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Forest Condition Monitoring in Finland

National Report 2002–2005

Edited by Päivi Merilä, Tuire Kilponen and John Derome

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Abstract
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, 1994 and 2003. In Finland, the Finnish Forest Research Institute (Metla) is responsible for carrying out annual forest vitality and health surveys on a 610 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 under the Finnish Forest Focus/ICP Forests programmes during 2002 to 2004/5 as well as the results of other studies of forest condition in Finland.

Suomi on vuodesta 1985 lähtien osallistunut yleiseurooppalaiseen metsien terveydentilan seurantaohjelmaan (ICP metsäohjelma), joka perustuu kansainväliseen ilman epäpuhtauksien kaukokulkeutumista koskevaan sopimukseen (CLRTAP). Euroopan Unionin jäsenmaissa metsien terveydentilan seuranta pohjautuu vuosina 1986, 1994 ja 2003 vahvistettuihin säädöksiin. Metsäntutkimuslaitos (Metla) inventoi puiden kunnon vuosittain kansainvälisesti sovituin menetelmin 610:llä pysyvällä havaintoalalla (taso I, laaja-alainen seuranta). Metsien kunnon, ilman epäpuhtauksien sekä muiden stressitekijöiden välisiä vuorosuhteita tutkitaan 31 metsikössä eri puolilla Suomea (taso II, intensiivinen seuranta). Tässä raportissa esitetään ICP metsäohjelman Suomea koskevia tuloksia vuosilta 2002–2004/5 sekä muiden Suomen metsien terveydentilaa käsittelevien tutkimusten tuloksia.

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acidification, air pollution, biodiversity, biotic and abiotic forest damage, boreal forests, coverage, crown condition, defoliation, deposition, discolouration, forest health monitoring, forest pests, fungal diseases, forest soil, grasses, heavy metals, insect damage, litterfall, mass balance budgets, meteorology, monitoring, moose damage, national forest inventory, needle chemistry, nitrogen, Norway spruce, ozone, phenology, Scots pine, soil solution, sulphur, throughfall, understorey vegetation, windthrows

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Contents

Preface – *Alkusanat* 6

Summary 7

Yhteenveto 9

1 **Forest condition monitoring under the UN/ECE and EC programmes in Finland** 11
Yleiseurooppalainen metsien terveydentilan seuranta (YK-ECE/EU) Suomessa
John Derome, Martti Lindgren, Päivi Merilä, Egbert Beuker & Pekka Nöjd

2 **Forest condition in national systematic network (Forest Focus/ICP Forests, Level I) in 2002–2005** 21
Metsien terveydentila systemaattisen havaintoalaverkoston aloilla vuosina 2002–2005 (Forest Focus/ICP metsäohjelma, taso I)

2.1 **Results of the national crown condition survey** 21
Valtakunnallisen latvuskunnon seurannan tulokset
Martti Lindgren, Seppo Nevalainen & Antti Pouttu

2.2 **Biotic and abiotic damage on the Level I network** 32
Bioottiset ja abioottiset tuhot tason I havaintoaloilla
Seppo Nevalainen, Martti Lindgren & Antti Pouttu

3 **Results of the intensive monitoring of forest ecosystems (Forest Focus/ICP Forests, Level II)** 41
Metsien intensiiviseurannan tuloksia (Forest Focus/ICP metsäohjelma, taso II)

3.1 **Crown condition on the Level II network 2001–2004** 41
Puiden latvuskunto tason II havaintoaloilla vuosina 2001–2004
Martti Lindgren, Seppo Nevalainen & Antti Pouttu

3.2 **Needle chemistry on the intensive monitoring plots 1995–2003** 46
Neulasten kemiallinen koostumus intensiviseurannan havaintoaloilla vuosina 1995–2003
Päivi Merilä

3.3 **Litterfall production on 14 Level II plots during 1996–2003** 63
Karikesato 14 havaintoalalla (taso II) vuosina 1996–2003
Liisa Ukonmaanaho

3.4 **Understorey vegetation on the Level II plots during 1998–2004** 69
Aluskasvillisuus tason II havaintoaloilla vuosina 1998–2004
Maija Salemaa & Leena Hamberg

3.5 **Open area bulk deposition and stand throughfall in Finland during 2001–2004** 81
Avoimen paikan ja metsikkösadannan laskeuma Suomessa vuosina 2001–2004
Antti-Jussi Lindroos, John Derome & Kirsti Derome

3.6 Soil percolation water quality during 2001–2004 on 11 Level II plots **93**
Vajoveden kemiallinen koostumus 11 havaintoalalla (taso II) vuosina 2001–2004
John Derome, Antti-Jussi Lindroos & Kirsti Derome

3.7 Phenological assessments on the intensive monitoring plots **99**
Fenologinen seuranta intensiiviseurannan havaintoaloilla
Boy Possen & Egbert Beuker

3.8 Assessment of air quality on Level II plots **112**
Ilman laadun seuranta tason II havaintoaloilla
Kirsti Derome

4 Results of other studies related to forest damages and long-term monitoring **120**
Muiden ympäristö- ja metsätuhoseurantojen ja -tutkimusten tuloksia

4.1 The use of light microscopy to assess impact of ozone stress on Norway spruce needles in the field **120**
Otsonivaurioiden havainnointi kuusen neulasista valomikroskooppisesti
Sirkka Sutinen & Minna Kivimäenpää

4.2 Pest and disease situation during 2002–2005 according to the Forest Damage Advisory Service **130**
Metsätuhot vuosina 2002–2005 metsätuhotietopalvelun saamien tietojen perusteella
Antti Pouttu, Katriina Lipponen, Seppo Nevalainen, Martti Lindgren, Arja Lilja, Marja Poteri, Seppo Neuvonen, Heikki Henttonen & Jarkko Hantula

4.3 Forest damage observed in the 10th National Forest Inventory of Finland during 2004–2005 **136**
Valtakunnan metsien 10. inventoinnissa vuosina 2004–2005 havaitut tuhot
Kari T. Korhonen & Seppo Nevalainen

4.4 Hietajärvi – long-term results from a Finnish ICP Integrated Monitoring (IM) catchment **147**
Hietajärvi – pitkäaikaisen seurannan tuloksia ICP Yhdennetyn ympäristön seurannan (YYS) valuma-alueelta
Mike Starr, Martin Forsius, Tarja Hatakka, Riitta Niinioja, Tuija Ruoho-Airola, Liisa Ukonmaanaho & Jussi Vuorenmaa

Preface

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. Since 2003 the monitoring programme has been carried out under the EU Forest Focus regulation. In Finland, the Finnish Forest Research Institute (Metla) is responsible for carrying out annual forest vitality and health surveys on a 610 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 under the Finnish Forest Focus/ICP Forests programmes during 2002 to 2004/5 as well as the results of other studies of forest condition in Finland.

All the researchers involved in Metla's Forest Monitoring programme have participated to a varying extent in writing this report. However, the work would not have been possible without the skilful and highly motivated support provided by the field, laboratory and office personnel at Metla.

Alkusanat

Suomi on vuodesta 1985 lähtien osallistunut yleiseurooppalaiseen metsien terveydentilan seurantaohjelmaan (ICP metsäohjelma), joka perustuu kansainväliseen ilman epäpuhtauksien kaukokulkeutumista koskevaan sopimukseen (CLRTAP). Euroopan Unionin jäsenmaissa metsien terveydentilan seuranta pohjautuu vuosina 1986, 1994 vahvistetuihin säädöksiin ja niihin myöhemmin tehtyihin täydennyksiin. Vuodesta 2003 seurantaohjelma on toteutettu EU:n Forest Focus -säädöksen alaisuudessa. Metsäntutkimuslaitos (Metla) inventoi puiden kunnon vuosittain kansainvälisesti sovituin menetelmin 610 pysyvällä havaintoalalla (taso I, laaja-alainen seuranta). Metsien kunnon, ilman epäpuhtauksien sekä muiden stressitekijöiden välisiä vuorosuhteita tutkitaan 31 metsikössä eri puolilla Suomea (taso II, intensiivinen seuranta). Tässä raportissa esitetään ICP metsäohjelman Suomea koskevia tuloksia vuosilta 2002–2004/5 sekä muiden Suomen metsien terveydentilaa käsittelevien tutkimusten tuloksia.

Kaikki metsien terveydentilan seurantaohjelmassa työskentelevät tutkijat ovat osallistuneet tämän raportin laadintaan. Haluamme osoittaa kiitoksemme myös Metlan maasto-, laboratorio- ja toimistohenkilöstölle, jonka ammattitaitoinen työpanos on seurantaohjelman menestykselliselle toteuttamiselle korvaamattoman tärkeää.

Summary

There were no notable changes in the average defoliation level of the tree species (Norway spruce, Scots pine, broadleaves, mainly birch) on the Level I extensive monitoring network during 2002–2005. The average tree-specific degree of defoliation for the period 2002–2005 on mineral soil sites was 9.4% in pine, 18.3% in spruce and 11.7% in broadleaves. In 2004, the plots located on peatlands were included in the survey for the first time and the average defoliation was 8.2% in pine, 17.0% in spruce and 9.3% in broadleaves. The relatively high stand age, weather and climatic factors, and fungal and insect damage were the main factors affecting defoliation. No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 2002–2005.

During the period 2002–2005, 33.4% of the pines, 36.5% of the spruces and 40.1% of the broadleaves on the Level I network showed signs of biotic or abiotic damage. Most of the observed damage was slight, i.e. it had no effect on the vitality of the trees. There was considerable variation in the occurrence of individual damaging agents between the years: e.g. the increase in insect (*Tomicus* sp.) damage in 2003, the increase in damage caused by *Gremmeniella abietina* in pine in 2004, and needle rust *Chrysomyxa ledi* in 2005 in spruce. Birch rust and leaf anthracnose were common on birches in 2004.

The air quality (SO_2, NO_2, O_3, NH_3) at a number of Level II plots was monitored using passive samplers during 2000–2001 and in 2004. The SO_2 and NO_2 concentrations were clearly higher in wintertime, and the O_3 concentration reached a maximum in early spring. The seasonal patterns were similar in different parts of the country. There was no clear difference between the locations in the O_3 concentrations, but the SO_2 and NO_2 concentrations were higher at the sites in south-eastern Finland close to the Russian border, and lower at the site in Lapland.

The annual nitrogen and sulphur deposition in southern Finland was clearly higher than in northern Finland. Sulphate deposition in the open and in stand throughfall (8 pine plots, 8 spruce plots) during 2001–2004 was clearly lower than that measured in earlier years (monitoring started in 1996), especially on the plots in southern Finland. There was no corresponding decrease in the deposition of nitrogen compounds in either bulk deposition or in stand throughfall. The reduction in sulphur deposition was reflected as a slight decrease in foliar sulphur concentrations in spruce and pine during the same period.

Stand litterfall was monitored on 8 spruce plots and 6 pine Level II plots during 1996–2003. The annual litterfall production varied considerably between the years and plots. The annual amount of litterfall varied strongly between the years and between the plots. The mean annual litterfall on the spruce plots ranged from 61 to 503 g m^{-2}, and on the pine plots from 123 to 342 g m^{-2}. Needle litterfall accounted for 29% to 87% of the total litterfall on the spruce plots and 52% to 69% on the pine plots. There was a clear peak in litterfall on the pine plots in the autumn, while on the spruce plots it was more evenly distributed throughout the year.

A complete vegetation survey of the 31 Level II plots was carried out in 2003. The vegetation on the mineral soil plots was primarily determined by the site fertility gradient, combined with the variation in soil moisture and location along the south-north axis. The number of vascular plant species decreased towards the north on both the pine and spruce plots. In contrast, the number of bryophyte and lichen species increased from south to north on the pine plots, but not on the spruce plots. The cover percentages of the understorey plant species remained relatively constant on six

of the Level II plots that were surveyed every year during 1998–2003. The largest annual changes in the coverage of vascular plants and bryophytes were 10–15%-units. The coverage of dwarf shrubs increased on two of the southern plots, and that of bryophytes correspondingly decreased. Between-year variation in the amount of precipitation and needle/leaf litter appeared to regulate the coverage of the bryophyte layer.

Phenological monitoring has been carried out on four Level II plots since 2000. The trees on the northern plots flushed later than those on the southern plots, but did so at a lower effective temperature sum. Spruce flushed earlier than pine. No relationship was found between growth onset and any of the weather or climatic parameters, indicating that a 5-year time series is too short to predict shifts in growth onset.

A study was carried out on the use of light microscopy in the diagnosis of ozone-induced symptoms in spruce needles. Samples were collected from the three youngest needle age classes in two stands growing on sites of different soil fertility. Light microscopy revealed ozone-specific symptoms: decreased chloroplast size with electron dense stroma advancing gradually from the outer to inner cell layers. The symptoms were expressed as ozone syndrome indexes at the needle age class, tree and stand levels. The index value was the highest on the less fertile site. The study showed that light microscopy can be used for quantitative diagnosis of the impact of ozone stress on spruce in the field.

The report includes two summaries of biotic and abiotic forest damage based on the annual forest damage reports compiled for the Ministry of Agriculture and Forestry (available in Finnish in the Internet) and on the results of stand level damage assessments made on the 23611 sample plots in the 10th National Forest Inventory (NFI) during 2004–2005. The results of NFI show that the total area of all types of damage was 5.314 mill. ha, or 26.3% of the total forest land area. Abiotic factors and fungi were the most common groups of causal agents in the10th NFI data. The most frequently identified causes of damage in all stands were snow and moose. Resin-top disease and Scleroderris canker caused by *Gremmeniella abietina* are other commonly identified causal agents in pine-dominated forests. Rot fungi are the most frequent causes of damage in spruce-dominated forests. Annosum root rot (*Heterobasidion* sp.) was found in almost 100 000 ha of spruce forests. Other decay fungi were the most frequent causes of damage in deciduous stands. Compared to the previous inventory (9th NFI), the area of forest showing damage symptoms appears to have increased by 1.8%-units. The damage caused by moose has increased the most, especially in pine stands.

The results of integrated monitoring (ICP IM) activities at the Hietajärvi catchment in eastern Finland are presented at the end of the report. One of the Level II plots is also located in the catchment. The long-term monitoring data are used to evaluate the effectiveness of international agreements on the reduction of sulphur, nitrogen and heavy metals emissions. The data have also been used in numerous dynamic modelling studies on the impact of air pollution abatement policy and the future recovery of forest ecosystems. The data are being used to an increasing extent to assess the impacts of climate change on carbon cycling in catchments located in the boreal zone. The results clearly demonstrate the importance of long-term, multidisciplinary monitoring programmes.

Yhteenveto

Metsien terveydentilan laaja-alaisen seurannan (taso I) mukaan kaikkien puulajien keskimääräinen harsuuntumisaste on viime vuosina pysynyt melko vakaana. Kivennäismailla kasvavien mäntyjen keskimääräinen harsuuntumisaste jaksolla 2002–2005 oli 9,4 %, kuusien 18,3 % ja lehtipuiden (pääasiassa koivuja) 11,7 %. Vuonna 2004 otettiin seurantaan mukaan myös turvemaiden näytealoja ja niillä mäntyjen keskimääräinen harsuuntumisaste oli 8,2 %, kuusien 17 % ja lehtipuiden 9,3 %. Harsuuntuminen johtuu Suomessa pääasiassa puuston ikääntymisestä, erilaisista epäedullisista ilmasto- ja säätekijöistä sekä sieni- ja hyönteistuhoista. Koko maata tarkasteltaessa ei havaittu yhteyttä ilman epäpuhtauksien ja neulaskadon välillä vuosina 2002–2005.

Tutkimusjakson (2002–2005) aikana metsien terveydentilan laaja-alaisessa seurannassa (taso I) havaittiin bioottisia tai abioottisia tuhoja 33,4 %:ssa mäntyhavaintopuita, 36,5 %:ssa kuusia ja 40,1 %:ssa lehtipuita. Suurin osa havaituista tuhoista oli lieviä eli ei vähentänyt puiden elinvoimaisuutta. Vuosien välillä oli kuitenkin suuria eroja eri tuhonaiheuttajien esiintymisessä, esim. männyllä hyönteistuhot (ytimennävertäjätuhot) lisääntyivät vuonna 2003 ja versosurmatuhot 2004. Kuusella suopursuruoste yleistyi vuonna 2005. Koivuilla koivunruoste ja erilaiset lehtilaikut olivat yleisiä vuonna 2004.

