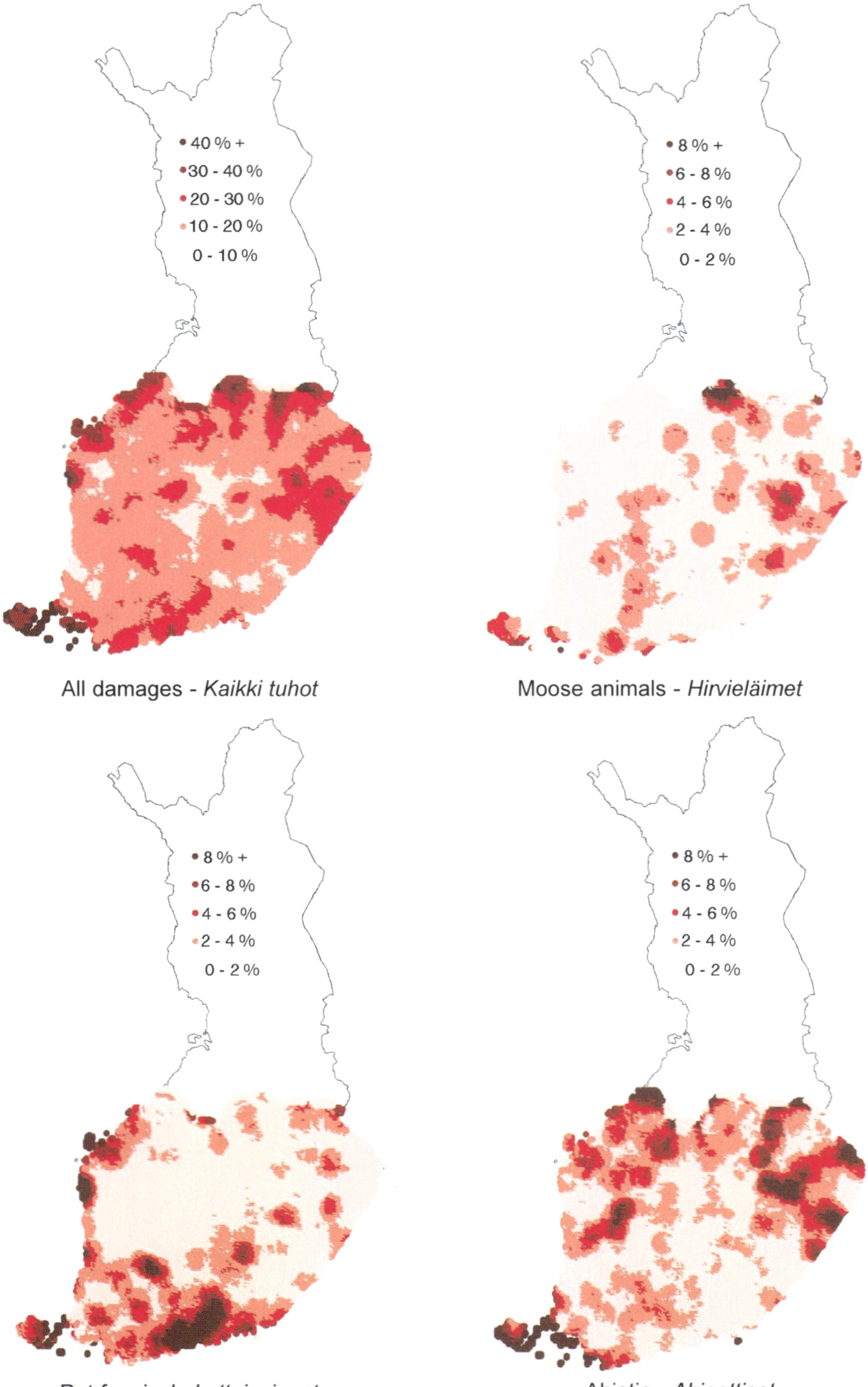

Figure 1. Geographic variation of all the damages together and some selected damages.
Kuva 1. *Kaikkien tuhojen ja eräiden valikoitujen tuhojen maantieteellinen vaihtelu.*

damage group on the Åland Islands. In the previous inventory, practically no moose or deer damage was recorded in this area.

In the areas near the coast (except the Åland Islands), damage caused by rot fungi (primarily Heterobasidion annosum) was relatively the most frequent. The rot damage mostly occurred in areas with a high proportion of old spruce forest. Moose and deer damage was relatively frequent in eastern Finland and the northern parts of the North-Savo district (in addition to the Åland Islands). This is partly explained by the fact that in eastern Finland especially, the predominance of young pine stands, which are susceptible to moose damage, is higher than e.g. in southernmost Finland.

8 Results from the first round of the Integrated Monitoring soil chemistry subprogramme

Ympäristön yhdennetyn seurantaohjelman ensimmäisen keräyskerran maaperätulokset

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Summary

The sampling design and results from the first sampling round of the soil chemistry subprogramme of the Integrated Monitoring (IM) programme are presented. Twenty permanent plots in the four Finnish IM catchments were sampled; four of the plots are now ICP Forests/ Level II plots. Variability in soil chemistry properties was greater between catchments than within. pH_{water} ranged from 3.5 to 4.1 in the humus layers and from 4.1 to 5.4 in the mineral soil (0–20 cm). Ranges for titratable exchangeable acidity, effective cation exchange capacity (CEC_e) and base saturation (BS_e) were 36–84 meq kg^{-1}, 207–332 meq kg^{-1} and 68–87 % for the humus layer. Corresponding values for the mineral soil were 2–35 meq kg^{-1}, 3–48 meq kg^{-1} and 15–49 %. Plots with the most acid mineral soil (i.e., lowest pH and BS and highest titratable acidity) were in the most southerly of the catchments, which receives the highest acidic deposition load. Soil acidification parameters were correlated with soil organic matter contents. Dry ashed, concentrated HCl soluble concentrations of Cu, Zn, Pb and Cd showed no anomalies from regional values. Concentrations of Pb in the humus layer (13.7–52.1 mg kg^{-1}) were correlated with the deposition load of Pb.

Yhteenveto

Ympäristön yhdennetty seuranta (YYS) hankkeen ensimmäisen keräyskerran maaperätulokset ja näytteenottomenetelmät esitetään seuraavassa. Näytteitä kerättiin neljältä valuma-alueelta, kaikkiaan 20 pysyvältä koealalta, joista neljä on myös ICP metsäohjelma/ taso II koealoja. Kemiallisten tunnusten vaihtelu oli suurempaa eri valuma-alueiden välillä kuin niiden sisällä. Humuskerroksen vesi-pH vaihteli 3,5–4,1 välillä ja kivennäismaan (0–20 cm) 4,1–5,4 välillä. Humuskerroksen vaihtuvan happamuuden, efektiivisen kationinvaihtokapasiteetin (CEC_e) ja emäskyllästysasteen (BS_e) vaihteluvälit olivat 36–48 meq kg^{-1}, 207–332 meq kg^{-1} ja 68–87 %. Vastaavasti kivennäismaalla vaihteluvälit olivat 2–35 meq kg^{-1}, 3–48 meq kg^{-1} ja 15–49 %. Kaikkein happamimmat kivennäismaat (alhaisimmat pH ja BS ja korkein vaihtuva happamuus) olivat eteläisimmällä valuma-alueella. Samalla valuma-alueella oli myös suurin vetyionilaskeuma. Maaperän happamoitumistunnukset ja orgaanisen aineksen osuus korreloivat keskenään. Raskasmetallien Cu, Zn, Pb ja Cd pitoisuudet eivät olleet tavanomaista korkeampia. Humuskerroksen lyijypitoisuus (13,7–52,1 mg kg^{-1}) kasvoi samansuuntaisesti lyijylaskeuman kanssa.

Introduction

The soil chemistry (SC) subprogramme of the UN-ECE ICP Integrated Monitoring programme (IM) as implemented in Finland is described and the results from the first round of sampling presented. The purpose of the SC subprogramme is to calculate and monitor changes in soil chemical properties (Bringmark 1989). The intention is to relate any changes in soil chemical properties to atmospheric inputs of acidity, heavy metals and nitrogen and to changes in the other components of the ecosystem that are being monitored (e.g. soil microbiology, vegetation, soil water, ground water and runoff). It is also envisaged that the SC data will be used in the testing and development of various biogeochemical models for predicting ecosystem response to air pollution loads (Nihlgård 1989, ICP IM Programme Centre 1998). The SC data can also be used to monitor the effects of climate change on soil chemical properties and on soil carbon stores.

The first round of the SC subprogramme in the four Finnish IM catchments was carried out at all the permanent plots established in 1988/89. Altogether 20 plots were sampled; four of them are now part of the network of ICP Forests/Level II plots. The intensive monitoring plots (plots where throughfall, stemflow and soil water have also been monitored; two in each catchment, one of which are now Level II plots) have been sampled twice more since.

The principles and basis of the IM SC subprogramme were described by Bringmark (1989) and guidelines for field sampling and laboratory analysis are given in the IM manual (EDC 1989a, 1989b, 1993, ICP IM Programme Centre 1998). The IM SC sampling and analytical methods were discussed at two international workshops (UNEP-CMEA 1989, UN-ECE 1990) and an inter-laboratory calibration exercise was carried out (Staatliches Amt fur Umwetschutz 1990–91). IM first round SC data has been presented in two annual synoptic reports (EDC 1990, 1991). Part of the Finnish first round SC data has been reported previously (Starr 1994) and the SC data summarised in the first national IM report (Starr 1995). In principle, SC is comparable to the soil programme of the ICP Forests/Level II programme (ICP Forest Programme Coordinating Centre 1998).

Material and Methods

Catchments and plots

The four Finnish catchments in which the SC subprogramme has been carried out are: Valkea-Kotinen (FI01), Hietajärvi (FI03), Pesosjärvi (FI04), and Vuoskojärvi (FI05) (Fig. 1). They fulfil the selection criteria given in the IM manual (EDC 1989a, 1993, ICP IM Programme Centre 1998). They are all situated in the boreal zone in protected conservation areas (Kotinen National Forest Reserve, Patvinsuo National Park, Oulanka National Park, and Kevo Nature Reserve). The forests are natural or at least semi-natural communities, and are representative of the phytogeographic zones in which they are located. Some important characteristics of the catchments are given in Table 1.