Raportissa esitetään passiivikeräimillä saatuja tuloksia ilman laadusta muutamilla Metsien intensiiviseurannan (taso II) aloilla vuosilta 2000–2001 ja 2004. Rikkidioksidi- (SO_2) ja typpidioksidi- (NO_2) pitoisuudet olivat korkeimmat talviaikana, kun taas otsonipitoisuudet olivat korkeimmillaan aikaisin keväällä. Vuodenaikaisvaihtelu oli samansuuntaista kaikilla mittauspaikoilla. Otsonipitoisuuksissa ei havaittu selviä eroja eri mittauspaikkojen välillä, sen sijaan SO_2- ja NO_2-pitoisuudet olivat korkeimpia Kaakkois-Suomessa, lähellä Venäjän rajaa olevilla mittauspaikoilla ja matalimpia Lapissa sijaitsevilla mittauspaikoilla.

Avoimen paikan ja metsikkösadannan (8 mänty- ja 8 kuusialaa) laskeumamittausten mukaan kokonaistypen ja sulfaattirikin (SO_4-S) keskiarvolaskeumat olivat selvästi suurempia Etelä-Suomessa verrattuna Pohjois-Suomeen vuosina 2001–2004. Verrattaessa vuosien 2001–2004 tuloksia aikaisempiin vuosiin (seuranta alkoi 1996) havaittiin, että avoimen paikan ja metsikkösadannan rikkilaskeuma on alentunut etenkin Etelä-Suomen havaintoaloilla. Vastaavaa laskeuman vähentymistä ei ollut havaittavissa typen yhdisteille avoimella paikalla tai metsikkösadannassa. Rikkilaskeumassa tapahtunut lasku näkyy lievästi laskevana trendinä myös neulasten rikkipitoisuudessa. Muutoin puiden ravinnetilassa ei ole havaintojakson aikana tapahtunut jyrkkiä muutoksia.

Karikesatoa on seurattu intensiiviseurannan kahdeksalla kuusi- ja kuudella mäntyalalla vuosina 1996–2003. Karikesato vaihteli runsaasti sekä vuosien että näytealojen välillä. Kuusikoissa keskimääräinen vuosittainen karikesato vaihteli 61–503 g m^{-2}, vastaavasti männiköissä 123–342 g m^{-2}. Neulaskarikkeen osuus kokonaiskarikesadosta oli kuusialoilla 29–87 % ja mäntyaloilla 52–69 %. Männiköissä karikesadossa esiintyi selkeä vuodenaikaisvaihtelu määrän ollessa suurimmillaan syksyisin, sen sijaan kuusikoissa karikesato oli tasaisemmin jakautunut ympäri vuoden.

Raportissa esitetään yhteenveto intensiiviseuranta-alojen toisesta aluskasvillisuusinventoinnista (v. 2003). Kivennäismailla sijaitsevien havaintoalojen aineistossa tärkein kasvillisuuden rakennetta kuvaava vaihtelusuunta ilmensi kasvupaikan ravinteisuutta, maaperän kosteutta ja koealan sijaintia etelä-pohjoissuunnassa. Putkilokasvilajien lukumäärä vähentyi pohjoiseen päin sekä männiköissä että kuusikoissa. Toisaalta sammal- ja jäkälälajien lukumäärä lisääntyi männi-

köissä pohjoiseen päin, mutta vastaavaa vaihtelua ei havaittu kuusikoissa. Kasvilajien peittävyysprosentit ovat pysyneet suhteellisen vakaina kuudella vuosittain tutkitulla taso II:n havaintoalalla seurantajakson 1998–2003 aikana; suurimmillaan muutokset ovat olleet 10–15 %-yksikköä. Varpujen peittävyydet lisääntyivät kahdella eteläisellä havaintoalalla, mutta samanaikaisesti sammalten peittävyys pieneni. Vuosien väliset erot sade- ja neulas/lehtikarikkeen määrissä näyttivät säätelevän sammalkerroksen peittävyyttä.

Fenologista havainnointia on tehty neljällä intensiiviseurannan havaintoalalla vuodesta 2000 lähtien. Kullakin havaintoalalla on seurattu kasvuunlähtöä, ts. silmujen puhkeamista. Pohjoisilla havaintoaloilla silmut puhkeavat selvästi myöhemmin kuin etelässä, mutta silmujen puhjetessa lämpösummakertymä on pohjoisessa alhaisempi kuin etelässä. Kasvuunlähtö tapahtuu aikaisemmin kuusella kuin männyllä. Kasvuunlähdön ja säätekijöiden välillä ei havaittu merkitsevää yhteisvaihtelua, mikä osoittaa, että viiden vuoden aikasarja on liian lyhyt kasvuunlähdon ennustamiseksi.

Raportissa julkaistaan tulokset erillistutkimuksesta, jossa tutkittiin otsonin aiheuttamiksi tunnettuja oireita valomikroskooppisesti kuusen neulasista. Neulasnäytteet kerättiin kahdesta ravinnetasoltaan erilaisesta metsiköstä, kuusten kolmesta nuorimmasta neulasvuosikerrasta. Valomikroskooppisesti voitiin todeta otsonille tyypilliset oireet: kloroplastin koon pieneneminen ja samanaikainen strooman tummuminen sekä oireiston eteneminen asteittain uloimmista solukerroksista sisempiin kerroksiin. Oireet esitettiin otsonioireindeksinä neulasvuosikerta-, puu- ja metsikkötasoille. Indeksi oli korkein ravinteisuudeltaan alhaisemmalla kasvupaikalla. Tutkimus osoitti, että valomikroskopia soveltuu kvantitatiiviseen otsonioireiden havainnointiin havupuilla kenttäolosuhteissa.

Lisäksi esitetään kaksi metsien abioottisia ja bioottisia tuhoja koskevaa katsausta, joista toinen perustuu maa- ja metsätalousministeriölle toimitettuihin metsätuhoraportteihin vuosilta 2002–2005 (http://www.metla.fi/metinfo/metsienterveys) ja toinen Valtakunnan metsien 10. inventoinnin (10. VMI) kuviokohtaisiin tuhotuloksiin 23 611 koealalta vuosilta 2004–2005. VMI-aineistossa tuhoja esiintyi kaikkiaan 5,314 milj. hehtaarilla tai 26,3 % metsämaan pinta-alasta. Abioottiset tekijät ja sienet ovat tärkeimpiä tuhonaiheuttajaryhmiä, ja lumi- ja hirvituhot ovat yleisimpiä tuhonaiheuttajia koko aineistossa. Tervasroso ja versosurma ovat mäntyvaltaisten metsien yleisimmät tunnistetut tuhonaiheuttajat. Lahottajasienet ovat puolestaan yleisimpiä kuusivaltaisissa metsissä. Juurikäämpien aiheuttamaa lahoa tavattiin lähes 100 000 ha:lla kuusikoissa. Lahottajasienet ovat yleisimpiä tuhonaiheuttajia myös lehtipuuvaltaisissa metsissä. Edelliseen inventointiin (9. VMI) verrattuna sellaisten metsiköiden pinta-ala, joissa tuhoja esiintyy, näyttää lisääntyneen 1,8 %-yksiköllä. Erityisesti hirvituhot ovat lisääntyneet männiköissä.

Lopuksi raportissa esitetään tuloksia Itä-Suomessa sijaitsevalta Hietajärven valuma-alueelta, joka kuuluu Ympäristön yhdennetyn seurannan (YYS) havaintoaloihin. Myös Metsien intensiiviseurannan (taso II) Lieksan havaintoala sijaitsee kyseisellä valuma-alueella. Alueelta on kerätty seuranta-aineistoa, jonka avulla voidaan arvioida kansainvälisten rikki-, typpi- ja raskasmetallipäästöjen rajoittamista koskevien sopimusten toteutumista. Tämän lisäksi aineistoa on hyödynnetty lukuisissa mallinnustehtävissä, joiden tarkoituksena on ollut kuvata päästöjen vähentämistoimien vaikutuksia ja ekosysteemin toipumiskehitystä. Aineistoa käytetään yhä enemmän myös arvioitaessa ilmastomuutoksen vaikutuksia valuma-alueiden hiilen kiertoon boreaalisessa vyöhykkeessä. Tulokset osoittavat pitkäaikaisen ja monitieteisen yhdennetyn seurannan tärkeyden.

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

Yleiseurooppalainen metsien terveydentilan seuranta (YK-ECE/EU) 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 co-financing of the assessments in EU member states was provided through Council Regulation (EEC) No. 3528/86. Since then, co-financing has also been available under a number of regulations such as the Forest Focus regulation (2003–2006). At the present time, the monitoring of forest condition and the effect of stress factors on ecosystem functioning is being carried out in 38 participating countries within these ICP Forests and EU programmes.

Large-scale, extensive monitoring takes place on a network of ca. 6,000 plots arranged on a systematic grid (16 x 16 km) covering the whole of Europe. This Level I network provides an annual picture of large-scale trends in crown condition (defoliation, discoloration, abiotic and biotic damage) at the European level. It also offers the possibility to investigate relationships between stress factors and forest condition. 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, and EU co-funding was extended to cover these activities. Approximately 800 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.

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. 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 ICP Forests and EU programmes in Finland. The Parkano Research Unit of the Finnish Forest Research Institute is responsible for the tasks of the National Focal Centre, and Dr. John Derome has acted as the national coordinator since 2004.

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 500 mineral soil and 100 peatland plots selected from the permanent sample plot network of the 8th National Forest Inventory, established in 1985 (Fig. 1). The systematic network used in the annual crown condition survey has been designed to provide information at the national level about crown condition and its variation in background areas. A number of parameters are measured on the trees. The most important variables used to describe crown condition in Finland are relative leaf- and needle-loss (i.e. defoliation), discoloration and abiotic and biotic damage of the crown. The distribution of tree species assessed in the 2005 inventory was ca. 56% Scots pine (*Pinus sylvestris*), ca. 27% Norway spruce (*Picea abies*), and ca. 17% birch (*Betula spp.*). In addition, a soil survey was carried out on 338 plots in 1986–1987, and an additional 104 plots in 1995. Needle samples were collected for elemental analysis on 160 plots (98 pine plots, 62 spruce plots) during 1987–1989 (Raitio 1994), and on ca. 30 plots (16–18 pine, 12–14 spruce) annually since 1992 (Luyssaert et al. 2005).

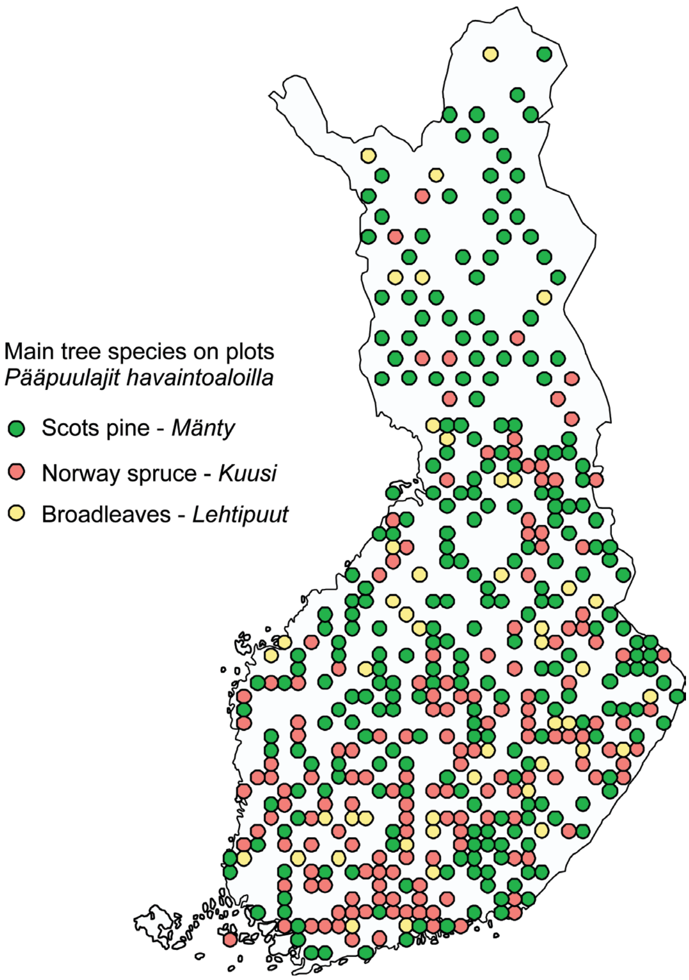

Figure 1. The network of the annual, largescale crown condition survey (Level I) in Finland.
Kuva 1. Laajamittainen metsien tilan seuranta (taso I), näytealaverkko Suomessa.

Intensive and continuous monitoring of forest ecosystems – Level II

Monitoring plot 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 are located in Scots pine stands and 14 in Norway spruce stands. All the plots, except for the four Integrated

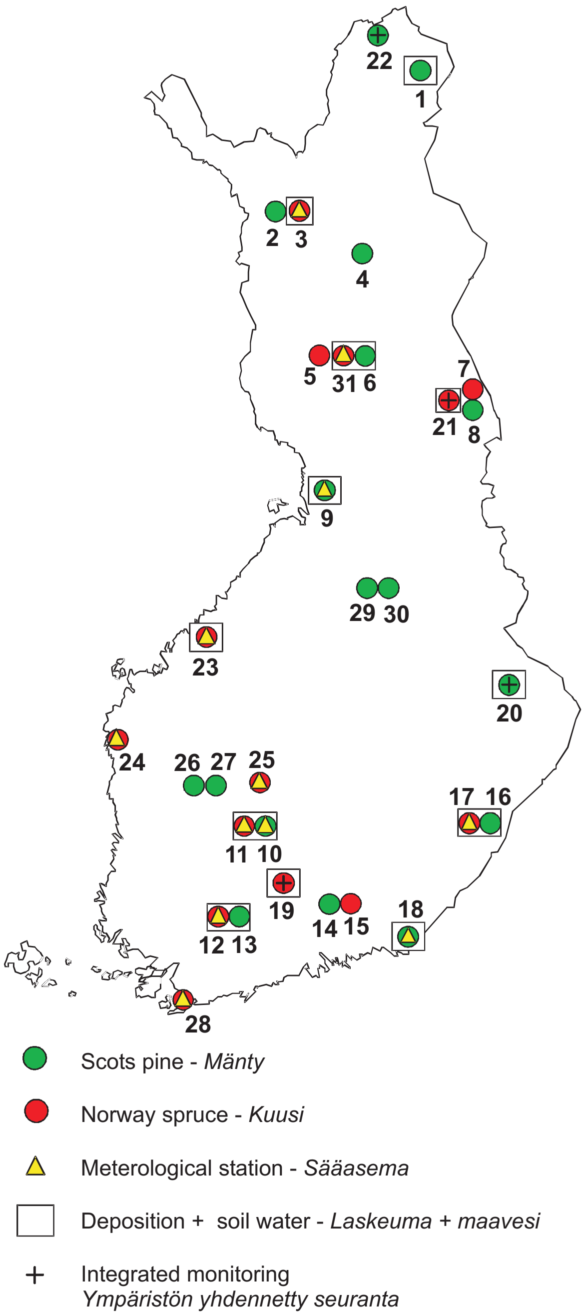

Figure 2. The intensive monitoring network of forest ecosystems in Finland.
Kuva 2. Metsäekosysteemien intensiiviseurannan havaintoalat Suomessa.

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 – *Alkuperäkoe*
Pim = Scots pine, Integrated Monitoring *Mänty, ympäristön yhdennetty seuranta*
Sim = Norway spruce, Integrated Monitoring *Kuusi, ympäristön yhdennetty seuranta*
fer = Fertilization – *Lannoitettu*

Monitoring (ICP-IM) plots, are located in commercially managed 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 intensive monitoring plots were established on drained peatland. The sites were originally wet, sparsely stocked pine mires that represent the most typical drained peatland site types in Finland. The peat in these site types has a low mineral nutrient status, but usually relatively high nitrogen reserves. As this may result in an unbalanced nutrient status in the tree stand, two of the four plots have been fertilized. The four plots are located at two locations in Finland, with a pair of unfertilized and fertilized plots at each location.

Three of the plots were established in long-term spruce provenience trials.

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

The observation plots proper consist of three sub-plots and a surrounding mantle (sub-plot 4) (Fig. 3). The sub-plots are square in shape (30 x 30 m). A 5–10 m wide strip has been left between the sub-plots for possible future use in special studies and for additional sampling. Sampling methods that may have a detrimental, long-term effect on the soil or stand, e.g. soil sampling, deposition and soil water collection, needle and litter sampling etc., are concentrated on one sub-plot. One of the other two sub-plots is reserved for vegetation studies, and the other for tree growth measurements.

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

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.

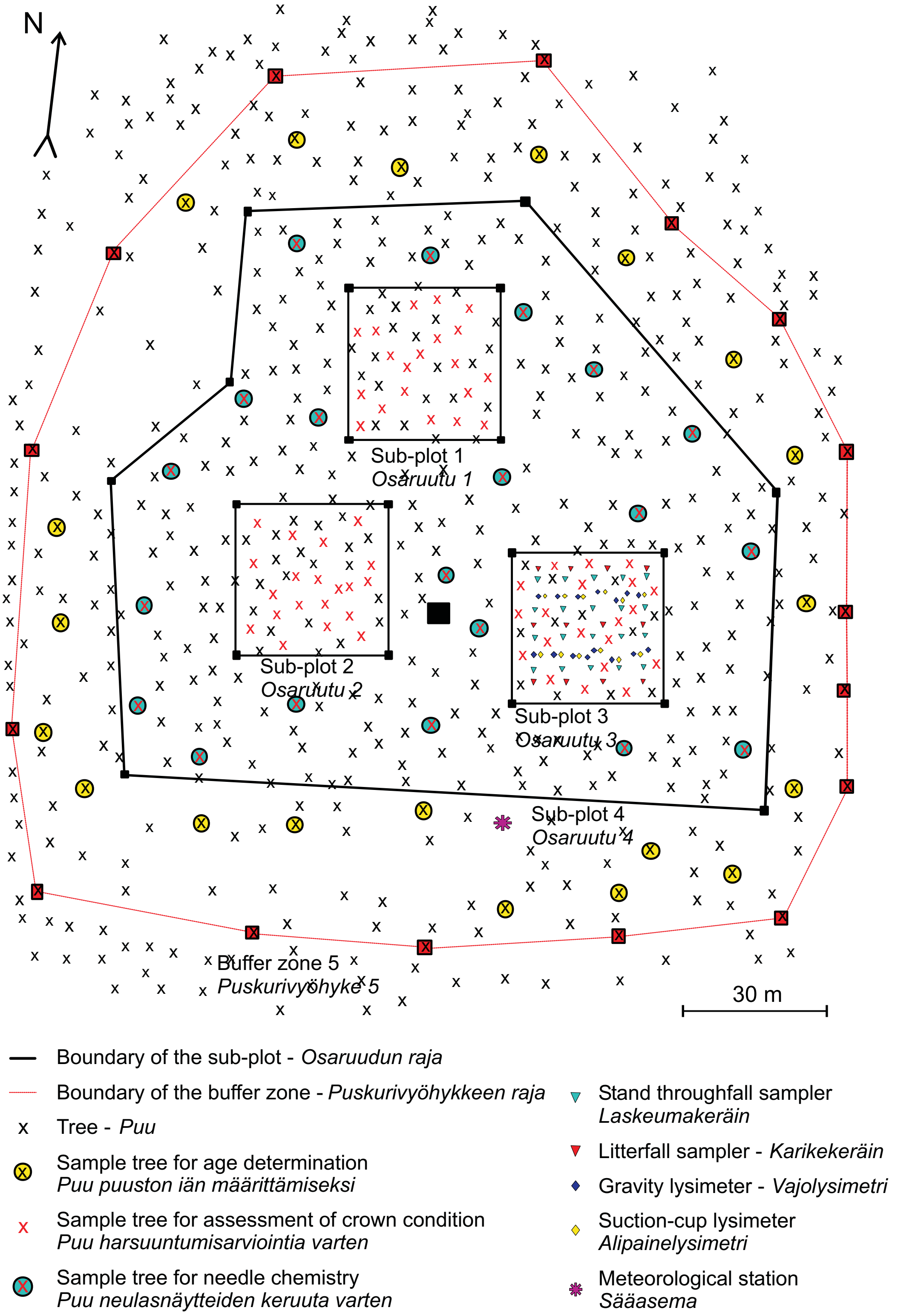

Figure 3. The design of the observation plot and location of the sub-plots.
Kuva 3. Kaavio metsäekosysteemien intensiivisen seurannan havaintoaloista.

Monitoring activities

Survey	Nr. 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, -20, -30, ... -100 cm)		Continuous*
– precipitation		Continuous*
– wind speed		Continuous*
– wind direction		Continuous*
– photosynthetically active radiation (PAR)		Continuous*
– solar radiation		Continuous*
Ground vegetation	31	Every 5 years
	6	Every year
Litterfall	14	Every 2 weeks during the snow-free period, once at the end of the winter
Phenology	7	Three times/week during the critical period

* = Hourly measurements

Database and data evaluation

A database has been set up for handling and archiving the Level I and Level II data, access to which is restricted to persons participating in the programme. The Level II database is maintained by Jarmo Mäkinen at the Parkano Research Unit (Metla) and Olavi Kurttio at the Vantaa Research Unit (Metla). The main database, containing the data forwarded annually to the data centres in Hamburg (Level I data, ICP Forests) and at the Join Research Centre in Ispra, Italy (Level II data), is located at the Parkano Research Unit.

Seurantatoiminnot

Toiminto	Havaintoalojen lukumäärä	Arviointi- tai mittausjakso
Latvuskunto	31	Vuosittain
Maaperä	31	Joka kymmenes vuosi
Neulaskemia	31	Joka toinen vuosi
Puuston kasvu	31	Joka viides vuosi
Läpimitan kasvu	12	Jatkuva*
Laskeuma	16	Jatkuva (Näytteenotto joka neljäs viikko, mutta lumettomana aikana joka toinen viikko)
Maavesi		
– vajovesilysimetrit	16	Jatkuva (Näytteenotto joka neljäs viikko lumettomana aikana)
– imulysimetrit	16	Jatkuva (Näytteenotto joka toinen viikko lumettomana aikana)
Meteorologia	12	
– ilman lämpötila		Jatkuva*
– suhteellinen kosteus		Jatkuva*
– maan lämpötila (-10, -20, -30, ... -100 cm)		Jatkuva*
– sademäärä		Jatkuva*
– tuulen nopeus		Jatkuva*
– tuulen suunta		Jatkuva*
– fotosynteettisesti aktiivinen säteily (PAR)		Jatkuva*
– kokonaissäteily		Jatkuva*
Aluskasvillisuus	31	Joka viides vuosi
	6	Joka vuosi
Karike	14	Joka toinen viikko lumettomana aikana, kerran talven lopussa
Fenologia	7	Kolme kertaa viiikossa kriittisenä aikana

* = Mittaukset tunneittain

Table 2. The basic stand characteristics of ICP Level II observation plots (measured during the winter 2004–2005).
Taulukko 2. ICP-havaintoalojen (taso II) keskeisimmät puustotunnukset (mitattu talvikaudella 2004–2005).

Plot nr. and name *Havaintoalan no. ja nimi*		Basal area with bark *PPA, kuorellinen,* m^2/ha	Stem number *Runko-luku, kpl/ha*	Mean diameter, weighted with basal area *Keskiläpimitta PPA:lla painotettu, cm*	Mean height arithmetical *Keskipituus (aritmeettinen), m*	Stem volume with bark *Runkotilavuus (kuorellinen),* m^3/ha	Stand age *Metsikön ikä*	Forest type *Metsätyyppi*	Soil type *: missing *Maannos *: puuttuu*
1	Sevettijärvi_P	13.3	350	24.7	11.5	76.4	205	Uliginosum-Vaccinium-Empetrum Type	Ferric podzol
2	Pallasjärvi_P	14.6	733	19.0	10.7	80.4	95	Empetrum-Myrtillus Type	*
3	Pallasjärvi_S	13.9	1104	17.6	11.0	72.8	145	Hylocomium-Myrtillus Type	Ferric podzol
4	Sodankylä_P	19.8	1133	17.0	13.9	137.1	85	Empetrum-Myrtillus Type	*
5	Kivalo_S	23.2	1663	15.3	11.6	133.3	75	Hylocomium-Myrtillus Type	Ferric podzol
6	Kivalo_P	24.8	1755	14.4	13.3	167.3	60	Empetrum-Myrtillus Type	Carbic podzol
7	Oulanka_S	27.1	1196	23.1	15.4	192.7	195	Hylocomium-Myrtillus Type	*
8	Oulanka_P	21.4	689	21.7	16.8	174.1	85	Hylocomium-Myrtillus Type	*
9	Ylikiiminki_P	14.1	548	19.3	14.3	100.1	95	Empetrum-Calluna Type	Ferric podzol
10	Juupajoki_P	20.1	378	27.2	22.4	210.6	85	Vaccinium Type	Ferric podzol
11	Juupajoki_S	35.8	852	25.2	21.9	375.5	85	Oxalis-Myrtillus Type	Dystric cambosol
12	Tammela_S	30.1	663	25.2	21.6	309.4	65	Myrtillus Type	Haplic podzol
13	Tammela_P	25.6	604	24.0	21.1	254.5	65	Vaccinium Type	Haplic podzol
14	Lapinjärvi_P	29.3	1174	19.1	17.9	255.6	55	Vaccinium Type	*
15	Lapinjärvi_S	30.1	644	25.6	22.8	327.7	70	Oxalis-Myrtillus Type	*
16	Punkaharju_P	33.2	959	22.1	22.8	358.6	85	Vaccinium Type	Ferric podzol
17	Punkaharju_S	31.1	374	33.1	27.1	386.7	75	Oxalis-Myrtillus Type	Cambic arenosol
18	Miehikkälä_P	18.6	415	24.9	20.2	177.8	125	Calluna Type	Ferric podzol
19	Evo_Sim	55.2	1254	30.9	26.3	658.1	175	Oxalis-Myrtillus Type	Cambic podzol
20	Lieksa_Pim	28.7	588	31.9	22.8	298.1	135	Empetrum-Vaccinium Type	Haplic podzol
21	Oulanka_Sim	26.8	1738	23.4	14.3	182.0	175	Hylocomium-Myrtillus Type	Haplic podzol
22	Kevo_Pim	12.1	688	28.5	11.5	68.6	185	Uliginosum-Empetrum-Myrtillus Type	*
23	Uusikaarlepyy_S	38.8	963	24.0	20.7	387.2	60	Oxalis-Myrtillus Type	Cambic podzol
24	Närpiö_S	27.8	641	28.2	19.5	244.4	60	Myrtillus Type	*
25	Vilppula_Spro	30.8	448	30.8	27.2	392.3	80	Oxalis-Myrtillus Type	*
26	Ikaalinen_P	12.1	719	17.6	12.8	77.7	95	Oligotrophic pine mire (drained)	*
27	Ikaalinen_Pfer	12.0	663	17.9	13.2	80.8	105	Oligotrophic pine mire (drained)	*
28	Solböle_Spro	28.5	448	29.2	24.3	326.8	80	Oxalis-Myrtillus Type	*
29	Pyhäntä_P	15.2	1326	13.9	10.6	84.0	115	Oligotrophic pine mire (drained)	*
30	Pyhäntä_Pfer	13.9	1252	13.2	10.3	75.0	125	Oligotrophic pine mire (drained)	*
31	Kivalo_Spro	22.7	1219	17.5	12.7	140.7	80	Hylocomium-Myrtillus Type	*

Table 3. Growing season and its length 2001–2004 and temperature sum and June–September precipitation for the periods 2001–2004 and 1971–2000 on Level II plots with meteorological measurements.
Taulukko 3. Vuosien 2001–2004 kasvukausi ja sen pituus, lämpösumma ja kesä–syyskuun sademäärä sekä vertailujakson 1971–2000 keskimääräinen lämpösumma ja kesä–syyskuun sademäärä metsien intensiiviseurannan säähavaintoasemilla (taso II).

Plot *Havaintoala*		Period and length (days) of the growing season[1] – *Kasvukausi ja sen pituus*[1] 2001	2002	2003	2004
3	Pallasjärvi_S	30.5. – 22.9. (114)	21.4. – 13.09. (146)	11.5 .– 29.08. (111)	28.4. – 11.09. (137)
5	Kivalo_S	13.5. – 22.9. (121)	22.4. – 14.09. (146)	11.5. – 29.08. (111)	27.4. – 12.09. (139)
9	Ylikiiminki_P	23.4. – 22.9. (144)	22.4. – 15.09. (147)	10.5. – 10.10. (154)	
10	Juupajoki_P	23.4. – 18.10. (169)	20.4. – 18.09. (152)	05.5. – 12.10. (161)	15.4. – 08.10. (177)
11	Juupajoki_S	22.4. – 18.10. (169)	20.4. – 18.09. (152)	04.5. – 06.10. (156)	15.4. – 08.10. (177)
12	Tammela_S	22.4. – 19.10. (175)	10.4. – 19.09. (163)	05.5. – 12.10. (161)	15.4. – 08.10. (177)
17	Punkaharju_S	22.4. – 18.10. (173)	10.4. – 18.09. (162)	05.5. – 13.10. (162)	17.4. – 08.10. (175)
18	Miehikkälä_P	22.4. – 18.10. (173)	10.4. – 19.09. (163)	05.5. – 14.10. (163)	15.4. – 08.10. (177)
23	Uusikaarlepyy_S	23.4. – 28.10. (174)	21.4. – 02.10. (165)	10.5. – 17.10. (161)	16.4. – 08.10. (176)
24	Närpiö_S	23.4. – 19.10. (170)	22.4. – 19.09. (167)	04.5. – 17.10. (167)	
25	Vilppula_Spro	22.4. – 19.10. (172)	20.4. – 18.09. (152)	04.5. – 12.10. (162)	
28	Solböle_Spro	22.4. – 04.11. (192)	10.4. – 03.10. (177)	03.5. – 17.10. (168)	

Plot *Havaintoala*		Temperature sum (5ºC threshold) – *Lämpösumma (>5ºC)* 2001	2002	2003	2004	Long term mean[2] *Pitkän ajan keskiarvo*[2] 1971–2000
3	Pallasjärvi_S	785	886	753	718	687
5	Kivalo_S	928	1073	873	852	832
9	Ylikiiminki_P	1193	1165	1177		1033
10	Juupajoki_P	1359	1507	1300	1232	1166
11	Juupajoki_S	1314	1510	1232	1184	1142
12	Tammela_S	1415	1562	1346	1252	1262
17	Punkaharju_S	1524	1591	1435	1360	1304
18	Miehikkälä_P	1504	1600	1415	1395	1361
23	Uusikaarlepyy_S	1249	1457	1267	1233	1142
24	Närpiö_S	1257	1429	1281		1187
25	Vilppula_Spro	1330	1652	1351		1178
28	Solböle_Spro	1614	1680	1462		1375

	Plot *Havaintoala*	Rainfall (mm) for the period 1.6.–30.9. *Sademäärä (mm) 1.6.–30.9.* 2001	2002	2003	2004	Long term mean[2] *Pitkän ajan keskiarvo*[2] 1971– 2000
3	Pallasjärvi_S	570	254	52		230
5	Kivalo_S	244	268	264	358	247
9	Ylikiiminki_P	433	207	131		239
10	Juupajoki_P	682	228	166	218	288
12	Tammela_S	301	247	134	281	283
17	Punkaharju_S	161	129	164	234	269
18	Miehikkälä_P	212	104	101	376	278
23	Uusikaarlepyy_S	167	53	80	65	232
24	Närpiö_S	354	246	141		258
25	Vilppula_Spro	496	206	104		293
28	Solböle_Spro	661	131	146		278

1) The growing season is defined as the period during which the temperature sum accumulates.
Terminen kasvukausi on se osa vuodesta, jolloin lämpösumma kertyy.