In 1988–89, four to five permanent plots were established on areas of mineral soil in each catchment (Fig. 1). In the case of Valkea-Kotinen, two plots were also laid out on peatland areas. Plots on peatland in Hietajärvi and Pesosjärvi catchments have subsequently also been established. The plots had to be located in the dominant forest site types of the catchment, had to be as flat as possible, and had to be as homogeneous as possible with regard to soil morphology, ground vegetation and tree stand (Starr et al. 1995). An attempt was also made to locate the plots on upper and lower slope segments within the same forest type. Some of the plots, intensive monitoring plots, also serve as sampling stations for other IM subprogrammes (e.g. throughfall, stem-flow, soil water) and are now part of the network of ICP Forests/Level II plots.

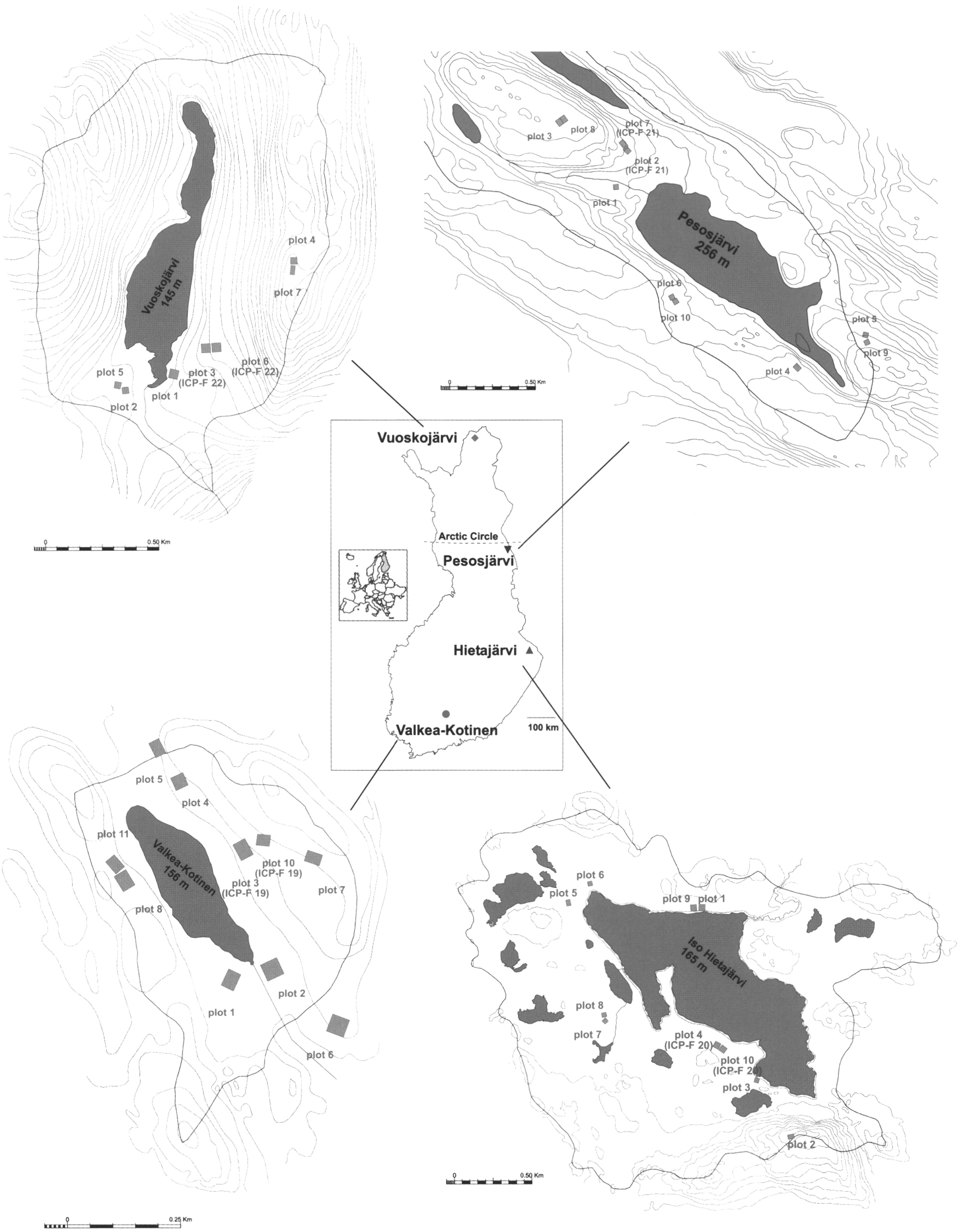

Figure 1. Maps of the four IM catchments showing location of the permanent plots at which the first round of the soil chemistry (SC) programme has been done (Inset map of Finland shows location catchments).

Kuva 1. *YYS valuma-alueet ja niillä sijaitsevat pysyvät koealat, joilta otettiin ensimmäisen keräyskerran maaperänäytteet (valuma-alueiden sijainti nähtävissä keskellä sijaitsevasta Suomen kartasta).*

Table 1. Some size, phytogeographic, climatic and deposition characteristics data for the four Finnish IM catchments.
Taulukko 1. *Taustatietoja neljältä YYS valuma-alueelta.*

	Valkea-Kotinen (FI01)	Hietajärvi (FI03)	Pesosjärvi (FI04)	Vuoskojärvi (FI05)
Location - *Sijainti*	61° 14´ N 25° 03´ E	63° 09´ N 30° 40´ E	66° 17´ N 29° 26´ E	69° 44´ N 26° 56´ E
Area, km^2 - *Pinta-ala, km^2*	0.3	4.6	5.4	1.8
Water area, % - *Veden osuus %*	10	24	9	8
Phytogeographic zone[#] *Kasvimaantieteellinen vyöhyke[#]*	Southern boreal (OC)	Middle boreal (OC-C1)	Northern boreal (O1)	Northern boreal (O1-O2)
Climatic zone[¤] - *Ilmastovyöhyke[¤]*	Humid continental (Dfb)	Continental subarctic (Dfc)	Continental subarctic (Dfc)	Continental subarctic (Dfc)
Annual precipitation, mm* - *Vuosittainen sademäärä**	619	650	554	395
Snow coverage, no. days*				
*Lumipeitteen kesto, päivien lkm**	130[†]	180	176[‡]	210
Temperature, °C* - *Lämpötila °C**				
Annual mean - *Vuosikeskiarvo*	3.1	1.9	-0.9	-2.0
January mean - *Tammikuun ka.*	-8.4	-12.1	-16.4	-15.7
July mean - *Kesäkuun ka.*	15.7	15.8	14.6	12.7
Deposition[§] - *Laskeuma[§]*				
SO_4^{2-}, mg S m^{-2}	442	365	202	124
NO_3^-, mg N m^{-2}	212	164	84	38
H^+, mmol m^{-2}	21.7	19.8	13.0	7.6
Pb, mg m^{-2}	1.33	0.99	0.54	0.26

[#] OC=indifferent, C1=slightly continental, O1=slightly oceanic, O2=suboceanic (Ahti et al. 1968).
[¤] Köppen Geiger climate classification (Strahler and Strahler 1992).
* Long-term (1961–90) average data. (Meteorological Yearbook of Finland 1991).
[§] Annual bulk deposition data for 1988–1996, for Pesosjärvi 1989–1996 (Kulmala et al.1998). Pb data for 1991–1996.
[†] 1989 data from Lammi, Vestola (Meteorological Yearbook of Finland 1990).
[‡] 1989 data (Meteorological Yearbook of Finland 1990).

Some site, stand and soil characteristics of each plot are summarised in Table 2. Depending on the terrain, the size of the plots varies from 25 x 35 m to 40 x 40 m. Two of the plots at Valkea-Kotinen (FI01/5 and FI01/6) have stands that have been thinned and one (FI01/6) is actually outside the watershed. However, the data for these plots are included in this report. The classification of the soils into FAO soil units (FAO-Unesco 1990a), as specified in the SC subprogramme, is based on a profile description made at the edge of each plot (Appendix 1).

Soil sampling

Soil sampling for the first round was carried out during a period of a few days in August 1988 for Vuoskojärvi, in October 1988 for Hietajärvi, and in June 1989 for Valkea-Kotinen and Pesosjärvi catchments.

For the mineral soil plots, up to three sets of soil samples were taken. One set was taken from layers of fixed depths, a second set from morphological (pedogenic) horizons, and a possible third set of undisturbed volumetric samples. The fixed depth layer samples are specifically for the SC subprogramme and it is the results from these samples that are presented in this report. The use of fixed depth layers for the SC subprogramme rather than morphological horizons, as originally specified (EDC 1989a), is in accordance with the recommendations made at a technical workshop (UNEP-CMEA 1989). Otherwise, the layer sampling procedures and numbers of subsamples and composite samples described below essentially follow IM guidelines (Bringmark 1989, EDC 1989a, 1989b, 1993, ICP IM Programme Centre 1998).

For the layer samples, each plot was divided into subplots on the basis of a 10 x 10 m grid and each subplot divided into systematically numbered 1 x 1 m squares (Fig. 2). For this first sampling round, square 1 in each subplot was selected. However, if sampling in that particular square was not possible (e.g. presence of a boulder or tree), sampling was transferred to the next available square. Four separate samples of each layer were taken at random within each selected 1x1 m square. The first of the four samples taken from each of the subplots were placed into the same bag, and similarly for all the second, third and fourth samples. In this way, four composite samples of each layer for each plot were collected.

The humus layer (Of+Oh horizon), the 0–5 cm, 5–20 cm and, where possible, also the 20–40 cm mineral soil layers were sampled. The humus layer samples were taken with a sharpened steel cylinder of 58 mm diameter. The litter layer (Ol), if present, was removed and the thickness of the remaining core recorded so that bulk density values could be calculated. A gouge-type auger with a diameter of 2 cm was used to sample the mineral soil layers. To ensure there was enough sample for analysis and archiving purposes, sometimes two or three auger cores (depending on humus thickness and size of plot) were taken to make up each of the four samples in each 1x1 m sampling square. If the thickness of a core for a particular layer was less than half of the target thickness, the core was rejected.