2) Long term means were calculated according to Ojansuu and Henttonen (1983).
Pitkän ajan keskiarvot on laskettu Ojansuun ja Henttosen (1983) mukaisesti.

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.
Puuttuvat havainnot saatiin mallittamalla lähimmän Ilmatieteen laitoksen säähavaintoaseman havaintojen perusteella.

References

Luyssaert, S., Sulkava, M., Raitio, H. & Hollmén, J. 2005. Are N and S deposition altering the mineral composition of Norway spruce and Scots pine needles in Finland? Environmental Pollution 138: 5–17.

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

Raitio H. 1994. Kangasmetsien ravinnetila neulasanalyysin valossa. In: Mälkönen, E. & Sivula, H. (eds.). Suomen metsien kunto. Metsäntutkimuslaitoksen tiedonantoja 527: 25–34.

2 Forest condition in national systematic network (Forest Focus/ICP Forests, Level I) in 2002–2005

Metsien terveydentila systemaattisen havaintoala-verkoston aloilla vuosina 2002–2005 (Forest Focus/ ICP metsäohjelma, taso I)

2.1 Results of the national crown condition survey

Valtakunnallisen latvuskunnon seurannan tulokset

Martti Lindgren[1], Seppo Nevalainen[2] & Antti Pouttu[1]

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The forest condition survey was conducted on 457 sample plots in 2002, on 453 sample plots in 2003, on 594 sample plots in 2004 and on 609 sample plots in 2005. The degree of defoliation and foliage discoloration and the occurrence of abiotic and biotic damage on Scots pine, Norway spruce and broadleaves were recorded. There were no notable changes in the average defoliation level of any tree species between the years 2002 and 2005. The average tree-specific degree of defoliation for the period 2002–2005 on mineral soil sites was 9.4% in pine, 18.3% in spruce and 11.7% in broadleaves. In 2004, the plots on peatland were included in the survey for the first time and the average defoliation was 8.2% in pine, 17.0% in spruce and 9.3% in broadleaves, and in 2005 8.2%, 16.8% and 9.4%, respectively. The proportion of dead trees was 0.4% during 2001–2002, 0.1% during 2002–2003, 0.14% in 2003–2004 and 0.1% during 2004–2005. No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 2002, 2003, 2004 or 2005. High stand age and weather and climatic factors, as well as abiotic and biotic damage, have a considerable effect on defoliation in Finland.

Metsien vuosittaisessa terveydentilan seurannassa arvioitiin puiden latvuskunto 457 näytealalla vuonna 2002, 453:lla 2003, 594:llä 2004 ja 609:llä 2005. Puiden kunnon mittareina käytetään latvuksen harsuuntumisastetta, värioireiden määrää sekä abioottisia että bioottisia tuhoja. Viime vuosina kaikkien puulajien keskimääräinen harsuuntumisaste on pysynyt melko vakaana. Kivennäismailla kasvavien mäntyjen keskimääräinen harsuuntumisaste jaksolla 2002–2005 oli 9,4 %, kuusien 18,3 % ja lehtipuiden (pääasiassa koivuja) 11,7 %. Vuonna 2004 otettiin seurantaan mukaan myös turvemaiden näytealoja. Mäntyjen keskimääräinen harsuuntumisaste turvemailla oli vuonna 2004 8,2 %, kuusien 17 % ja lehtipuiden 9,3 %. Vuonna 2005 vastaavat luvut olivat 8,2 %, 16,8 % ja 9,4 %. Vuosina 2001/2002 kuoli puista 0,4 % ja seuraavina vuosina kuolleisuus oli noin 0,1 %. Harsuuntuminen johtuu Suomessa pääasiassa puuston ikääntymisestä, erilaisista epäedullisista ilmasto- ja säätekijöistä sekä sieni- ja hyönteistuhoista. Koko maata tarkasteltaessa ei havaittu yhteyttä ilman epäpuhtauksien ja neulaskadon välillä vuosina 2002–2005.

Introduction

Concern about 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 surveyed crown condition annually 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 (current edition: Manual on methods… 2006) and, since 1995, also in accordance with Commission regulations (EEC) Nos. 3528/86 and 1398/95, and since 2003 Regulation 2152/2003.

This report presents 1) the regional distribution of forest condition in Finland, 2) the year-to-year variation in forest condition, and 3) the factors which may explain, based on correlation analysis, the regional pattern and changes in forest condition.

Materials and methods

The large-scale crown condition survey (Level I) was carried out in Finland on a systematic network of permanent sample plots established during 1985–1986 in connection with the 8th National Forest Inventory (NFI) (Jukola-Sulonen et al. 1990). The country was divided into a southern and a northern region (demarcation line 66º N). The network in the southern region is based on a 16 x 16 km grid, and that in the northern region on a 24 x 32 km grid. The total forest area represented 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. During summer 2004, 150 new plots were added to the monitoring network, and in 2005 15 plots. The present network includes 499 sample plots on mineral soil and 110 on peatland (Table 1).

The forest condition survey was conducted on 457 sample plots in 2002, on 453 sample plots in 2003, on 594 sample plots in 2004, and on 609 sample plots in 2005 (Table 1). The degree of defoliation and foliage discoloration and occurrence of abiotic and biotic damage on pine, spruce and broadleaves were recorded. Defoliation and discoloration of Scots pine and broad-leaved trees are 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 (Lindgren et al. 2005). A tree is classified as damaged when its leaf or needle loss is more than 25%, and as discoloured when 10% of its leaf or needle mass has abnormal coloration (e.g. needle yellowing). The degree of recognizable damage is also assessed and grouped into three categories: 1) slight, 2) moderate, and 3) severe. Since 2004 the new damage assessment method (UN/ECE/ICP manual update 6/2004) has been applied on the large-scale assessment of crown condition in Finland. For more comprehensive information about the abiotic and biotic damage in Finland, see Chapters 2.2, 4.2 and 4.3 in this volume.

Results

There were no notable changes in the average defoliation level of any tree species between the years 2002 and 2005. On all tree species the average tree-specific degree of defoliation varied by less than 1%-unit on mineral soil plots during 2002–2005 (Fig. 1). In 2005 the average defoliation degree was 9.5% in pine, 17.9% in spruce and 11.4% in broadleaves (Fig. 1). On the peatland plots the corresponding average defoliation degree was 8.2% (8.2% in 2004) in pine, 16.8%

Table 1. The number of assessed trees, sample plots and observers during 1986–2005. The number of plots includes 97 peatland plots in 2004 and 110 in 2005. Number of trees in 2004 includes 1200 Scots pines, 313 Norway spruces and 379 broadleaves and for 2005 1361 pines, 347 spruce and 446 broadleaves growing on peatland plots.
Taulukko 1. Seurantajakson 1986–2005 aikana arvioitujen puiden, näytealojen sekä arvioijien lukumäärät. Vuoden 2004 näytealojen lukumäärä sisältää 97 turvemaiden alaa ja puiden lukumäärä 1200 mäntyä, 313 kuusta ja 379 lehtipuuta. Vuonna 2005 turvemaiden alojen lukumäärä oli 110 ja näillä aloilla kasvoi yhteensä 1361 mäntyä, 347 kuusta ja 446 lehtipuuta.

Year *Vuosi*	Number of trees *Puiden lkm*	Scots pine *Mänty*	Norway spruce *Kuusi*	Broadleaves *Lehtipuut*	Number of plots *Näytealojen lkm*	Number of observers *Arvioijien lkm*
1986	3982	2233	1445	304	378	4
1987	3971	2171	1432	368	376	4
1988	3870	2129	1391	347	370	4
1989	3807	2032	1355	500	360	4
1990	3746	2002	1329	415	358	4
1991	3764	2004	1272	488	356	4
1992	4391	2377	1367	647	409	4
1993	4276	2347	1307	622	399	4
1994	4180	2301	1265	614	392	4
1995	8754	4520	2838	1396	455	7
1996	8732	4522	2851	1359	455	7
1997	8779	4582	2814	1383	460	7
1998	8758	4584	2829	1345	459	8
1999	8662	4538	2816	1308	457	8
2000	8576	4560	2706	1310	453	8
2001	8579	4608	2693	1278	454	8
2002	8593	4648	2691	1254	457	9
2003	8482	4610	2622	1250	453	10
2004	11210	6174	3123	1913	594	11
2005	11535	6450	3089	1996	609	11

(17%) in spruce and 9.4% (9.3%) in broadleaves. Of the trees assessed on mineral soil plots in 2002, 97% of the pines, 73% of the spruces and 91% of broadleaves (mainly *Betula spp.*) were not or slight defoliated (leaf or needle loss less than 25%) (Fig. 2). In 2003 the proportions were 96% in pine, 75% in spruce and 92% in broadleaves, and in 2004 96%, 76% and 91% and 2005 97%, 78% and 92%, respectively (Fig. 2). The proportion of moderate or severely defoliated trees remained relatively constant in pine (ca. 3%) and in broadleaves (ca. 8–9%) during the period 2002–2005. In spruce the proportion of moderate or severely defoliated trees was 27% in 2002, 26% in 2003, 24% in 2004, and 22% in 2005 (Fig. 2). In 2004, peatland stands were included in the survey for the first time. The proportion of less than 25% defoliated pines was 99%, spruces 77% and broadleaves 96% (Fig. 2) in 2004, and 99%, 80% and 96% in 2005, respectively. The proportion of dead trees on all plots was 0.4% during 2001–2002, 0.1% during 2002–2003, 0.14% during 2003–2004 and 0.1% during 2004–2005.

On the mineral soil plots the proportion of over-25% defoliated pines was 1.2% in 2002 (Fig. 3), 2.1% in 2003 (Fig. 4), 2.5% in 2004 (Fig. 5), and 2.8% in 2005 (Fig. 6). For spruce the proportions were 32.8%, 34.5%, 28.6% and 26.5%, and in broadleaves 5.1%, 5.8%, 6.0% and 6.8%, respectively (Figs. 3, 4, 5 and 6). On the peatland plots the proportion of over-25 defoliated pines were 1.3% in 2004 and 2005, and in broadleaves 4.9% in 2004, 2.5% in 2005, and in spruce 26.9% in 2004 and 2005 (Figs. 5 and 6).

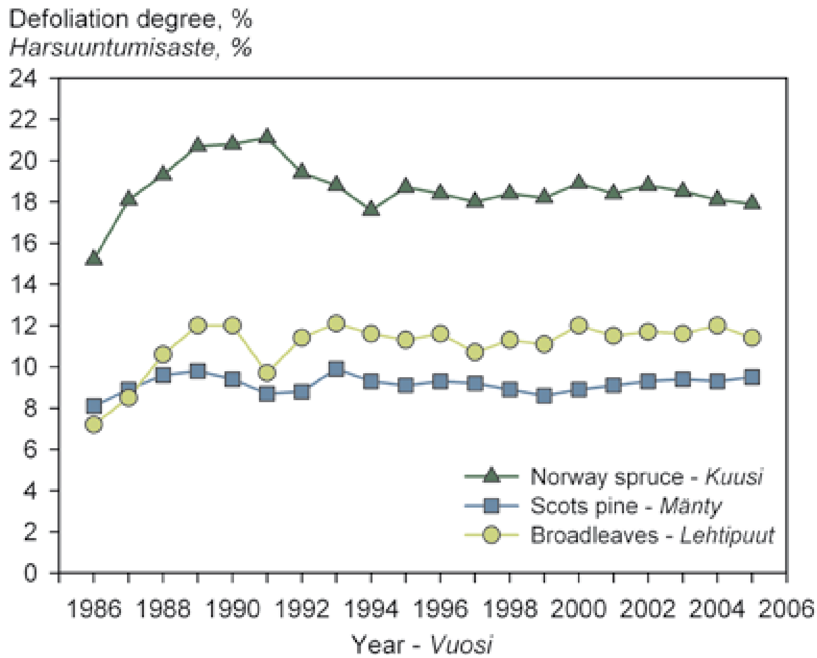
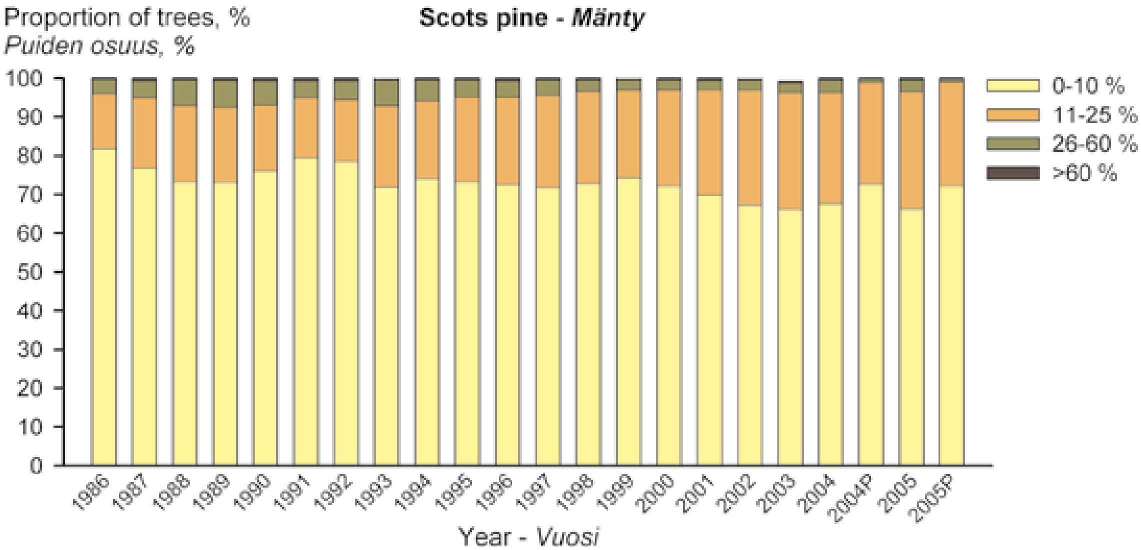


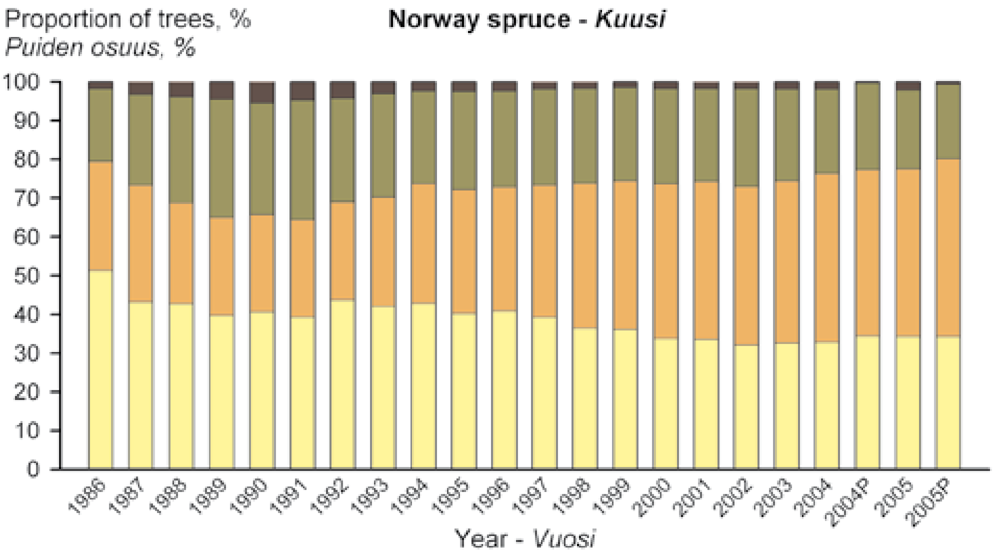
Figure 1. The average defoliation level of Scots pine, Norway spruce and broadleaves on mineral soil plots during 1986–2005. The average defoliation degree was calculated using the same defoliation-class mid-point values as in 1986 (0–10% defoliation = 5%, 11–20% def. = 15%, 21–30% def. = 25% etc.).
Kuva 1. Männyn, kuusen ja lehtipuiden keskimääräinen harsuuntumisaste kivennäismailla vuosina 1986–2005. Keskiarvoja laskettaessa on käytetty samaa harsuuntumisluokan keskilukua kuin vuonna 1986, esim. (0–10 % lehti- tai neulaskato eli harsuuntumisaste = 5 %, 11–20 % harsuuntumisaste = 15 %, 21–30 % harsuuntumisaste = 25 % jne.)