The horizon samples were taken from the soil pit dug to describe the soil profile. They were taken for classification purposes and to compare with the SC layer samples. The location of the pit was subjectively chosen as being representative of the plot. The depth of the pit was 70 to 100 cm, depending on stoniness and depth to bedrock. This depth was usually enough to expose the soil parent material (BC or C horizon). After describing the profile, samples of each master horizon, including the humus layer, were taken. In the case of the B horizon, a sample of the upper 7.5-cm and the remainder of the horizon were taken separately. For each horizon, soil taken from several spots around the walls of the pit with a trowel.

The volumetric mineral soil samples were taken for the purpose of determining bulk density. This property is needed to calculate the stores of soil components. The samples were taken from the soil pit using a steel cylinder of 72 mm diameter and 50 mm height. Three such volumetric cores per layer were combined. At some pits, the volumetric samples were taken from same layers as the SC layer samples. The soil in other pits was too stony to allow many sets of samples to be taken and the horizon and volumetric samples are the same, i.e. the horizon samples were taken with the cylinder.

Volumetric layer samples were taken from the peat plots, FI01/1 and FI01/2. The plots were divided into subplots and 1 x 1 m squares as described for the mineral soil plots. A sampler with a cross section of 5 x 5 cm was used to take single sample from square 1 in each of the subplots. The litter and living moss layer was removed and the 0–5, 5–10, 10–20 and 20–40 cm layers cut to length using a sharp knife. For each layer, samples from each subplot were placed into the same plastic bag so as to produce a single composite sample for each layer. A profile description was not made but the peat type and degree of decomposition (von Post scale) were recorded.

Sample preparation

The samples were kept in plastic bags for up to three days in cool (+4 °C) and dark conditions until they were transported to the laboratory. Upon arrival, the samples were placed in a deep freezer until they could be air-dried. Drying took place in a ventilated drying chamber regulated at between 40 and 60 °C. Coarse fragments (stems, roots, cones, etc.) were removed from the air-dried humus layer and peat samples by hand (IM manual recommends sieving through a 3 mm). The samples were then weighed and milled into a fine powder. The air-dried mineral soil samples were passed through a 2 mm sieve. The <2 mm fraction was weighed and retained. The prepared samples were kept in plastic bags and stored in cool and dark conditions to await analyses.

Soil chemical analyses

As far as possible, the procedures and methods outlined in the IM Manual have been followed (EDC 1989a, 1989b, 1993, ICP IM Programme Centre 1998). Full details have been documented by Ukonmaanaho & Starr (1996). The samples were analysed for the complete set of mandatory SC properties: pH (measured in water and in 1M KCl), exchangeable titratable acidity (EA), exchangeable (extractable) base cations (Na, K, Ca and Mg), total organic carbon (TOC), loss-on-ignition (LOI), and total nitrogen. The following optional IM properties were also determined: exchangeable titratable aluminium acidity (EA_{Al}), total titratable acidity (TTA), total P and S, and "total" Mn, Pb, Cd, Cu and Zn. Effective and potential cation exchange capacities (CEC_e, CEC_p) and related base saturations (BS_e, BS_p) were calculated.

Soil pH was measured using a glass electrode. A soil-water (or KCl solution) suspension was shaken in an end-over-end rotator for 1 h and allowed to settle over night before inserting the electrode into the supernatant. EA was determined from the 1M KCl suspension after pH measurement. The suspension was filtered and a 50 ml aliquot titrated with 0.02 M NaOH to a pH end-point value of 8.2. To measure EA_{Al}, 10 ml of 4 % NaF was then added, left to stand for 30 minutes and then back titrated with 0.02 M HCl to pH 8.2. Exchangeable base cations were extracted with 1 M NH_4Cl and concentrations determined from the filtrate using inductively coupled plasma emission spectroscopy (ICP-AES). The suspensions for the pH measurements and NH_4Cl extraction were made using IM recommended soil: solution ratios (1:10 for organic soil and 1:4 for mineral soil on a weight basis). Schleicher and Schuell 589[3] blauband papers were used for filtering. CEC_e was calculated as the sum of base cations (Ca+Mg+K+Na=BC) and EA on an equivalent basis and its associated base saturation, BS_e, as BC/CEC_e. TTA was measured using the $BaCl_2$+ triethanolamine (TEA) method. We mainly followed the procedure described by McKeague (1978), as the description in the IM manual (EDC 1989a) was inadequate. We used 2 g of organic soil and 10 g mineral soil and a total $BaCl_2$+ TEA buffer solution volume of 200 ml. For the extraction step, a shaking (end-over-end) time of 1 h was used. CEC_p and its

Table 2. Site, stand and soil characteristics of each plot.
Taulukko 2. *Koealojen pinta-ala sekä puusto- ja maaperätiedot.*

Plot no *Koealan numero*	Plot size m *Koealan koko m*	Elevation m a.s.l. *Korkeus m mp.*	Site type[1)] *Kasvupaikkatyyppi*	Stand species composition[2)] *Puusto* Dominant *Pääpuulajit*	 Non-dominant *Muut*	Soil type[3)] *Maannos*	Parent material[4)] *Muuttumaton pohjamaa*	Site position[4)] *Koealan sijainti*	Drainage class[4)] *Kosteus luokitus*
Valkea-Kotinen									
1†	40x30	156	Spruce-pine swamp (KR)	P	S	Fibric Histosol	Organic (Peat)	Bottom	Very poorly drained, always saturated, ponded
2†	40x40	156	Drained vaccinium myrtillus spruce swamp (Mtkg)	S	P, B	Terric Histosol	Organic (Peat)	Bottom	Very poorly drained, always saturated, ponded
3	40x30	161	Oxalis-Myrtillus (OMT)	S, B	P	Dystric Cambisol	Glacial (Till)	Middle slope	Well drained, saturated for short periods, slow to moderate runoff
4	30x30	157	Myrtillus (MT)	S	B, P	Gleyic Cambisol	Glacial (Till)	Lower slope/ Bottom	Imperfectly drained, saturated for short periods, ponded
5	35x25	159	Myrtillus (MT)	P	S, B	Dystric Cambisol/ Cambic Podzol	Glacial (Till)	Middle slope	Well drained, saturated for short periods, moderately rapid runoff
6	40x40	161	Myrtillus (MT)	S	P, B	Dystric Cambisol/ Cambic Podzol (lithic)	Glacial (Till)	Crest	Somewhat excessively drained, saturated for short periods, moderately rapid runoff
7	35x25	172	Myrtillus (MT)	S	P, B	Dystric Cambisol/ Cambic Podzol	Glacial (Till)	Middle slope	Well drained, saturated for short periods, moderately rapid runoff
Hietajärvi									
1	40x40	168	Empetrum-Vaccinium (EVT)	P	B, S	Haplic Podzol	Glacio-fluvial (sorted)	Lower slope/ Bottom	Somewhat excessively drained, saturated for short periods, slow runoff
2	40x30	211	Vaccinium-Myrtillus (VMT)	P	-	Haplic Podzol	Glacial (Till)	Crest	Well drained, saturated for short periods, moderately rapid runoff
4	40x40	167	Empetrum-Vaccinium (EVT)	P	B	Haplic Podzol	Glacio-fluvial (sorted)	Bottom	Somewhat excessively drained, saturated for short periods, neither receiving nor shedding water
5	40x30	168	Empetrum-Vaccinium (EVT)	P	B	Haplic Podzol	Glacio-fluvial (sorted)	Bottom	Moderately well drained, saturated for short periods, slow runoff

Table 2. Continues.
Taulukko 2. *Jatkuu.*

Plot no *Koealan numero*	Plot size m *Koealan koko m*	Elevation m a.s.l. *Korkeus m mp.*	Site type[1] *Kasvupaikkatyyppi*	Stand species composition[2] *Puusto* Dominant *Pääpuulajit*	 Non-dominant *Muut*	Soil type[3] *Maannos*	Parent material[4] *Muuttumaton pohjamaa*	Site position[4] *Koealan sijainti*	Drainage class[4] *Kosteus luokitus*
Pesosjärvi									
1	30x30	263	Hylocomium-Myrtillus (HMT)	S	P, B, A	Gleyic Podzol	Glacio-fluvial (sorted)	Lower slope/ Bottom	Moderately well drained, saturated for for short periods, ponded
2	40x30	270	Hylocomium-Myrtillus (HMT)	P	S, B	Haplic Podzol	Glacial (Till)	Lower slope	Well drained, saturated for short periods, moderately rapid runoff
3	40x30	293	Hylocomium-Myrtillus (HMT)	S	B, P, A	Haplic Podzol	Glacial (Till)	Crest	Well drained, saturated for short periods, moderately rapid runoff
4	40x30	273	Empetrum-Myrtillus (EMT)	P	S, B, A	Haplic Podzol (lithic)	Glacial (Till)	Middle slope	Well drained, saturated for short periods, moderately rapid runoff
5	30x30	270	Hylocomium-Myrtillus (HMT)	S	P, B	Haplic Podzol	Glacial (Till)	Crest	Moderately well drained, saturated for for short periods, slow runoff
Vuoskojärvi									
1	40x40	146	Lichen woodland	P	Bt	Haplic Podzol	Glacial (Till)	Bottom	Somewhat excessively drained, saturated for short periods, neither receiving nor shedding water
2	30x30	146	SELiPIT	Bt	P	Haplic Podsol (fragipan)	Glacial (Till)	Bottom	Somewhat excessively drained, saturated for short periods, neither receiving nor shedding water
3	40x40	158	Lichen woodland	P	Bt	Haplic Podsol	Glacial (Till)	Lower slope	Somewhat excessively drained, saturated for short periods, slow runoff
4	30x30	231	SELiT	Bt	P	Haplic Podzol (lithic)	Glacial (Till)	Crest	Excessively drained, saturated for short periods, moderately rapid runoff

[1] See Eurola et al. (1982) for peatland site types (†), Cajander (1926 and 1949) for mineral soil site types and Hämet-Ahti (1963) for Vuoskojärvi site types.
SELiT = subalpine Empetrum-Lichenes type, sELiPIT= subalpine Empetrum-Lichenes-Pleurozium type
[2] P = Scots pine *(Pinus sylvestris)*, S = Norway spruce *(Picea abies)*, B = Birch (*Betula* spp.), A = Aspen *(Populus tremula)*, Bt = Mountainbirch (*Betula pubescens* spp. *tortuossa*).
[3] FAO (1990a).
[4] FAO (1990b).