Between 2002 and 2005, there was a more than 5%-unit increase in the plot-specific defoliation degree on 5.4% of the pine, 14.2% of the broadleaved, and 8.1% of the spruce plots (Fig. 7). A recovery of more than 5 %-units (i.e. decrease) in the plot-specific defoliation degree occurred on 2.5% of the pine, 12.7% of the broadleaved, and 7.5% of the spruce plots between 2002 and 2005 (Fig. 7).

The proportion of needle discoloration (extent of discoloured needle/leaf mass more than 10 %) on pine remained at the same level (under 1%) in 2003, as in 2002, and that of spruce decreased from 4.5% to 3.8%. However, the proportion of slightly discoloured (extent of discoloured needle mass 1–10 %) conifers was higher in 2003 than that in the previous year. The proportion of discoloured trees in 2004 was under 1% in pine, 6.4% in spruce and 6.6% in broadleaves. In 2005, the proportion of needle discoloration on pine remained at the same level (under 1%) as in 2004, and that of spruce increased from 7.5% to 10.2%. However, most of these discoloured spruces belonged to the 10 to 25% discoloration class, and the incidence of moderate or severe discolouration was rare. Leaf discoloration on broadleaves decreased from 8.5% to 2.1%. During the study period, the most frequent discoloration symptoms in conifers were needle tip yellowing and needle yellowing, and the symptoms were mainly concentrated on needles older than two years. On broadleaved trees the most frequent symptoms were yellowing and browning of the leaves. The results of abiotic and biotic damage are presented in chapter 2.2 in this volume.

No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 2002, 2003, 2004 (deposition data for 1993 are based on the HILATAR model, Hongisto 1998) or 2005 (updated data from the Finnish Meteorological Institute).





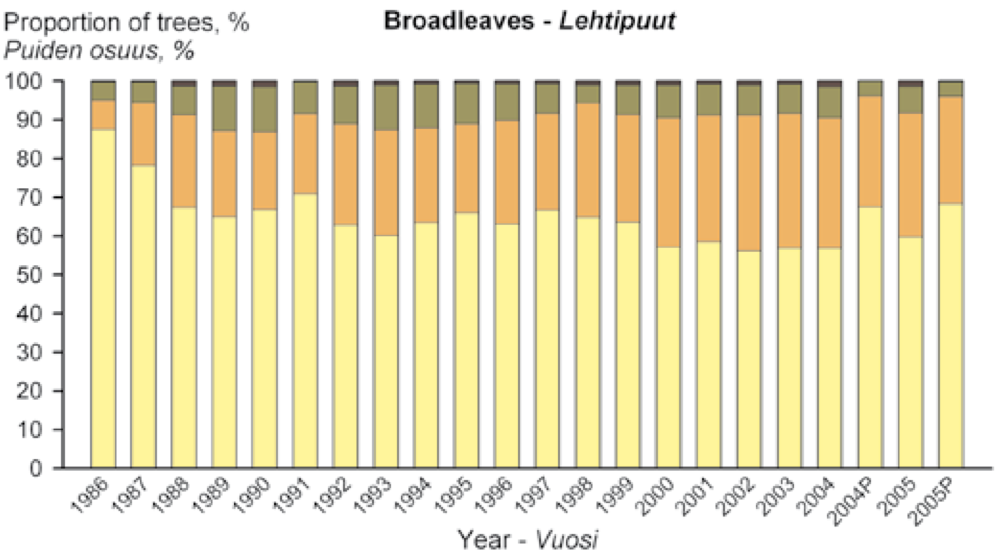


Figure 2. Defoliation frequency distribution for Scots pine, Norway spruce and broadleaves on mineral soil and peatland (P) plots during 1986–2005.
Kuva 2. Männyn, kuusen ja lehtipuiden harsuuntumisjakaumat kangasmailla ja turvemailla (P) 1986–2005.

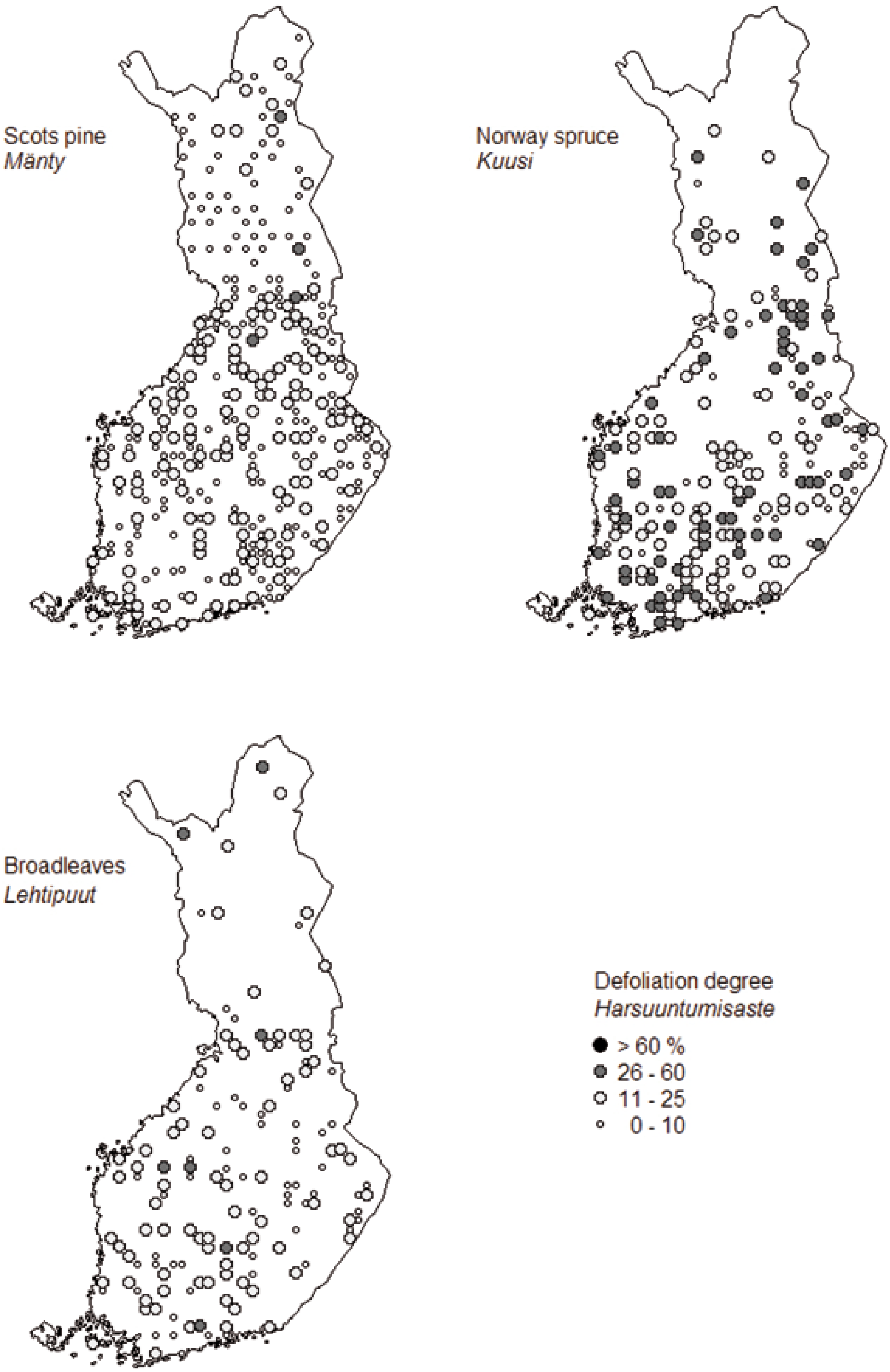


Figure 3. Plot-wise defoliation degrees for Scots pine, Norway spruce and broadleaves on mineral soil plots in 2002.
Kuva 3. Männyn, kuusen ja lehtipuiden näytealakohtaiset keskiarvot kivennäismailla vuonna 2002.

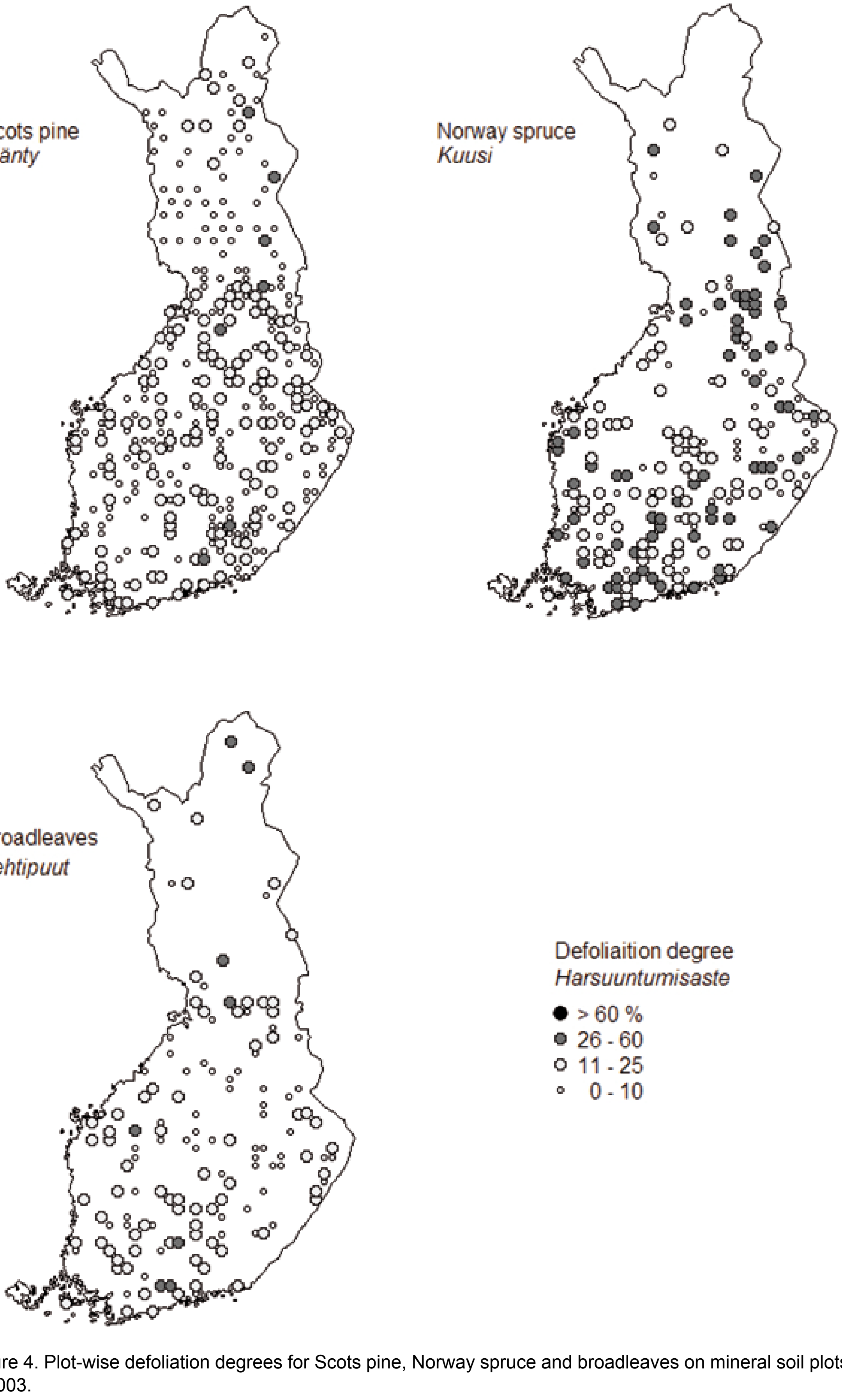


Figure 4. Plot-wise defoliation degrees for Scots pine, Norway spruce and broadleaves on mineral soil plots in 2003.
Kuva 4. Männyn, kuusen ja lehtipuiden näytealakohtaiset keskiarvot kivennäismailla vuonna 2003.

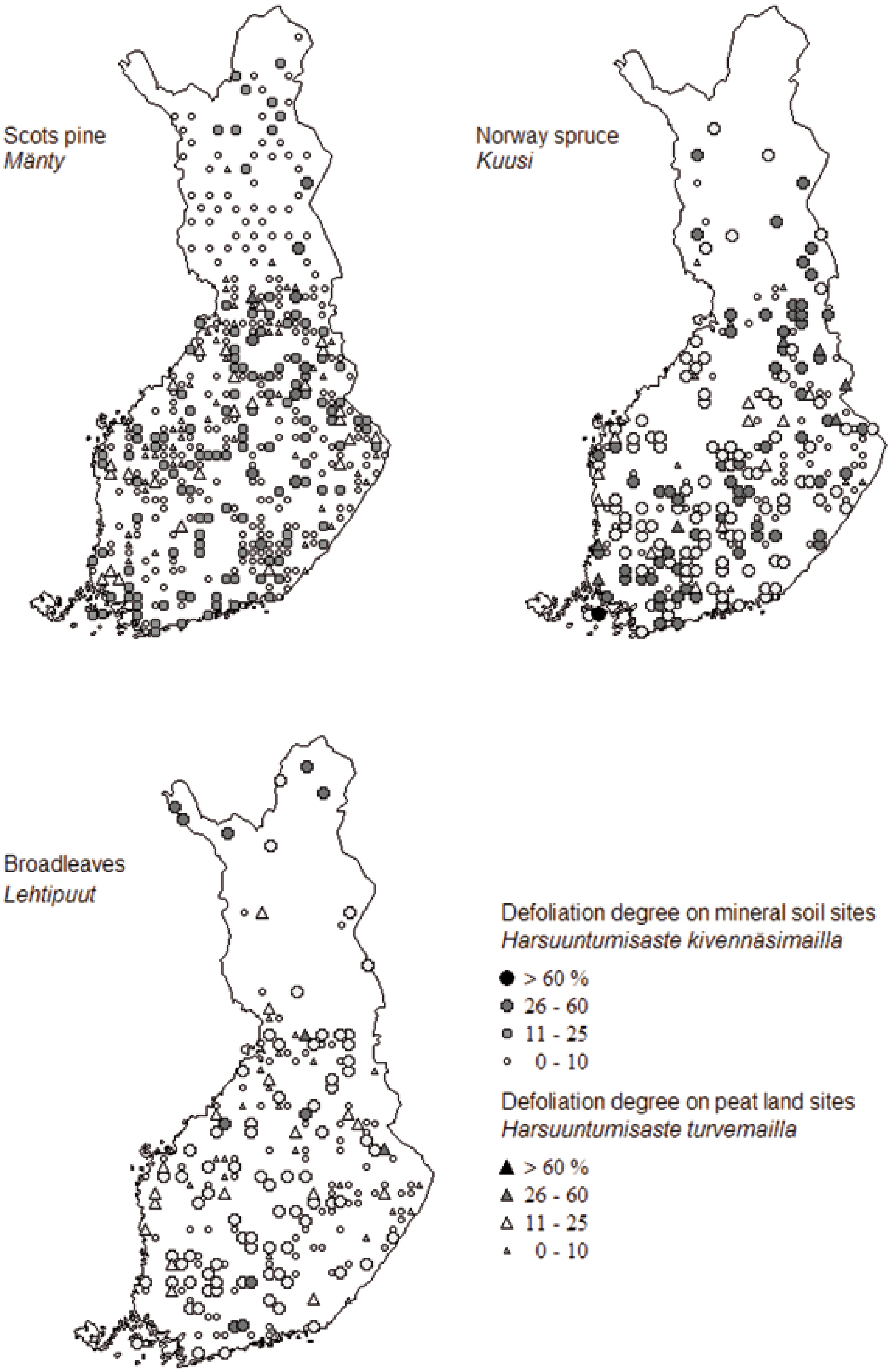


Figure 5. Plot-wise defoliation degrees for Scots pine, Norway spruce and broadleaves on mineral soil and peatland plots in 2004.
Kuva 5. Männyn, kuusen ja lehtipuiden näytealakohtaiset keskiarvot kivennäis- ja turvemailla vuonna 2004.

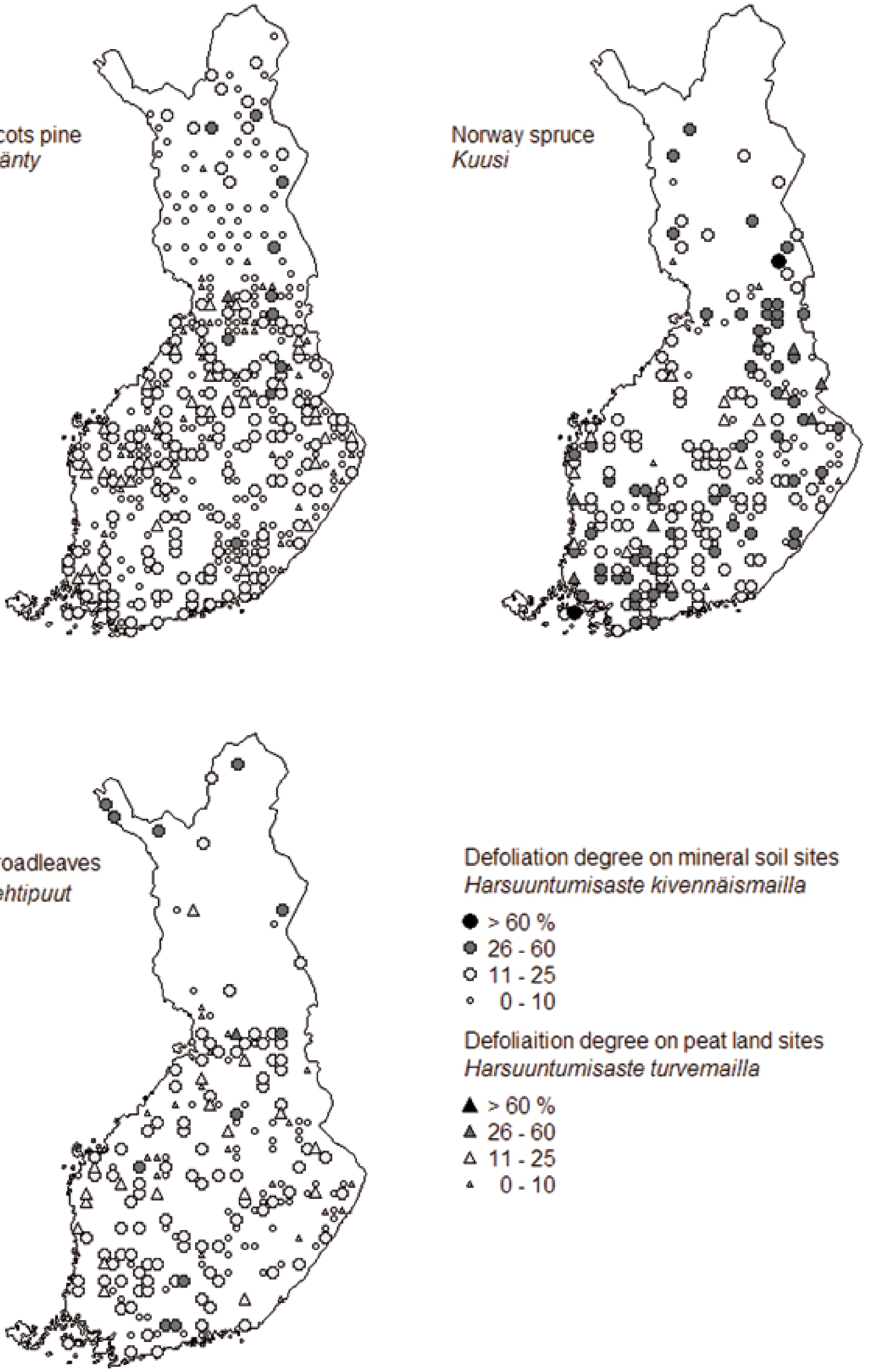


Figure 6. Plot-wise defoliation degrees for Scots pine, Norway spruce and broadleaves on mineral soil and peatland plots in 2005.

Kuva 6. Männyn, kuusen ja lehtipuiden näytealakohtaiset keskiarvot kivennäis- ja turvemailla vuonna 2005.

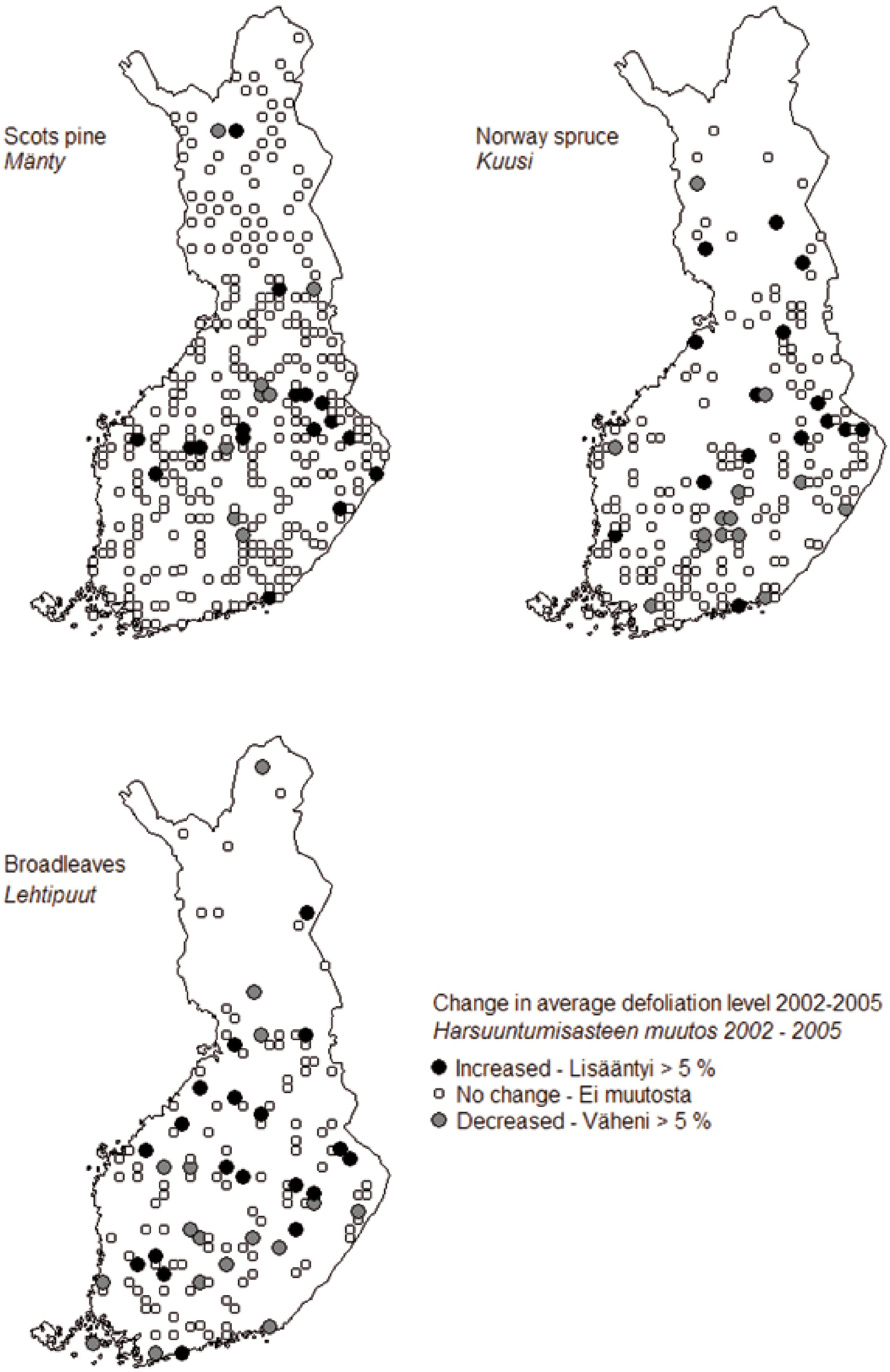


Figure 7. Change in plot-wise defoliation degree of Scots pine, Norway spruce and broadleaves on mineral soil plots between 2002 and 2005.
Kuva 7. Vuosien 2002 ja 2005 välinen, näytealakohtainen harsuuntumisasteen muutos männyllä, kuusella ja lehtipuilla kivennäismailla.

Conclusions

A large number of natural factors, the most important of which are connected with stand age, climate and weather, and abiotic or biotic damage, affect forest condition in Finland (Jukola-Sulonen et al. 1990, Salemaa et al. 1991, Lindgren et al. 2000, Nevalainen and Heinonen 2000). 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 (Salemaa et al. 1991). Defoliation in broadleaves again increased in the years 1992–1993. A slight increase in pine defoliation was also observed in 1993 and 1997. Although the proportion of non-defoliated and slightly defoliated trees has varied in recent years, there have been no essential changes in the proportion of moderately or severely defoliated trees, or average defoliation degree, of any of the tree species during the previous years. The average defoliation level was slightly lower on the peatland plots than on mineral soil plots in 2004 and 2005 when peatland sites were included for the first time in the survey. No correlation was found between the defoliation pattern of conifers or broadleaves and the modelled sulphur or nitrogen deposition at the national level in 2002, 2003, 2004 or 2005.

References

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

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

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

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

Lindgren, M., Salemaa, M. & Tamminen, P. 2000. Forest condition in relation to environmental factors. In: Mälkönen, E. (ed.). Forest condition in a changing environment – the Finnish case. Forestry Sciences, Vol. 65. Kluwer Academic Publishers. p. 142–155.

Lindgren, M., Nevalainen, S., Pouttu, A., Rantanen, H. & Salemaa, M. 2005. Metsäpuiden elinvoimaisuuden arviointi. Forest Focus/ICP-Forests, Level I. Maasto-ohje (Field guide). Metsäntutkimuslaitos. 38 p.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 2006. Part II. Visual assessment of crown condition. 69 p. [Internet site]. UN-ECE. Programme coordination centre, Hamburg. Available at: http://www.icp-forests.org/manual.htm.

Nevalainen, S. & Heinonen, J. 2000. Dynamics of defoliation, biotic and abiotic damage during 1986–1998. In: Mälkönen, E. (ed.). Forest condition in a changing environment – the Finnish case. Forestry Sciences 65. Kluwer Academic Publishers, Dordrecht. p. 133–141.

Regulation (EC) No. 2152/2003 of 17 November 2003, Concerning monitoring of forest and environmental interactions in the community (Forest Focus). Brussels: 2003, Official Journal of European Communities No. L324/1 of 11 December 2003. 8 p.

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

2.2 Biotic and abiotic damage on the Level I network
Biottiset ja abioottiset tuhot tason I havainto-aloilla

Seppo Nevalainen[1], Martti Lindgren[2] & Antti Pouttu[2]

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During the period 2002–2005, 33.4% of the Scots pine observation trees, 36.5% of the Norway spruces and 40.1% of the broadleaves showed signs of biotic or abiotic damage. Most of the observed damage was slight, i.e. did not decrease the vitality of the trees. Considerable changes were observed in the occurrence of the individual causal agents over the years, for instance the increase of insect (*Tomicus* sp.) damage in 2003, the increase of damage caused by *Gremmeniella abietina* in pine in 2004, and needle rust *Chrysomyxa ledi* in 2005 in spruce. Birch rust and leaf anthracnose were common on birches in 2004. Abiotic damage, due to soil factors (dryness, wetness or nutrient imbalance), was also common in 2003 and 2004. The geographical distribution of the most common causes was also plotted on maps. From the point of view of tree condition (measured as the extent of damage), *Gremmeniella abietina*, competition and *Tomicus* sp. were by far the most important of the individual damage causes in pine. The number of damage causes important for spruce and broadleaved trees was much larger than for pine. Competition, needle rust, soil factors (dryness, wetness or nutrient imbalance), unknown causes and non-identified decay fungi were among the causes in spruce trees. Competition, anthracnose, unknown insects and rust fungi were important in broadleaved trees. Spatial and temporal patterns of the most important abiotic or biotic epidemics are clearly visible in this annual survey. The observed causes of damage can act as predisposing, inciting or contributing factors in forest decline. The results should therefore be interpreted against this theoretical background.

Tutkimusjakson (2002–2005) aikana havaittiin bioottisia tai abioottisia tuhoja 33,4 %:ssa mänty-havaintopuita, 36,5 %:ssa kuusia ja 40,1 %:ssa lehtipuita. Suurin osa havaituista tuhoista oli lieviä, eli ei vähentänyt puiden elinvoimaisuutta. Vuosien välillä oli kuitenkin suuria eroja eri tuhonaiheuttajien esiintymisessä, esim. männyllä hyönteistuhot (ytimennävertäjätuhot) lisääntyivät vuonna 2003 ja versosurmatuhot 2004. Kuusella suopursuruoste yleistyi vuonna 2005. Koivuilla koivunruoste ja erilaiset lehtilaikut olivat yleisiä vuonna 2004. Maaperätekijöistä (kuivuus, märkyys tai ravinteiden epätasapaino) johtuvia tuhoja tavattiin myös yleisesti vuosina 2003 ja 2004. Yleisimmistä tuhonaiheuttajista esitetään esiintymiskarttoja. – Puiden kunnon kannalta (kun arviointikriteerinä käytetään tuhon laajuutta yksittäisissä puissa) männyllä selvästi tärkeimpiä tuhonaiheuttajia olivat versosurma, kilpailu ja ytimennävertäjät. Kuusella ja lehtipuilla tuhonaiheuttajien kirjo oli suurempi kuin männyllä: kuusella tärkeimpiä olivat kilpailu, suopursuruoste, maaperätekijät (kuivuus, märkyys, ravinne-epätasapaino) sekä tunnistamattomien tekijöiden ja tunnistamattomien lahottajasienten aiheuttamat tuhot; lehtipuilla puolestaan kilpailu, lehtilaikut ja tunnistamattomat hyönteiset sekä ruosteet. Tärkeimmät tuhoepidemiat paljastuvat hyvin tässä vuotuisessa seurannassa. Havaitut tuhot voivat olla metsävaurioissa altistavina, vaurioita lisäävinä tai puiden lopulliseen kuolemaan myötävaikuttavina tekijöinä, ja tuloksia tulisikin arvioida tätä teoreettista viitekehystä vasten.

Introduction

In Europe, the overall vitality of forests is mainly monitored on the basis of the relative loss of leaf and needle biomass (defoliation, crown thinning) and discoloration. The defoliation method has several disadvantages, despite its practicality. The leaf biomass of the crown is strongly affected by tree age, climatic and genetic factors, shading and a large number of abiotic or biotic stresses. In some cases, the rapid deterioration in the vitality of forests has been attributed to abiotic or biotic damage (Innes et al. 1986, Keane et al. 1989, Innes and Schwyzer 1994). It has even been proposed that the condition of trees strongly reflects the fluctuating effects of biotic or abiotic agents or site conditions (Skelly and Innes 1994).

In Finland the variation in annual defoliation caused by abiotic and biotic damage can be so large that it is difficult to identify any long-term trends in defoliation (Nevalainen and Heinonen 2000). The monitoring results have indicated no clear correlation between air pollution and crown condition in Finland (Lindgren 2002). However, as the annual variation is large, it is essential to carry out a thorough nalysis of the causes of variations in the forest health results, especially in areas subjected to low levels of air pollution. The issues of climate change and increased frequency of extreme weather events, as well changes in silvicultural practices, have the potential to increase biotic and abiotic damage. Large-scale, regular monitoring of forest health has therefore become more important than ever before.

The aims of this study are to describe the temporal and spatial occurrence of the most important biotic and abiotic damage on the Level I network in Finland during 2002–2005.