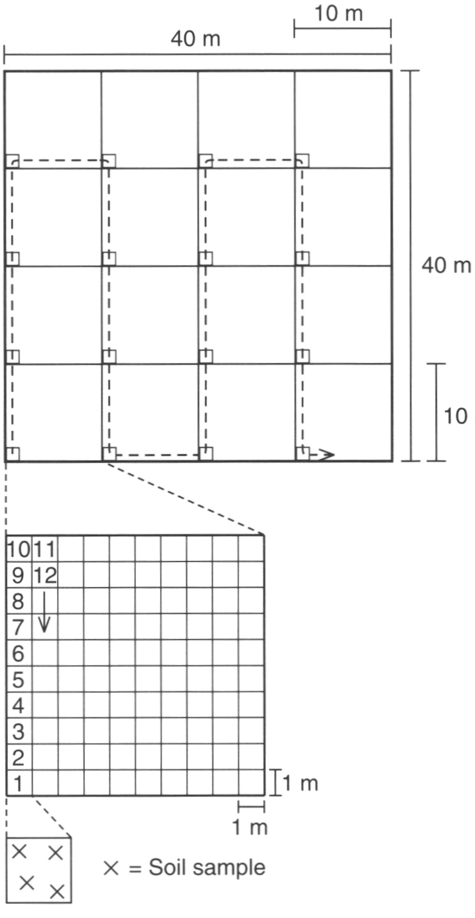

Figure 2. The Finnish IM soil chemistry (SC) sampling design.
Kuva 2. *Maaperäkemia (SC) osaohjelman näytteenottomenetelmä Suomessa.*

associated base saturation, BS_p, where calculated in the same way as CEC_e and BS_e, but using TTA instead of EA.

Total N and total C were determined using a LECO CHN-600 analyser. Because the soils are non-calcareous, total C corresponds to TOC values. For the mineral soil plots, LOI was determined using a LECO TGA-500 analyser. For the peat plots (FI01/1 and FI01/2), LOI was determined using an equivalent manual thermogravimetric procedure. Total S was determined using a LECO S analyser.

The original recommended IM wet digestion method for determination of total elemental concentrations of heavy metals was 2 M HNO_3 for mineral soil and HNO_3+$HClO_4$ (4:1) for the humus layer and peat. At an IM workshop (UN-ECE. 1990), it was agreed to recommend the use of HNO_3+$HClO_4$ (4:1) for both humus layer and mineral soil samples, although strong preferences for national digestion methods were expressed. Later, digestion with *Aqua Regia* (HCl+HNO_3; 3:1) with H_2O_2 for both mineral and organic soil was specified (EDC 1993), primarily on the grounds that it was the recommended method by the ICP Forest's Soil Expert Panel (Ministerie van de Vlaamse Gemeenschap 1991). None of these wet digestion methods were available to us at the time and so we decided to use our laboratory's standard method for the total analysis of plant material, namely dry ashing (3 h at 550 °C) and dissolution of the ash in concentrated HCl acid (Halonen et al. 1983) followed by ICP-AES. Nickel, Cr, V, Hg, As and Se concentrations were not measured because of the risk of volatization losses during dry ashing or because the element was not included in the ICP-AES programme at the time (Ni has since been added). For the humus layer the dry ashed concentrations are total concentrations while for the mineral soil they correspond to the organically bound fraction plus a non-organic fraction considered "slowly available" (i.e. occluded and easily weatherable fraction but not the silicate bound fraction) (Bringmark 1989). The intention is to determine that fraction of heavy metals that is ecologically available or potentially so.

Bulk density of the sample layers is included in the list of mandatory SC properties. Our bulk density values are presented in Appendix 2. The humus layer values are averages calculated from the four composite layer samples collected at each plot. Values for the mineral soil refer to the oven dry weight of the <2 mm fraction of soil per unit volume, i.e. bulk density of the fine earth fraction. In cases where the bulk density was measured for the horizon, a value for the layer was derived by multiplying the bulk density value of each horizon included in layer by the thickness it contributed, summing these values and then dividing by the overall thickness of the layer. Volumetric samples could not be taken from plots FI01/3 and FI05/1 because the soils were too stony. Surrogate bulk density values from plots FI01/7 and FI05/3 have therefore given for these plots.

Numerical handling

All data (except pH) have been calculated on an oven-dry mass basis. Scatter plots of related variables were used to identify outliers. The four replicate values for each sampled layer from the mineral soil plots proved particularly useful in this respect. Errors due to typing or calculating were corrected while remaining outliers were substituted by regression estimates if possible. About 17 % and 5 % of the humus layer and mineral soil samples had values for one or more variables corrected in this way. The corrections for the humus layer samples were confined to the titratable acidity parameters, i.e., EA, EA_{Al} and TTA.

The data are presented for each catchment, plot and layer. In the case of the upland soil plots, the values are the arithmetic means of four values (i.e., the four replicate composite samples for each layer). In the case of the peat plots (FI01/1 and FI01/2), the values are those of the single composite sample for each layer.

Results and discussion

Description and comparability of data

Soil pH, titratable acidity, cation exchange capacity and base saturation values are presented in Table 3. The mass concentrations of 1M NH_4Cl extractable base cations (K, Na, Ca and Mg) are presented in Table 4.

Values for the upland soil plots fall within the ranges of regional values presented by Tamminen & Starr (1990), Tamminen (1991) and Starr & Tamminen (1992). For the two peat plots (FI01/1 and FI01/2), pH_{water} and CEC_e values, although of the same order of magnitude, were lower than could be expected when compared to values reported by Westman (1981) for minerotrophic peatland site types of lower fertility. This discrepancy may be because of differences in methods. Nevertheless, BS_e values were higher than those presented by Westman (1981), reflecting the higher trophic status of the IM sites. Values for pH_{water}, CEC_p, BS_p and base cations are compatible with the results presented for drained oligotrophic peat site types presented by Pätilä & Nieminen (1990).

LOI, TOC, total N and S values are given in Table 5. There is little published total S data for Finnish upland soils against which to compare our data but the values for TOC and N are compatible with those presented by Tamminen & Starr (1990) and Tamminen (1991). Total S values for the two peat plots (FI01/1 and FI01/2) are similar to values published by Pätilä & Nieminen (1990).

The mass concentrations of "total" (dissolution of ashed samples) P, Mn, Cu, Zn, Pb and Cd are presented in Table 6. The values for Cu, Zn, Pb and Cd are directly comparable with those presented by Tamminen & Starr (1990) as the same dry ashing method was used.

Evaluation and interpretation of the data

Levels of soil acidity and acidification

Ulrich (1981) defined various ranges of acid buffering in mineral soil by pH values. Using these ranges and our pH_{water} values (Table 3), soil in the 0–5 cm layer would fall into the cation exchange range (pH 4.2–5.0). The exception being plots FI01/4, FI01/6 and FI04/4, which would just fall into the aluminium buffering range (pH 2.8–4.2). Soil in the 5–20 cm layer fall either into the cation exchange range or into the silicate weathering range (pH 5.0–6.0), and the soil in the 20–40 cm layer would fall into the silicate weathering range. Aluminium acidity (EA_{Al}) clearly

Table 3. Soil pH, exchangeable titratable acidity (EA), exchangeable titratable aluminium acidity (EA_{Al}), total titratable acidity (TTA), and effective and potential cation exchange capacities (CEC_e and CEC_p) and their respective base saturations (BS_e and BS_p) by layer for each plot. Values are means of four values unless otherwise indicated.
Taulukko 3. *Maaperän pH, vaihtuva happamuus (EA), vaihtuva alumiini (EA_{Al}), kokonaishappamuus (TTA), efektiivinen ja potentiaalinen kationinvaihtokapasiteetti (CEC_e ja CEC_p) sekä efektiivinen ja potentiaalinen emäskyllästysaste (BS_e ja BS_p) koealoittain ja kerroksittain esitettynä. Tulokset ovat neljän rinnakkaisnäytteen keskiarvoja ellei toisin ole mainittu.*

Catchment *Valuma-alue*	Plot *Koe-ala*	Layer cm *Kerros cm*	pH_{water}	pH_{KCl}	EA (meq kg^{-1})	EA_{Al}	TTA	CEC_e	CEC_p	BS_e (%)	BS_p
Valkea-Kotinen	1†	0–5	3.5	2.6	73	0	736	231	894	68	18
		5–10	3.3	2.5	83	10	1376	320	1612	74	15
		10–20	3.5	2.6	67	13	1325	236	1494	72	11
		20–40	3.7	2.6	59	15	1020	247	1207	76	16
	2†	0–5	3.8	2.9	48	0	1108	296	1356	84	18
		5–10	3.6	2.7	53	6	1268	354	1568	85	19
		10–20	3.8	2.8	45	10	1443	326	1725	86	16
		20–40	4.1	3.0	37	12	1523	289	1755	87	14
	3	Humus	4.1	3.3	36	2	712	286	961	87	26
		0–5	4.3	3.3	32	23	159	46	173	30	8
		5–20	4.5	3.7	20	16	179	26	185	21	3
	4	Humus	3.8	2.9	56	10	1074	332	1350	83	20
		0–5	4.1	3.4	30	23	150	44	164	33	9
		5–20	4.6	3.8	16	12	174	21	180	26	3
	5	Humus	4.0	3.2	45	4	907	279	1142	84	21
		0–5	4.5	3.5	26	20	154	40	167	33	8
		5–20	5.2	3.9	10	7	184	19	193	49	4
	6	Humus	3.9	3.1	45	7	691	228	874	80	21
		0–5	4.1	3.3	35	26	207	48	221	28	6
		5–20	4.7	3.8	18	14	219	24	225	26	3
	7	Humus	4.0	3.2	45	7	746	259	961	83	22
		0–5	4.5	3.5	28	22	169	38	179	25	6
		5–20	4.8	3.8	11	9	125	15	129	25	3
Hietajärvi	1	Humus	3.5	2.6	59	5	1042	253	1235	76	16
		0–5	4.4	3.5	8	7	81	12	84	32	5
		5–20	5.3	3.8	2	1	72	4	74	48	2
		20–40	5.7	3.8	1	0	27	2	28	54	5
	2	Humus	3.6	2.8	58	2	895	226	1063	74	16
		0–5	4.5	3.4	12	8	74	15	78	23	5
		5–20	5.4	3.9	6	4	139	8	141	25	1
	4	Humus	3.6	2.7	58	4	921	225	1089	74	15
		0–5*	4.5	3.6	10	6	78	11	80	15	2
		5–20	5.1	3.8	2	1	66	3	67	31	1
		20–40	5.5	3.8	1	1	28	2	29	39	3
	5	Humus	3.6	2.8	58	5	817	207	966	72	15
		0–5	4.4	3.6	9	6	32	10	33	17	5
		5–20	5.2	3.8	3	2	75	4	76	34	2
		20–40	5.8	3.8	1	0	10	2	12	52	14