Material and methods

In Finland the occurrence of biotic and abiotic damage has been monitored since the beginning of forest health monitoring in 1985. Damage is recorded at different levels of intensity and spatial extent, ranging from the 75,000 plots of the National Forest Inventory (NFI) to 31 plots at Level II. Currently, the Level I network of the ICP Forests/Forest Focus programme comprises ca. 11,000 trees on 609 permanent plots. The network includes plots on mineral soil (499) and on peatland (110). The material of this study consisted of all the trees monitored at Level I. The number of monitored trees varied between the years, due to cuttings and the selection of new trees and new plots. The number of trees in each year is given in Table 1. For details of the selection of the plots and sample trees, see chapter 2.1 in this volume. A national system for describing the symptom, apparent severity (degree of damage) and the cause, as well as the age of the damage, was used prior to 2004. The degree of damage was recorded as follows: 0) symptoms observed, but the condition of the tree not affected, 1) slight – the damage can slightly reduce the vitality of the tree, 2) moderate – the damage can strongly reduce the viability of the tree, and 3) severe – the injury can kill the tree. An example of the variables and codes used in the national damage survey can be found e.g. in Nevalainen (1999).

The ICP Forests manual ‘Assessment of damage causes’ (referred to as Biotic manual), was tested in 2004 and fully adopted in 2005 in Finland. Currently, the European assessment of damage consists of symptom description, determination of the causal factor, and quantification of the symptoms. The age of the damage (new or old) is also recorded. The principles of the national damage survey in Finland have thus always been similar to that in the current Biotic manual, except that the coding of damage symptoms and causes was less detailed, and the quantification was not used prior to 2004. The common codes used during 2002–2005 for the causal agents are shown in Table 2. The coding of causes was more detailed in 2005. For instance, 22 insects and 16 fungi were coded to the species level.

Results

In general, the proportion of trees with damage symptoms changed only slightly on the Level I plots during the period. Scots pine (*Pinus sylvestris* L.) trees had less abiotic and unidentified damage, but more insect damage, than Norway spruce (*Picea abies* L.) or hardwood species (mostly *Betula* sp.). The symptoms caused by fungi were the most common in broadleaved species, however (Table 1). Altogether, 33.4% of the pines, 36.5% of the spruces and 40.1% of the broadleaves showed signs of biotic or abiotic damage.

Considerable changes were observed in the occurrence of the agent groups over the years. In pine, the most notable changes were the increase in insect damage in 2003 (mostly caused by *Tomicus* spp., 471 trees, 10.2% pines) and the increase of damage caused by fungi in 2004, most of which was due to *Gremmeniella abietina* (Lagerb. Morelet) (645 trees, 10.4% of pines). In 2004, *Gremmeniella* damage was common throughout the middle and western part of the country, but a cluster was also found in the southeastern part of Finland (Fig. 1). In spruce, symptoms caused

Table 1. The occurrence of causal agent groups in the observation trees on the Level I plots during 2002–2005.
Taulukko 1. Tuhonaiheuttajaryhmien esiintyminen I tason koealojen havaintopuissa 2002–2005.

Tree species *Puulaji*	Agent group *Aiheuttajaryhmä*	% of trees – *% puista*					Number of trees *Puita, kpl*
		Year – *Vuosi*				Mean	
		2002	2003	2004	2005	*Ka.*	
Scots pine *Mänty*	No damage – *Ei tuhoa*	68.5	63.1	67.0	66.6	66.4	14497
	Game and grazing – *Selkärankaiset*	0.5	0.4	0.4	0.4	0.4	94
	Insects – *Hyönteiset*	9.4	11.6	9.5	10.9	10.3	2259
	Fungi – *Sienet*	8.1	9.5	12.1	9.7	10.0	2186
	Abiotic – *Abioottiset*	2.0	3.1	2.6	1.8	2.3	511
	Direct action of man – *Ihmisen toiminta*	2.7	2.8	1.8	2.3	2.4	521
	Other – *Muut tekijät*	8.4	8.6	5.2	7.1	7.1	1556
	Unknown – *Tunnistamaton*	0.5	1.0	1.4	1.1	1.0	224
	Number of trees – *Puita, kpl*	4610	4610	6173	6455		21848
Norway spruce *Kuusi*	No damage – *Ei tuhoa*	70.6	61.2	65.2	57.9	63.5	7236
	Game and grazing – *Selkärankaiset*	0.1	0.2	0.1	0.1	0.1	13
	Insects – *Hyönteiset*	0.3	0.1	0.2	0.6	0.3	35
	Fungi – *Sienet*	7.7	11.9	13.6	20.0	13.6	1550
	Abiotic – *Abioottiset*	3.0	9.9	9.4	5.6	7.1	805
	Direct action of man – *Ihmisen toiminta*	5.1	5.0	3.7	4.0	4.4	498
	Other – *Muut tekijät*	8.5	7.3	4.5	8.3	7.1	805
	Unknown – *Tunnistamaton*	4.7	4.5	3.4	3.5	4.0	452
	Number of trees – *Puita, kpl*	2560	2621	3121	3092		11394
Other *Muut*	No damage – *Ei tuhoa*	66.9	61.2	55.3	59.3	59.9	3811
	Game and grazing – *Selkärankaiset*	2.0	1.8	1.0	0.8	1.3	81
	Insects – *Hyönteiset*	3.8	2.4	4.7	10.2	5.8	370
	Fungi – *Sienet*	9.1	9.2	24.5	13.2	15.0	956
	Abiotic – *Abioottiset*	4.7	11.4	5.3	4.9	6.2	397
	Direct action of man – *Ihmisen toiminta*	3.5	3.4	1.6	2.1	2.5	158
	Other – *Muut tekijät*	8.2	7.9	2.3	5.6	5.6	354
	Unknown – *Tunnistamaton*	1.9	2.7	5.3	4.0	3.8	239
	Number of trees – *Puita, kpl*	1201	1251	1916	1998		6366

Table 2. Causes of at least moderate damage in Level I observation trees during 2002–2005.
Taulukko 2. Puiden elinvoimaa alentavien tuhojen aiheuttajat I tason havaintopuissa 2002–2005.

Cause of damage – *Tuhonaiheuttaja*	% of trees – *% puista*			
	Tree species – *Puulaji*			All – *Kaikki*
	Pine *Mänty*	Sruce *Kuusi*	Other *Muut*	
Unidentified – *Tunnistamaton*	4.7	9.7	12.1	8.9
Wind – *Tuuli*	3.2	0.8	0.3	1.3
Snow – *Lumi*	4.7	3.3	7.1	4.6
Frost – *Halla, pakkanen*		1.2	3.1	1.3
Other abiotic – *Muut abioottiset*	1.1	2.2	5.5	2.7
Soil factors – *Maaperätekijät*	7.9	25.9	8.4	16.8
Harvesting – *Puutavaran korjuu*	4.0	9.7	3.5	6.7
Other man-made – *Muut ihmisen aiheuttamat*	1.5	3.9	4.6	3.4
Moose, deer, reindeer – *Hirvieläimet*	1.4		4.1	1.4
Other vertebrates – *Muut selkärankaiset*		0.2	0.3	0.2
Tomicus sp. – *Ytimennävertäjät*	5.9			1.6
Diprionidae – Mäntypistiäiset	2.7			0.7
Other defoliating insects – *Muut neulastuholaiset*		0.3	3.8	1.1
Ips sp. – *Kirjanpainajat*		0.1		0.0
Other insects – *Muut hyönteiset*		0.2	4.0	1.1
Unidentified insect – *Tunnistamattomat hyönteiset*		0.3	0.3	0.2
Heterobasidion sp. – *Juurikäävät*	2.0	22.1	1.7	11.7
Other decay fungi – *Muut lahottajasienet*	2.4	1.8	19.8	6.4
Gremmeniella – Versosurma	23.4			6.3
Cronartium sp. – *Tervasrosot*	15.7		0.2	4.2
Other rust fungi – *Muut ruostesienet*	0.2	1.5		0.8
Needle cast fungi – *Neulaskaristeet*	0.2	0.2		0.1
Other fungi – *Muut sienet*			0.5	0.1
Unidentified fungus – *Tunnistamaton sieni*		2.3	7.9	3.1
Competition – *Kilpailu*	18.6	9.2	11.2	12.2
Multiple injuries due ageing – *Ikääntymisestä johtuva monituho*	0.5	5.2	1.5	3.0
Total – *Yhteensä*	100.0	100.0	100.0	100.0
Number of trees – *Puita, kpl*	657	1202	605	2464

by fungi were very frequent (20 % of trees) in 2005. In 14.6% of the spruce trees the damage was caused by the needle rust *Chrysomyxa ledi* (De Bary). This fungus was most frequent in a belt-like zone running through middle Finland, and in scattered plots in the northern part of the country in 2005 (Fig. 2). Abiotic damage, due to soil factors (dryness, wetness or nutrient imbalance), was also common in 2004 (6.9% of the trees). Soil factors were also important in hardwoods in 2003 (6.6% of the trees). Fungal damage was important in hardwood species in 2004. 13.0% of the trees showed symptoms caused by 'other fungi'. These symptoms were mostly caused by two groups of fungi: "leaf spot fungi", i.e. unspecified leaf anthracnoses of birch (238 trees, 12.4%) and birch rust *Melampsoridium betulinum* (Fr.) Kleb. (147 trees, 7.7%). In 2004, birch rust occurred in Central Finland (Fig. 3). The proportion of unidentified damage has remained satisfactorily low (Table 1).

Most of the observed damage was slight. The proportion of moderate and severe damage was 3.0% for pine, 10.4% for spruce and 9.4% for broadleaves. The proportion of at least moderate damage was the greatest in 2002 (0.62%) and the smallest during 2003 (0.39%). During the years 2002 and 2003, this kind of damage was statistically significantly more frequent than during the

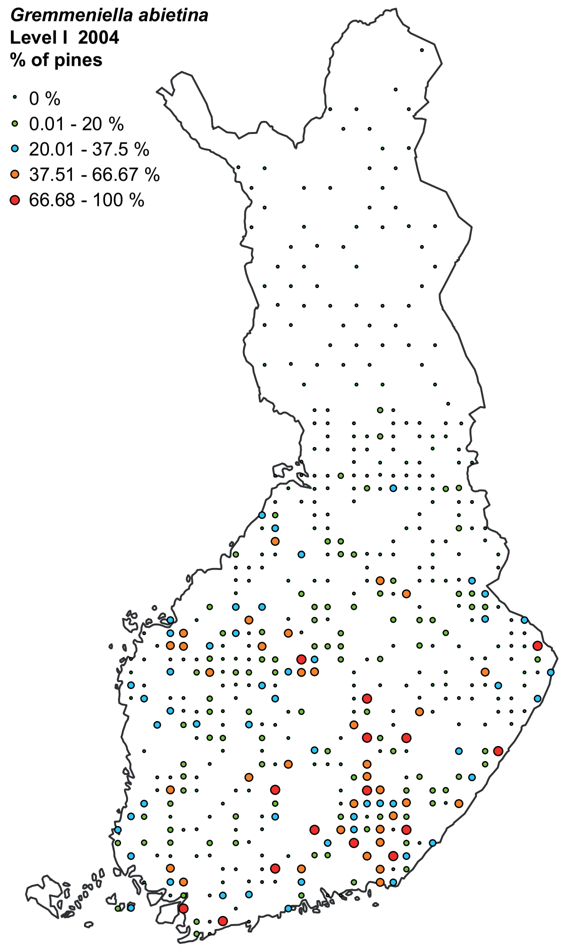

Figure 1. The occurrence of *Gremmeniella abietina* on Level I plots in 2004 as a proportion of the total number of Scots pine observation trees.
Kuva 1. Versosurman esiintyminen I tason havaintoaloilla vuonna 2004, % mäntyhavaintopuista.

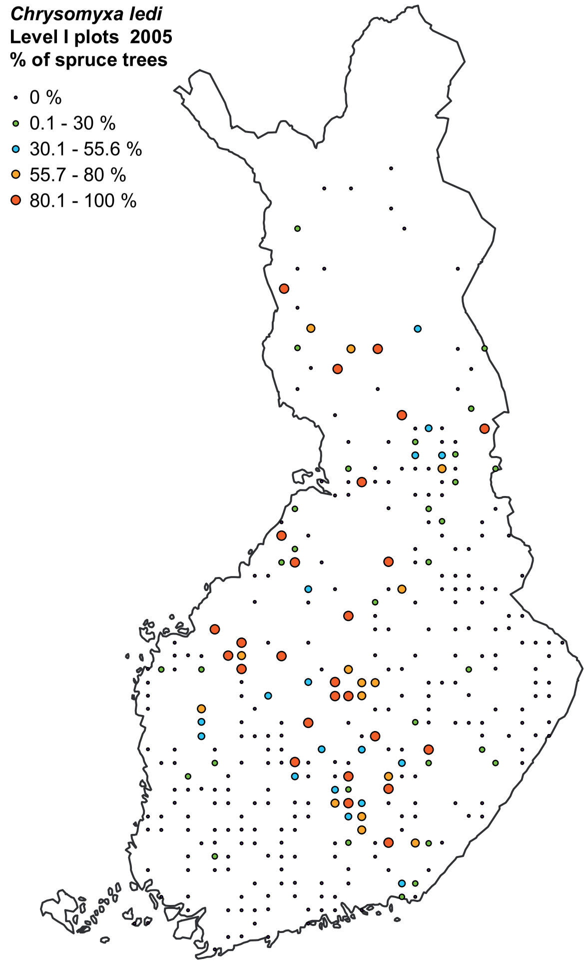

Figure 2. The occurrence of *Chrysomyxa ledi* on Level I plots in 2005 as a proportion of the total number of Norway spruce observation trees.
Kuva 2. Suopursuruosteen esiintyminen I tason havaintoaloilla vuonna 2005, % kuusihavaintopuista.

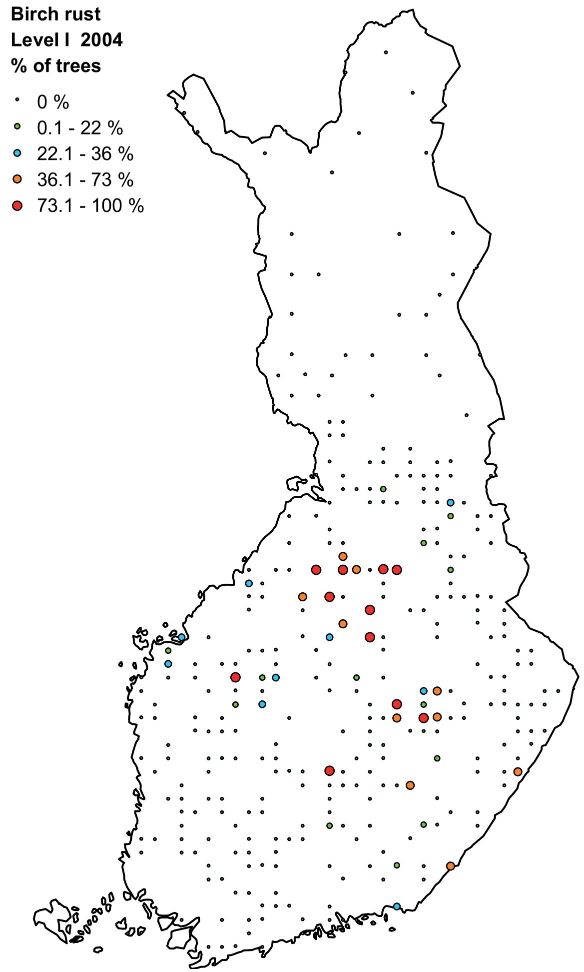

Figure 3. The occurrence of *Melampsoridium betulinum* on Level I plots in 2004 as a proportion of the total number of birch observation trees.
Kuva 3. Koivunruosteen esintyminen I tason havaintoaloilla vuonna 2004, % koivuhavaintopuista.

other two years of the period. The proportion of severe damage was 0.3% for pines, 0.6% for spruces and 0.9% for broadleaves. The year-to-year variation in this proportion was small. The yearly mortality values (the proportion of trees that had died after the previous year's inventory) ranged from 0.1% in 2003 to 0.4% in 2002, i.e. 9–28 trees per year. During 2002–2005, only three of the trees that were cut down had suffered from severe damage in the previous year. The causes for at least moderate damage highlight the factors that were potentially the most important for tree condition (Table 2). In all the tree species, competition (between trees) was very important. In pine, *Gremmeniella abietina* and *Cronartium* sp. were the most important other causes of at least moderate damage, while in spruce soil factors (dryness, wetness or nutrient imbalance) and *Heterobasidion* were the most important. Decay fungi were also important in deciduous species.