Table 3. *Continues*
Taulukko 3. *Jatkuu*

Catchment *Valuma-alue*	Plot *Koe-ala*	Layer cm *Kerros cm*	pH_{water}	pH_{KCl}	EA	EA_{Al}	TTA	CEC_e	CEC_p	BS_e	BS_p
					meq kg^{-1}					%	
Pesosjärvi	1	Humus	3.9	3.0	50	0	862	314	1126	84	23
		0–5	4.4	3.4	12	7	57	20	65	42	13
		5–20	4.9	3.9	10	7	119	17	125	41	5
		20–40	5.3	3,9	6	4	76	9	79	36	4
	2	Humus	3.8	3.1	61	0	709	250	898	76	21
		0–5	4.2	3.3	16	10	37	21	42	23	12
		5–20	5.0	3.9	7	4	76	10	79	33	4
		20–40	5.3	3.9	2	1	20	4	22	47	10
	3	Humus	3.7	3.0	60	1	745	250	936	75	20
		0–5	4.3	3.4	14	10	44	20	50	28	12
		5–20	5.1	3.9	5	3	69	8	72	34	4
		20–40	5.3	3.9	32	2	26	5	28	31	5
	4	Humus	3.7	2.9	60	0	841	271	1052	78	20
		0-5	4.1	3.2	19	12	67	26	74	27	10
		5-20	4.8	3.8	12	9	96	16	100	25	4
		20-40	5.2	3.9	64	4	46	9	49	34	6
	5	Humus	3.7	3.0	59	1	783	259	984	77	20
		0–5	4.3	3.3	13	8	37	22	45	40	20
		5–20	4.9	3.8	119	9	63	15	67	26	6
Vuoskojärvi	1	Humus	3.8	2.9	63	20	916	258	1111	76	18
		0–5	4.3	3.5	17	12	109	22	114	24	5
		5–20	5.1	3.8	5	4	95	7	98	36	3
	2	Humus	3.9	3.0	49	0	759	253	963	81	21
		0–5	4.4	3.5	13	8	93	20	100	35	7
		5–20	4.9	3.8	6	5	94	9	97	34	3
	3	Humus	3,7	2.9	84	33	979	259	1154	68	15
		0–5	4.3	3.4	23	17	86	28	91	20	6
		5–20	5.0	3.8	7	6	95	9	98	26	3
	4	Humus	3,9	2.8	45	11	796	227	978	80	19
		0–5	4.6	3.6	19	14	92	25	98	23	6
		5–20	5.4	3.8	5	4	81	9	84	40	4

*† Organic (peat) soil plot, n = 1 for each layer, * n = 3*

Table 4. Mass concentrations of 1M ammonium chloride extractable base cations by layer for each plot. Values are means of four values unless otherwise indicated.
Taulukko 4. *Maaperän emäskationipitoisuus 1M ammoniumkloridiuutoksesta saatuna maakerroksittain ja koealoittain. Tulokset ovat neljän rinnakkaisnäytteen keskiarvoja ellei toisin ole mainittu.*

Catchment	Plot	Layer cm	K	Na	Ca	Mg
Valuma-alue	*Koeala*	*Kerros cm*	mg kg^{-1}			
Valkea-Kotinen	1†	0–5	715.7	42.8	2051.1	429.6
		5–10	381.8	57.3	3511.3	596.3
		10–20	167.6	46.9	2555.7	429.8
		20–40	102.9	53.3	2900.9	457.3
	2†	0–5	808.7	37.9	3807	437.3
		5–10	448.1	51.9	4697.6	639.4
		10–20	238.1	54.2	4407.1	645.5
		20–40	56.5	44.4	4108.8	527.2
	3	Humus	682.2	18.3	3762.5	530.2
		0–5	35.9	4.2	206.3	33.9
		5–20	23.4	4.3	69.4	14.4
	4	Humus	729.8	28.4	4327.6	484.2
		0–5	41.7	5.9	221.7	25.5
		5–20	24.6	5.4	70.9	11.6
	5	Humus	767.6	19.8	3495.8	485.5
		0–5	39.2	3.4	198.8	25.7
		5–20	20.6	3.2	139.9	13
	6	Humus	703.7	22.3	2807.1	289.4
		0–5	61	5.8	185.2	27.4
		5–20	35.9	3.3	84.1	10.3
	7	Humus	838.7	23.5	3244.3	364.6
		0–5	50.9	4.8	132.4	22.2
		5–20	22.2	3.9	48.2	7.0
Hietajärvi	1	Humus	834.5	20.9	2853.1	353.9
		0–5	25.1	3.2	46.4	6.8
		5–20	12.2	2.9	21.3	3.0
		20–40	6.9	3.4	16.6	2.1
	2	Humus	1043.9	16.6	2295.8	313.6
		0–5	23.3	2.7	43.5	7.4
		5–20	13.3	2.3	23.7	3.8
	4	Humus	1022.3	21.1	2240.3	348.2
		0–5*	14.5	2.5	18.0	4.1
		5–20	7.4	2.1	9.9	1.8
		20–40	3.1	1.9	9.7	1.4
	5	Humus	916.6	20.3	2072.8	253
		0–5	9.5	2.3	19.5	3.4
		5–20	7.0	2.7	17.4	2.4
		20–40	2.9	2.6	17.8	1.8

Table 4. Continues.
Taulukko 4. *Jatkuu*

Catchment	Plot	Layer cm	K	Na	Ca	Mg
Valuma-alue	*Koeala*	*Kerros cm*	mg kg^{-1}			
Pesosjärvi	1	Humus	1143	21	3836.8	520.3
		0–5	31.2	3.5	116.5	19.8
		5–20	17.8	2.6	100.1	13.6
		20–40	10.4	3.1	46.1	5.2
	2	Humus	1306.8	15.4	2406.5	419.6
		0–5	19.3	2.5	59.2	15.0
		5–20	13.3	2.0	42.5	8.6
		20–40	7.7	3.4	24	5.6
	3	Humus	1117.3	22.0	2361.9	520.0
		0–5	21.2	3.2	69.8	18.4
		5–20	12.8	2.9	33.4	7.6
		20–40	7.4	3.2	13.4	4.2
	4	Humus	990.2	20.3	2892.3	491.3
		0–5	21	3.2	88.2	24.2
		5–20	14.5	2.9	48.8	11.7
		20–40	13.3	2.9	29.9	11.8
	5	Humus	1140.6	19.8	2512.4	550.7
		0–5	27.2	4.0	105.0	32.3
		5–20	12.5	2.6	46.9	12.7
Vuoskojärvi	1	Humus	802.3	74.3	2370.1	642.2
		0–5	18.0	7.5	57.5	20.1
		5–20	7.1	7.4	28.9	7.0
	2	Humus	843.3	49.5	2532	656.5
		0–5	17.5	9.5	82.9	23.6
		5–20	10.7	9.2	37.4	9.1
	3	Humus	954.1	53.0	2026.8	580.9
		0–5	17.9	8.6	63.5	19.2
		5–20	9.3	6.9	28.8	5.6
	4	Humus	617	36.9	2315.5	593.2
		0–5	14.5	9.0	73.8	15.6
		5–20	7.0	8.9	47.9	7.5

† Organic (peat) soil plot; n = 1 for each layer
* n = 3

Table 5. Loss on ignition (LOI) and mass concentrations of total organic carbon (TOC), total nitrogen and total sulphur by layer for each plot. Values are means of four values unless otherwise indicated.
Taulukko 5. *Hehkutushäviö (LOI) ja orgaaninenhiili (TOC), kokonaistyppi ja -rikki maakerroksittain ja koealoittain. Tulokset ovat neljän rinnakkaisnäytteen keskiarvoja ellei toisin ole mainittu.*

Catchment *Valuma-alue*	Plot *Koeala*	Layers cm *Kerros cm*	LOI	TOC %	N	S
Valkea-Kotinen	1†	0–5	97.4	53.2	0.97	0.16
		5–10	97.0	52.2	0.95	0.19
		10–20	97.4	52.3	1.13	0.28
		20–40	97.7	56.1	1.23	0.23
	2†	0–5	96.1	53.1	1.21	0.17
		5–10	95.8	52.2	1.07	0.17
		10–20	96.3	52.8	1.26	0.23
		20–40	96.5	55.8	1.60	0.33
	3	Humus	68.9	39.0	1.22	0.14
		0–5	8.4	4.4	0.17	0.02
		5–20	7.3	3.0	0.14	0.03
	4	Humus	88.2	49.2	1.31	0.18
		0–5	6.8	3.4	0.13	0.01
		5–20	7.2	2.8	0.12	0.04
	5	Humus	79.4	43.7	1.23	0.16
		0–5	7.3	3.7	0.15	0.01
		5–20	7.6	3.3	0.15	0.03
	6	Humus	64.4	35.8	0.97	0.12
		0–5	8.6	5.0	0.17	0.02
		5–20	8.5	3.6	0.15	0.04
	7	Humus	72.6	40.4	1.14	0.15
		0–5	7.5	4.0	0.15	0.02
		5–20	5.4	2.3	0.11	0.03
Hietajärvi	1	Humus	89.8	49.1	1.05	0.15
		0–5	3.6	1.8	0.03	0.01
		5–20	2.8	0.9	0.03	0.02
		20–40	1.4	0.3	0.01	0.01
	2	Humus	90.3	49.6	1.01	0.14
		0–5	2.3	1.1	0.04	0.01
		5–20	3.8	1.3	0.09	0.01
	4	Humus	89.9	48.5	0.97	0.14
		0–5*	2.9	0.8	0.03	0.01
		5–20	2.4	0.6	0.02	0.01
		20–40	0.9	0.2	0.02	0.01
	5	Humus	82.7	46.2	0.86	0.11
		0–5	1.7	0.9	0.01	0.00
		5–20	2.8	0.8	0.01	0.01
		20–40	1.0	0.2	0.01	0.01

Table 5. Continues.
Taulukko 5. *Jatkuu.*

Catchment *Valuma-alue*	Plot *Koeala*	Layers cm *Kerros cm*	LOI	TOC %	N	S
Pesosjärvi	1	Humus	92.1	50.6	1.16	0.15
		0–5	3.3	1.9	0.08	0.01
		5–20	3.7	1.6	0.06	0.01
		20–40	2.1	0.8	0.03	0.02
	2	Humus	90.9	52	0.98	0.13
		0–5	1.2	1.3	0.04	0.00
		5–20	1.7	0.9	0.04	0.01
		20–40	0.3	0.3	0.02	0.01
	3	Humus	90.8	51.3	1.01	0.13
		0–5	2.7	2.0	0.06	0.01
		5–20	2.8	1.2	0.04	0.01
		20–40	1.2	0.5	0.02	0.01
	4	Humus	92.8	53.7	0.94	0.14
		0–5	3.2	1.8	0.06	0.01
		5–20	3.3	1.3	0.06	0.01
		20–40	1.9	0.7	0.03	0.01
	5	Humus	93.1	53.3	1.06	0.14
		0–5	3.4	2.2	0.07	0.01
		5–20	2.5	0.9	0.02	0.01
Vuoskojärvi	1	Humus	88.3	48.7	1.07	0.15
		0–5	4.9	2.0	0.15	0.01
		5–20	3.5	1.2	0.13	0.01
	2	Humus	84.4	45.8	1.21	0.15
		0–5	3.9	1.8	0.03	0.01
		5–20	4.5	1.2	0.03	0.01
	3	Humus	91.3	49.4	1.14	0.16
		0–5	3.5	1.6	0.03	0.01
		5–20	2.6	1.1	0.03	0.01
	4	Humus	72	40.5	0.95	0.13
		0–5	3.3	2.0	0.10	0.01
		5–20	2.3	1.1	0.04	0.01

† Organic (peat) soil plots, n = 1 for each layer
*n = 3

Table 6. Mass concentrations of "total" (dry ash) P, Mn, Cu, Zn, Pb and Cd by layer for each plot. Values are means of four values unless otherwise indicated.
Taulukko 6. *P, Mn, Cu, Zn, Pb ja Cd kokonaispitoisuudet (kuivapolttomenetelmällä) maakerroksittain ja koealoittain. Tulokset ovat neljän rinnakkaisnäytteen keskiarvoja ellei toisin ole mainittu.*

Catchment *Valuma-alue*	Plot *Koeala*	Layer cm *Kerros cm*	P	Mn	Cu mg kg^{-1}	Zn	Pb	Cd
Valkea-Kotinen	1†	0–5	680.8	229.8	7.1	45.5	24.5	0.5
		5–10	506.8	74.7	5.0	30.5	26.1	0.6
		10–20	569.7	26.1	4.1	15.3	14.5	0.6
		20–40	535.6	15.7	6.7	5.4	7.6	0.5
	2†	0–5	597.8	144.1	3.9	48.1	17.2	0.5
		5–10	503.7	58.8	3.7	35.7	26.1	0.5
		10–20	539.4	26.7	2.5	18.8	14.1	0.5
		20–40	465.9	15.3	2.5	10.1	8.4	0.5
	3	Humus	677.7	229.6	7.4	27.3	37.3	0.8
		0–5	136.5	44.9	3.9	11.7	12.9	1.1
		5–20	233.7	71.7	8.3	22.3	6.3	2.2
	4	Humus	647.6	102.2	7.3	35.5	35.9	0.6
		0–5	87.2	50.5	5.5	11.1	9.6	1.0
		5–20	208.1	63.7	12.3	31.2	3.5	2.1
	5	Humus	848.8	223.1	7.2	52.9	39.0	0.9
		0–5	433.0	41.4	12.8	33.3	10.2	1.2
		5–20	648.2	48.9	14.6	35.4	5.3	1.8
	6	Humus	912.8	448.9	7.3	56.6	48.2	0.9
		0–5	564.4	150.7	11.3	66.9	17.8	1.6
		5–20	1603.7	145.9	20.2	97.4	5.5	2.3
	7	Humus	1074.6	572.1	8.4	78.4	52.1	1.0
		0–5	670.3	293.8	12.7	76.1	16.3	1.5
		5–20	651.5	137.5	11.1	47.1	6.8	1.6
Hietajärvi	1	Humus	674.0	65.1	5.3	36.5	25.3	< 0.5
		0–5	233.8	16.3	1.1	3.2	12.8	< 0.5
		5–20	367.7	29.5	1.5	8.8	18.6	< 0.5
		20–40	224.2	30.1	2.0	6.2	13.3	< 0.5
	2	Humus	792.2	451.1	7.1	53.9	37.0	< 0.5
		0-5	207.7	51.3	1.3	7.0	9.6	< 0.5
		5-20	872.5	282.6	2.4	27.2	24.6	< 0.5
	4	Humus	770.0	262.2	6.2	53.4	33.7	< 0.5
		0–5*	212.1	13.8	1.5	6.5	11.7	< 0.5
		5–20	450.2	47.3	2.0	12.9	20.1	< 0.5
		20–40	251.5	52.7	2.9	10.0	11.8	< 0.5
	5	Humus	652.9	267.9	5.8	49.7	33.0	< 0.5
		0–5	147.3	22.7	1.9	9.8	9.5	< 0.5
		5–20	435.7	63.4	1.8	14.9	24.0	< 0.5
		20–40	192.9	55.2	2.5	9.5	13.4	< 0.5

Table 6. Continues.
Taulukko 6. *Jatkuu.*

Catchment *Valuma-alue*	Plot *Koeala*	Layer cm *Kerros cm*	P	Mn	Cu	Zn	Pb	Cd
					mg kg^{-1}			
Pesosjärvi	1	Humus	920.3	390.1	5.7	38.3	16.2	0.7
		0–5	96.1	41.3	1.5	2.0	4.0	0.5
		5–20	154.8	67.8	4.1	3.7	2.2	1.3
		20–40	187.1	58.3	7.1	4.5	1.9	1.3
	2	Humus	967.4	565.1	6.3	42.8	18.9	0.7
		0–5	242.3	29.5	2.6	2.3	4.9	0.7
		5–20	527.9	133.6	8.3	5.6	3.0	1.6
		20–40	276.2	57.2	11.6	3.4	2.3	1.2
	3	Humus	951.7	283.4	5.7	28.6	17.8	0.7
		0–5	119.8	11.5	3.1	2.7	3.7	0.6
		5–20	187.9	42.0	7.1	3.2	2.4	1.4
		20–40	160.3	68.9	11.0	4.0	2.6	1.4
	4	Humus	858.8	404.6	5.6	42.8	17.1	0.7
		0–5	197.7	18.5	6.0	3.8	5.4	1.0
		5–20	293.2	57.9	16.3	3.7	3.8	2.0
		20–40	230.9	47.3	21.9	2.5	2.6	1.7
	5	Humus	1023.7	422.5	7.0	33.8	17.3	0.8
		0–5	148.1	26.4	4.5	4.2	9.3	0.8
		5–20	231.6	60.9	5.5	12.9	5.8	1.2
Vuoskojärvi	1	Humus	832.2	102.6	5.1	38.1	15.6	< 0.5
		0–5	162.8	43.1	4.5	10.1	15.9	< 0.5
		5–20	266.4	75.8	8.3	17.1	24.4	< 0.5
	2	Humus	879.4	245	5.9	48.4	14.0	< 0.5
		0–5	136.0	35.7	3.1	6.7	13.9	< 0.5
		5–20	206.7	73.3	8.5	15.7	25.8	< 0.5
	3	Humus	952.8	87.2	5.1	28.6	13.7	< 0.5
		0–5	115.3	43.2	3.8	10.5	13.5	< 0.5
		5–20	238.4	84.5	8.3	18.3	22.0	< 0.5
	4	Humus	607.7	62.8	4.7	29.6	13.9	< 0.5
		0–5	145.1	45.2	7.1	12.2	19.0	< 0.5
		5–20	184.3	100	13.3	22.5	27.4	< 0.5

† Organic (peat) soil plots, n = 1 for each layer
*n = 3

accounted for most of the titratable exchangeable acidity (EA) in the mineral soil.

Theoretically, when mineral soil pH values are < 4.2 and BS_e values < 15 %, the soil solution is no longer dominated by Ca^{2+} ions, and Al^{3+} ions and heavy metals may start to reach toxic concentrations (Reuss 1983, Ulrich 1981). Mineral soil with CEC_e values < 5 meq kg^{-1} (and pH values < 5.0) is considered as having a low buffering capacity and a very low degree of elasticity (resilience) against inputs of acidity (Meiwes et al. 1986). Mineral soil with CEC_e values < 5 meq kg^{-1} occur in the 5–20 cm and 20–40 cm layers in the Hietajärvi and Pesosjärvi catchments (Table 3). The soil at these plots may thus be considered potentially the most sensitive to acidic deposition. However, pH_{water} values are > 5.0 and BS_e values remain above 15 %. Furthermore, water infiltrating the soil would first encounter the considerable buffering capacity of the humus layer (Starr et al. 1996). The plots with the most acidified mineral soil (i.e., highest EA and TTA values and lowest pH_{water} and BS_e values) are associated with the Valkea-Kotinen catchment. However, BS_e values are all > 15 %, indicating that there is no immediate threat to forest health.

Depending upon the acid load, sensitivity of the soil and its initial acidity, acid deposition may contribute to the levels of soil acidification (Berdén et al. 1987). Of the four catchments, Valkea-Kotinen receives the highest acidic deposition load (Table 1; Ukonmaanaho et al. 1998a). Soil acidification also develops however as a result of natural processes (e.g., podzolization, nutrient uptake and accumulation of organic matter) and land use and management practices (e.g., clear felling, prescribed burning). The differences in soil acidification among the catchments are therefore not a simple reflection of regional acidic deposition loads.

Because of a warmer climate, the potential for nutrient uptake and soil microbiological activity is greater in southern Finland. Since the nutrients Ca, Mg and K are also base cations, nutrient uptake necessarily results in the acidification of the mineral soil. Biomass production leads to the accumulation of soil organic matter and levels of soil acidification and total S in the IM catchments were clearly related to soil organic matter contents (Fig. 3). Regional maps of soil pH_{water} (Starr & Tamminen 1992) show that the highest mineral soil and the lowest humus layer pH_{water} values tend to occur in northern Finland. Conversely, the lowest mineral soil and the highest humus layer pH_{water} values tend to occur in southern Finland. Of the IM catchments the mineral soil tended to be the most acidified and the humus layer the least acidified in the Valkea-Kotinen catchment. Mineral soil LOI and TOC values also tended to be greater at Valkea-Kotinen. The levels of soil acidification at Valkea-Kotinen may thus be more related to stand growth and soil biological activity rather than to loads of acidic deposition. Proton (H^+) budgets calculated for Valkea-Kotinen, however, did show that external sources (deposition) were greater than internal sources (biomass accumulation) (Forsius et al. 1995). Nevertheless, the acid deposition loads would have to be considerably higher than experienced in order to mobilise soil aluminium to toxic levels (Derome 1989, Nissinen & Ilvesniemi 1990, Starr et al. 1996).

Trace and heavy metals

Compared to Cu and Cd, concentrations of total Mn, Zn and Pb are considerably greater in the humus layer than those in the underlying mineral soil (Table 6). The enrichment of Mn and Zn is probably due to the effects of uptake and retention by organic matter, i.e., biological enrichment. Concentrations of Pb in the humus layer showed a clear south north gradient, with the highest concentrations in Valkea-Kotinen, the most southerly catchment. The deposition load of Pb also shows the same trend (Ukonmaanaho et al. 1998b). Thus, the higher Pb concentrations in the humus layer are most probably due to traffic emissions. In the mineral soil layers, only Cu concentrations showed a consistent trend with depth (concentrations increasing with depth). Except for Zn (Fig. 3), dry ash metal contents in the mineral soil were not correlated with soil

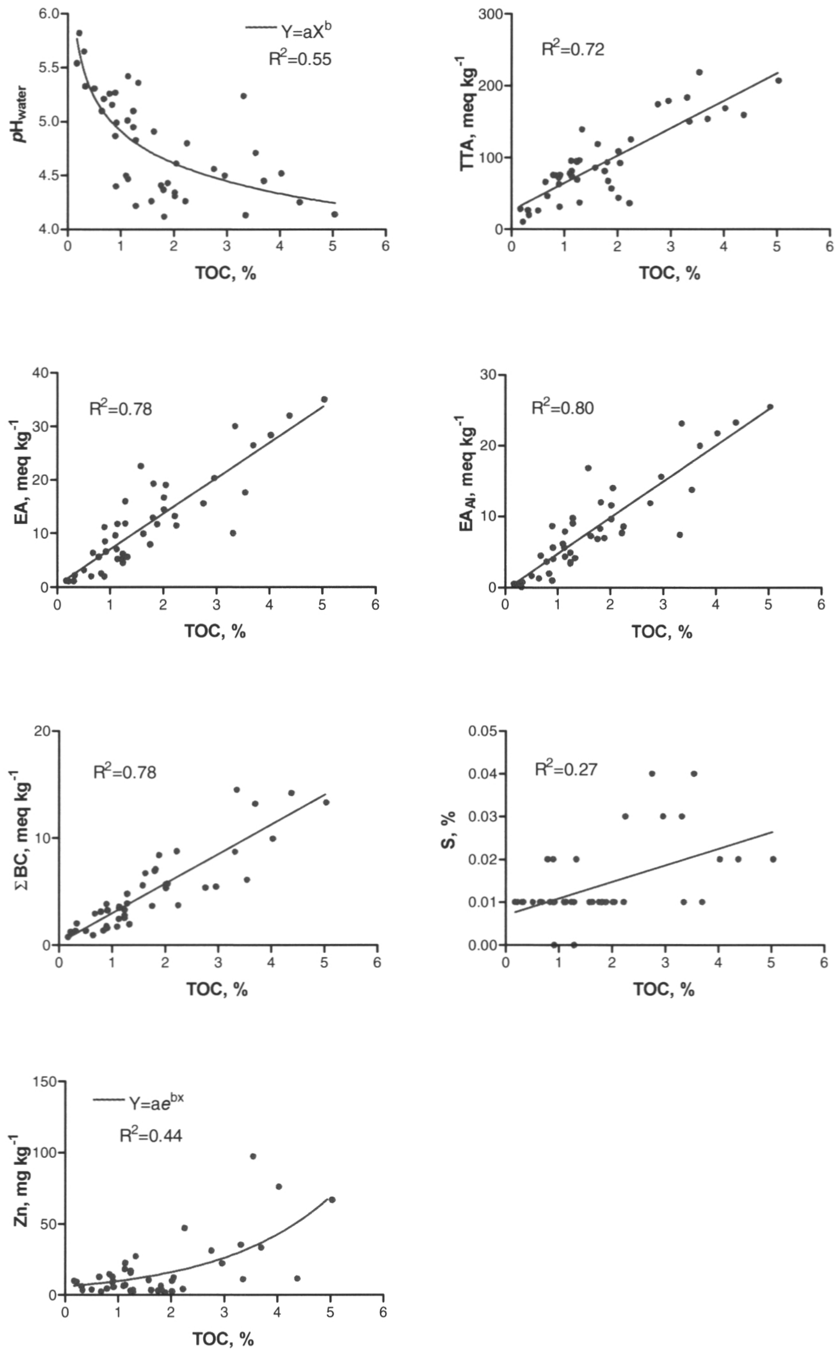

Figure 3. Dependence of soil pH_{water}, total titratable acidity (TTA), exchangeable titratable acidity (EA), exchangeable titratable aluminium acidity (EA_{Al}), sum of exchangeable base cations (ΣBC), total sulphur (S), and total (dry ash + HCl digested) zinc (Zn) concentrations of all soil samples on total organic carbon (TOC) concentrations. Solid lines are the simple linear regression models, except pH_{water}, and Zn.

Figure 3. *Vesi pHn sekä kokonaishappamuuden (TTA), vaihtuvan happamuuden (EA), vaihtuvan alumiini happamuuden (EA_{Al}), emäskationien summan (ΣBC), kokonaisrikin (S) ja kokonaissinkin (Zn, kuivapoltto+HCl uutto) pitoisuuksien riippuvuus orgaanisen hiilen (TOC) pitoisuudesta. Yhtenäinen viiva on saatu lineaarisesta regressiomallista, lukuunottamatta vesipH:ta ja Zn:ä.*

organic matter contents. Therefore, an important part of the dry ash concentration of these metals must come from the inorganic (mineral) fraction of the soil.

Conclusions

The main conclusions concerning the first round of the IM soil chemistry subprogramme are summarised as follows:

- Differences in soil chemistry were greater between catchments than between plots within catchment,
- Measures of soil acidification (pH, EA, EA_{Al}, TTA, CEC and BS) showed the soils were acidified, but not as to pose a threat to tree health in any of the catchments,
- Levels of soil acidification were not clearly related to acid deposition but were associated with soil organic matter contents,
- Soil dry ash concentrations of Cu, Zn, Pb and Cd showed no anomalies with published values,
- Concentrations of Pb in the humus layer were determined by Pb deposition.

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Appendix 1. Field based soil profile descripitions available.

Valkea-Kotinen (FI01) catchment

Horizon	cm	Description
Plot: FI01/4		
O*)	-5–0	Moist, slightly decomposed organic matter (moder); boundary abrupt and smooth.
EA	0–5	Grayish brown (10YR 5/2); moist, loose, stony sand; single grain structure; roots very few to few; boundary abrupt and wavy.
Bh	5–13	Strong brown (7.5YR 4/6); moist, loose, stony sandy loam; single grain structure; roots few to common; boundary gradual and wavy.
Bw	13–37	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; roots very few to few; boundary gradual and wavy.
BC(g)	37–60+	Light olive brown (2.5Y 5/4); moist, loose, very stony sandy loam; faint mottles; single grain structure; roots very few to few.
Plot: FI01/5		
O	-3–0	Moist, slightly decomposed organic matter (moder); boundary abrupt and smooth.
EA	0–3	Grayish brown (10YR 5/2); moist, loose, stony loamy sand mixed with charcoal particles; single grain structure; roots v. few to few; boundary abrupt and broken.
Bhs	3–10	Strong brown (7.5YR 4/6); moist, loose, stony loamy sand; single grain structure; roots common to many; boundary diffuse.
Bw	10–32	Dark yellowish brown (10YR 4/6); moist, loose, stony loamy sand; roots very few to few; boundary gradual and wavy.
BC(g)	32–60+	Light olive brown (2.5Y 5/6); moist, loose stong loamy sand; faint mottles; single grain structure; roots very few to few.
Plot: FI01/6		
O	-3–0	Dry, slightly decomposed organic matter (mor); boundary abrupt and smooth.
EA	0–2	Light brownish gray (10YR 6/2); dry, loose, stony sandy loam mixed with charcoal particles; single grain structure; roots very few to few; boundary abrupt and broken.
Bs	2–9	Dark yellowish brown (10YR 4/6); dry, loose, stony sandy loam; single grain structure; roots common to many; boundary diffuse.
B	9–30	Yellowish brown (10YR 5/8); dry, loose, very stony sandy loam; single grain structure; roots common to many; boundary gradual.
BC	30–42	Light olive brown (2.5Y 5/6); dry, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt.
R	42+	Bedrock
Plot: FI01/7		
O	-3–0	Moist, slightly decomposed organic matter (moder); boundary abrupt and wavy.
AE	0–2	Dark yellowish brown (10YR 3/4); moist, loose, stony sand; single grain structure; roots common to many; boundary diffuse and broken.
Bw	2–22	Strong brown (7.5YR 4/6); moist, loose, stony loamy sand; single grain structure; roots common to many; boundary gradual and wavy.
BC	22–62+	Yellowish brown (10YR 5/8); moist, loose, stony loamy sand; single grain structure; moderately firm; roots very few to few.

Appendix 1. Continues.

Hietajärvi (FI03) catchment

Horizon	cm	Description
Plot: FI03/1		
O	-4–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and wavy.
E	0–8	Light brownish gray (10YR 6/2); moist, loose, sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bs	8–26	Yellowish brown (10YR 5/6); moist, loose, sandy loam to loamy sand; roots common to many; boundary clear and wavy.
BC	26–41	Light yellowish brown (2.5Y 6/4) to olive brown (2.5Y 4/4); moist, loose, sandy loam; roots very few; boundary gradual and wavy.
2C(g)	41–80+	Olive (5Y 5/3); moist, moderately to very firm silt loam; platy (stratification) structure; faint mottles; roots very few.
Plot: FI03/2		
O	-4–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–8	Light gray (10YR 7/2); moist, moderately firm, stony loamy sand; single grain structure; roots common to many; boundary clear and wavy.
Bs	8–30	Yellowish brown (10YR 5/8); moist, moderately firm, stony loamy sand; single grain structure; roots common to many; boundary gradual and wavy.
C	30–70+	Light yellowish brown (2.5Y 6/4); moist, very firm, stony loamy sand; single grain structure; boulders abundant; roots none.
Plot: FI03/4		
O	-4–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–9	Light brownish gray (10YR 6/2); moist, moderately firm, gravelly loamy sand to sand; single grain structure; roots common to many; boundary clear and wavy.
Bs	9–21	Yellowish brown (10YR 5/8) to dark yellowish brown (10YR 4/6); moist, moderately firm, gravelly loamy sand to sand; single grain structure; roots common to many; boundary gradual and smooth.
BC(g)	21–35+	Light yellowish brown (2.5Y 6/4) to light olive brown (2.5Y 5/6); moist, moderately firm, gravelly loamy sand to sand; faint mottles; single grain structure; roots few to v. few; boundary gradual and wavy.
2C(g)	35–80+	Light yellowish brown (2.5Y 6/4); moist, moderately firm, gravelly sand; platy (stratification) structure; faint mottles; roots few to very few.
Plot: FI03/5		
O	-4–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–8	Light brownish gray (10YR 6/2); moist, moderately firm, loamy sand; single grain structure; roots common to many; boundary clear and wavy.
Bs	8–20	Yellowish brown (10YR 5/8); moist, moderately firm, loamy sand; single grain structure; roots common to many; boundary clear and wavy.
BC(g)	20–40	Light olive brown (2.5Y 5/6); moist, very firm, loamy sand; faint mottles; single grain structure; roots very few to few; boundary gradual and irregular.
C(g)	40–80+	Light yellowish brown (2.5Y 6/4); moist, very firm, loamy sand; faint mottles; single grain structure; roots very few to few.

Appendix 1. Continues.

Pesosjärvi (FI04) catchment

Horizon	cm	Description
Plot: FI04/1		
O	-6–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–8	Light gray (10YR 7/1); moist, moderately firm, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bhs	8–20	Dark brown (7.5YR 3/4); moist, moderately firm, stony sandy loam; single grain structure; roots very few to few; boundary clear and wavy.
BC(g)	20–51	Olive brown (2.5Y 4/); moist to wet (lower layer), moderately firm, stony sandy loam; faint mottles; single grain structure; roots verey few to few; boundary clear and smooth.
2C(g)	51–55+	Olive gray (5Y 4/2); moist, very firm, slightly stony sandy loam; faint mottles; single grain structure; roots none.
Plot: FI04/2		
O	-5–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–11	Light gray (10YR 7/1); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bs	11–18	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; single grain structure; roots common to many; boundary diffuse.
BC	18–36	Olive brown (2.5Y 4/4); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary clear and smooth.
C(g)	36–75+	Olive gray (5Y 4/2); moist, loose, stony sandy loam; faint mottles; single grain structure; roots none.
Plot: FI04/3		
O	-3–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–6	Light gray (10YR 7/1); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bs	6–17	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; single grain structure; roots common to many; boundary diffuse and wavy.
BC(g)	17–32	Olive brown (2.5Y 4/4); moist, loose, stony sandy loam; single grain structure; faint mottles; roots very few to few; boundary diffuse and wavy.
2C	32–61	Olive gray (5Y 5/2); moist, very firm, stony sandy loam; single grain structure; single grain structure; roots none.
Plot: FI04/4		
O	-7–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and wavy.
E	0–8	Light gray (10YR 7/1); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bs	8–30	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary gradual and smooth.
BC	30–44	Olive brown (2.5Y 4/4); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and smooth.
R	44+	Bedrock
Plot: FI04/5		
O	-6–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–8	Light brownish gray (2.5Y 6/2); moist, loose, stony sandy loam; single grain structure; roots common to many; boundary clear and wavy.
Bs	8–18	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary gradual and irregular.
B	18–48	Yellowish brown (10YR 5/4); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary clear and smooth.
BC	48–65+	Grayish brown (2.5Y 5/2); moist, loose, stony sandy loam; single grain structure; roots none.

Appendix 1. Continues.

Vuoskojärvi (FI05) catchment

Horizon	cm	Description
Plot: FI05/1		
O	-2–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–3	Grayish brown (10YR 5/2); moist, loose, stony sandy loam; single grain structure roots none; boundary clear and smooth.
Bs	3–11	Dark yellowish brown (10YR 4/6); moist, loose, stony sandy loam; single grain structure; roots common to many; boundary clear and smooth.
BC	11–30	Light olive brown (2.5Y 5/4); moist, loose, stony sandy loam; single grain structure; roots common to many; boundary gradual and smooth.
C	30–54+	Olive (5Y 5/3); moist, loose, stony sandy loam; single grain structure; roots none.
Plot: FI05/2		
O	-2–0	Moist, slightly decomposed organic matter (mor); boundary abrupt and smooth.
E	0–6	Grayish brown (10YR 5/2); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary abrupt and wavy.
Bsm	6–16	Dark brown (7.5YR 4/4); moist, weakly to moderately cemented discontinuous platy iron pan, stony sandy loam; roots very few to few; boundary abrupt and wavy.
Bs	16–38	Yellowish brown (10YR 5/6); moist, moderately firm, stony sandy loam; single grain structure; roots very few to few; boundary gradual and wavy.
C	38–56+	Olive (5Y 5/3); moist, moderately firm, stony sandy loam; single grain structure; roots none.
Plot: FI05/3		
O	-4–0	Moist, moderately decomposed organic matter (mor); boundary abrupt and smooth.
E	0–4	Brown (10YR 5/3); moist, loose, stony sandy loam; single grain structure; roots none; boundary clear and irregular.
Bs	4–11	Yellowish brown (10YR 5/6); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary gradual and smooth.
BC	11–42	Light olive brown (2.5Y 5/6); moist, loose, stony sandy loam; single grain structure; roots none; boundary gradual and wavy.
C(g)	42–65+	Olive (5Y 4/4); moist, loose, stony loamy sand; single grain structure; faint mottles; roots none.
Plot: FI05/4		
O	-2–0	Moist, moderately decomposed organic matter (mor); boundary abrupt and smooth.
E	0–3	Grayish brown (10YR 5/2); moist, loose, stony sandy loam; single grain structure; roots none; boundary abrupt and broken.
Bhs	3–12	Dark yellowish brown (10YR 3/4); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary clear and wavy.
C	12–62	Olive (5Y 5/3); moist, loose, stony sandy loam; single grain structure; roots very few to few; boundary clear and wavy.
R	62+	Bedrock.

*) All O horizons refer to the Of or Of+Oh layers but do not include Ol (litter) layers.

Appendix 2. Bulk density values by layer for each plot.

Plot	Layer cm	Bulk Density $g\ dm^{-3}$	Actual, Surrogate or Extrapolation [§]
Valkea-Kotinen			
1[†]	0–5	69	Actual
	5–10	76	-”-
	10–20	86	-”-
	20–40	106	-”-
2[†]	0–5	74	Actual
	5–10	106	-”-
	10–20	122	-”-
	20–40	152	-”-
3	Humus	166	Actual
	0–5	904	Surrogate; plot 7
	5–20	1062	-”-
4	Humus	140	Actual
	0–5	958	Extrapolation
	5–20	1249	-”-
5	Humus	131	Actual
	0–5	1012	Extrapolation
	5–20	1238	-”-
6	Humus	143	Actual
	0–5	717	Extrapolation
	5–20	907	-”-
7	Humus	134	Actual
	0–5	904	Extrapolation
	5–20	1062	-”-
Hietajärvi			
1	Humus	94	Actual
	0–5	1044	-”-
	5–20	1000	-”-
	20–40	1098	-”-
2	Humus	122	Actual
	0–5	1267	-”-
	5–20	1416	-”-
4	Humus	102	Actual
	0–5 *	1124	-”-
	5–20	1283	-”-
	20–40	1450	-”-
5	Humus	123	Actual
	0–5	1200	-”-
	5–20	1227	-”-
	20–40	1559	-”-

Plot	Layer cm	Bulk Density $g\ dm^{-3}$	Actual, Surrogate or Extrapolation [§]
Pesosjärvi			
1	Humus	124	Actual
	0–5		Not available
	5–20		-”-
	20–40		-”-
2	Humus	109	Actual
	0–5	1436	Extrapolation
	5–20	1338	-”-
	20–40	1496	-”-
3	Humus	112	Actual
	0–5	1265	Extrapolation
	5–20	1387	-”-
	20–40	1679	-”-
4	Humus	110	Actual
	0–5	1406	Extrapolation
	5–20	1222	-”-
	20–40	1370	-”-
5	Humus	106	Actual
	0–5		Not available
	5–20		-”-
Vuoskojärvi			
1	Humus	144	Actual
	0–5	998	Surrogate; plot 3
	5–20	1261	-”-
2	Humus	121	Actual
	0–5	880	Extrapolation
	5–20	1046	-”-
3	Humus	118	Actual
	0–5	998	-”-
	5–20	1261	-”-
4	Humus	152	Actual
	0–5	1272	-”-
	5–20	1152	-”-

[§] Actual determinations from layer; extrapolation to layers from determinations made from volumetric samples of soil horizons from the same plot, or surrogate values from another plot.
[†] Organic soil plots, n = 1.
* n = 3

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