There were no dramatic changes in the degree of defoliation during the period (see also chapter 2.1 in this volume). The degree of defoliation of healthy trees especially remained very stable (Fig. 4). Fig. 4 shows, schematically, the dynamics of defoliation in pines with different causal agents. It appears that defoliation in trees with damage caused by pine saw flies (Diprionidae) is decreasing. Also note the higher levels of defoliation in damaged trees compared to non-symptomatic trees. Using the same approach we can see, for instance, that the needle rust (*Chrysomyxa ledi*) did not increase the overall defoliation of spruce. In some individual trees, the previous year's rust infection had clearly increased the degree of defoliation the next year, but it was very difficult to prove this effect in the whole material. In pines, in contrast, the trees were significantly more defoliated throughout the period if they had had a *Gremmeniella* infection during the inventory year or the year before.

The extent of damage was more than 10% in 36% of the trees in 2004–2005. The frequency of this damage, which potentially can affect the defoliation scores, was higher in spruces than in the other species (Table 3). Trees with abiotic damage had the highest mean value of damage

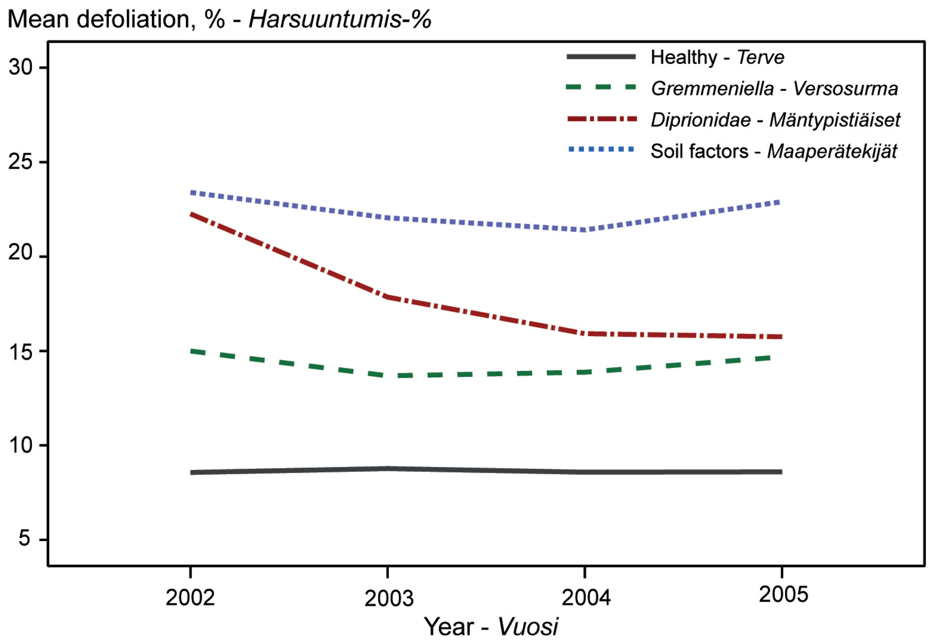

Figure 4. The dynamics of defoliation of Scots pine in 2002–2005 according to some causes of damage on Level I plots.
Kuva 4. Männyn harsuuntumisen vaihtelu 2002–2005 joidenkin tekijöiden vaivaamissa puissa I tason havaintoaloilla.

extent. The agent group ‘other’, which mainly comprises damage due to competition, was also important in this respect. *Gremmeniella abietina*, competition and *Tomicus* sp. were by far the most important of the individual damage causes in pine, when both the mean value of the extent and the proportion of injured trees were taken into account. For spruce and broadleaved trees, many more causes were important than for pine trees. Competition, soil factors, needle rust, nutrient imbalance or deficiency, unknown causes and non-identified decay fungi were among the causes in spruce. In addition to competition, anthracnoses, unknown insects and rust fungi were important in broadleaved trees.

Table 3. The mean extent of damage and proportion of trees with damage extent greater than 10% by tree species and agent groups. Data: Level I observation trees 2004–2005.
Taulukko 3. Tuhon laajuus keskimäärin ja niiden puiden osuus, joissa tuhon laajuus oli yli 10 %, puulajeittain ja aiheuttajaryhmittäin. Aineisto: I tason havaintopuut 2004–2005.

Tree species *Puulaji*	Agent group *Aiheuttajaryhmä*	Mean of damage extent, % *Tuhon laajuus keskimäärin, %*	% of trees with extent 11>100 % *Niiden puiden osuus, joissa tuhon laajuus oli 11–100 %, %*	Number of trees *Puita, kpl*
Scots pine	Game and grazing – *Selkärankaiset*	4.6	9.1	11
Mänty	Insects – *Hyönteiset*	4.5	12.4	923
	Fungi – *Sienet*	9.3	29.5	708
	Abiotic – *Abioottiset*	11.4	50.0	186
	Direct action of man – *Ihmisen toiminta*	2.9	6.9	29
	Other – *Muut tekijät*	10.6	66.2	468
	Unknown – *Tunnistamaton*	18.1	42.6	47
	Total – *Yhteensä*	12.1	31.6	2372
Norway spruce	Insects – *Hyönteiset*	12.0	36.4	22
Kuusi	Fungi – *Sienet*	9.9	20.6	863
	Abiotic – *Abioottiset*	26.7	69.1	366
	Direct action of man – *Ihmisen toiminta*	7.5	25.0	8
	Other – *Muut tekijät*	20.7	83.2	291
	Unknown – *Tunnistamaton*	22.8	66.1	56
	Total – *Yhteensä*	16.6	44.8	1606
Decidiuous	Game and grazing – *Selkärankaiset*	65.0	0.0	1
Lehtipuut	Insects – *Hyönteiset*	9.6	16.2	308
	Fungi – *Sienet*	11.5	27.8	565
	Abiotic – *Abioottiset*	21.8	60.2	98
	Direct action of man – *Ihmisen toiminta*	11.9	25.0	8
	Other – *Muut tekijät*	20.3	81.7	104
	Unknown – *Tunnistamaton*	13.3	37.5	32
	Total – *Yhteensä*	16.0	32.8	1116
All	Game and grazing – *Selkärankaiset*	11.7	16.7	12
Kaikki	Insects – *Hyönteiset*	8.47	13.7	1253
	Fungi – *Sienet*	10.8	25.5	2136
	Abiotic – *Abioottiset*	11.7	62.3	650
	Direct action of man – *Ihmisen toiminta*	7.47	13.3	45
	Other – *Muut tekijät*	19.5	73.8	863
	Unknown – *Tunnistamaton*	18.0	51.1	135
	Total – *Yhteensä*	13.4	36.0	5094

Discussion

The results of this study confirm several earlier findings. Abiotic/biotic damage and defoliation have a significant co-occurrence in individual trees. Different causes of damage cause defoliation in different years and in different areas (Nevalainen and Yli-Kojola 1994, Nevalainen and Heinonen 2000). The effects of biotic damage can last for several years, as shown by retrospective analysis (Kurkela et al. 2005).

Very few identified agents were common and important even in the specialist surveys. The Level I network is not a representative sample of the forests in Finland, due to the rather sparse network and to the fact that the sample is restricted to dominant and co-dominant trees. Therefore some important damaging agents, such as moose damage, and some locally very severe injuries (storms, insect damage) will not be detected in the monitoring. Level I data cannot be considered suitable for detailed regional analyses nor for estimates of the occurrence of damage per area, for instance.

The systematic network used in the annual forest condition monitoring has been designed to give information at the national level about crown condition and its variation principally in background areas. The network is too sparse for surveys of smaller geographical areas. Moreover, the results are only indicative especially in Northern Finland because of the small number of spruce and broad-leaves stands in the sample in that region. Due to the low density of the network, changes in forest vitality in small areas do not appear clearly in the survey results carried out in other countries either.

However, identifying the factors that may affect the vitality of forests is the key task in this work. Spatial and temporal patterns of the most important abiotic or biotic epidemics are clearly evident in the Level I data, primarily because it is an annual survey. This kind of data is very suitable for studying the temporal co-occurrence of defoliation and the most important biotic/abiotic forms of damage. The monitoring at Level I can produce excellent time series of some of the most common epidemics. The field teams have shown high motivation and professional skill also in the identification of damage causes. Although some of the causes always remain unknown, the (detailed) symptom codes help in identifying some of the causes of epidemics.

Manion (1981) classified stress factors into three groups. Predisposing factors are long-term factors that alter the tree’s ability to defend against or repair damage. Inciting factors are short-term stresses or injuries that reduce carbohydrate storage, often resulting in branch dieback. Contributing factors usually include biotic stresses or disease agents, that invade the tree leading to mortality, and many of these invade trees which have been subject to prolonged stress.

This conceptual framework is very relevant and should be utilized when the results of forest health studies are being analysed. In our conditions, tree age and unfavourable soil conditions (including the long-term effects of air pollution) can act as predisposing factors. Insect defoliation, extreme drought, mechanical injury or frost damage may be the most common inciting factors in Finland, while bark-beetles or root-decay fungi may act as contributing factors. Including biotic/abiotic damage in the analysis therefore greatly assists the interpretation of national and regional patterns of forest damage.

References

Assessment of damage causes. Submanual for Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UN/ECE, Convention on long-range transboundery air pollution, International co-operative programme on Assessment and monitoring of air pollution effects on forests. [Internet site]. Updated 06/2004. Available at: http://www.icp-forests.org/bioticdocs/manual-index.pdf.

Keane, M., McCarthy, R. & Hogan, J. 1989. Forest health surveys in Ireland: 1987 and 1988 results. Irish Forestry 46 (1): 59–62.

Kurkela, T., Aalto, T., Varama, M. & Jalkanen, R. 2005. Defoliation by the common pine sawfly (Diprion pini) and subsequent growth reduction in Scots Pine: A retrospective approach. Silva Fennica 39(4): 467–480.

Innes, J.L. & Schwyzer, A. 1994. Stem damage in Swiss Forests: Incidence, causes and relations to crown transparency. European Journal of Forest Pathology 24: 20–31.

Innes, J.L., Boswell, R., Binns, W.O. & Redfern, D.B. 1986. Forest health and air pollution. 1986 survey. Great Britain Forestry Commission, Research and Development Paper 150. 5 p.

Lindgren, M. 2002. Results of the 2001 national crown condition survey (ICP-Forests/Level I). In: Rautjärvi, H., Ukonmaanaho, L. & Raitio, H. (eds.). Forest condition monitoring in Finland. National report 2001. The Finnish Forest Research Institute, Research Papers 879: 42–50.

Manion, P.D. 1981. Tree disease concepts. Prentice Hall, Inc. Englewood Cliffs, NJ. 399 p.

Nevalainen, S. 1999. Nationwide forest damage surveys in Finland. In: Forster, B., Knizek, M. & Grodzki, W. (eds.). Methodology of Forest Insect and Disease Survey in Central Europe. Proceedings of the Second Workshop of the IUFRO Working Party 7.03.10, April 20–23, 1999, Sion-Chateauneuf, Switzerland. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf. p. 24–29.

Nevalainen, S. & Heinonen, J. 2000. Dynamics of defoliation, biotic and abiotic damage during 1986–1998. In: Mälkönen, E. (ed.). Forest Condition in a Changing Environment – the Finnish case. Forestry Sciences 65. Kluwer Academic Publishers, Dordrecht. p. 133–141.

Nevalainen, S. & Yli-Kojola, H. 1994. Abioottisten ja bioottisten tuhojen vaikutus metsien elinvoimaan. In: Mälkönen, E. & Sivula, H. (eds.). Suomen metsien kunto. Metsien terveydentilan tutkimusohjelman väliraportti. Metsäntutkimuslaitoksen tiedonantoja 527: 35–53.

Skelly, J.M. & Innes, J.L. 1994. Waldsterben in the forests of Central Europe and eastern North America: fantasy or reality? Plant Disease 78: 1021–1031.

3 Results of the intensive monitoring of forest ecosystems (Forest Focus/ICP Forests, Level II)

Metsien intensiiviseurannan tuloksia (Forest Focus/ICP metsäohjelma, taso II)

3.1 Crown condition on the Level II network 2001–2004

Puiden latvuskunto tason II havaintoaloilla vuosina 2001–2004

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The degree of defoliation, foliage discoloration and abiotic and biotic damage were recorded on the 14 Norway spruce mineral soil plots, 13 Scots pine mineral soil plots and 4 Scots pine peatland plots of the Level II network during 2001–2004. During this period, more than 85% of the spruces and more than 95% of the pines were classified as none or slight defoliated. On the spruce and pine mineral soil plots there was an increase in the proportion of slightly or moderately defoliated trees, as well as a slight increase in the average defoliation degree, from 2001 to 2004, but not on the pine peatland plots. In 2004 the average defoliation level of spruce was 19% and of pine was 10.7% on the mineral soil plots and 13.3% on the peatland plots. The proportion of discoloured spruces was lowest in 2003 (3.7%) and highest in 2004 (8.5%). On the mineral soil sites the highest proportion of discoloured pines occurred in 2003 (1.1%) and on peatland plots in 2004 (1.3%). During the period 2001–2004, the most common biotic damage agents were fungal pathogens in both tree species and insects on pine. In addition, abiotic damage on spruce increased especially in 2003.

Vuosina 2001–2004 metsäekosysteemien intensiivisessä seurannassa (ICP metsäohjelma/taso II) oli mukana 14 kuusi- ja 13 mäntyalaa ja 4 turvemailla sijaitsevaa mäntyalaa. Latvuskunnon arvioinnin yhteydessä puista arvioidaan niiden harsuuntumisaste, värioireiden määrä sekä erilaiset tuhot. Jaksolla 2001–2004 >85 % kuusista ja >95 % männyistä luokiteltiin lievästi tai ei lainkaan harsuuntuneiksi. Seurantajakson aikana alle 25 % harsuuntuneiden puiden osuus samoin kuin keskimääräinen harsuuntumisaste lisääntyivät jonkin verran molemmilla puulajeilla kivennäismaiden aloilla, mutteivät turvemaiden aloilla. Kuusien keskimääräinen harsuuntumisaste oli 19 % vuonna 2004. Mäntyjen keskimääräinen harsuuntumisaste oli kivennäismaiden aloilla 10,7 % ja turvemailla 13,3 % vuonna 2004. Värioireellisten kuusten osuus oli alin vuonna 2003 (3,7 %) ja korkein vuonna 2004 (8,5 %). Värioireellisia mäntyjä oli seurantajaksolla selvästi vähemmän. Seurantajaksolla 2001–2004 havupuiden yleisimpiä tuhonaiheuttajia olivat sienet ja männyllä myös hyönteiset. Lisäksi abioottiset tuhot lisääntyivät kuusella vuonna 2003.

Introduction

The 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 plots, and on the four Scots pine plots on peatland. Defoliation, needle discoloration, and abiotic and biotic damage were assessed on 20 trees on each sub-plot. The results for 2001 and 2004 are therefore based on 721 pines and 792 spruces growing on the Level II mineral soil plots, and on 240 pines on the peatland plots. The assessment of sample trees was carried out according to the ICP-Forests manual (current edition: Manual on methods... 2006). In Finland, however, defoliation and discoloration of spruce were estimated on the upper half of the living crown, and of pine on the upper 2/3 of the living crown in 5% classes in the same way as in Level I. During summer 2004 the new method (manual update 06/2004) for damage assessment was applied.

Results

In general, more than 85% of the spruces and more than 95% of the pines were classified as none or slight defoliated during 2001–2004 (Table 1). However, on the spruce and pine mineral soil sites there was an increase in the proportion of slightly or moderately defoliated trees, as well as a slight increase in the average defoliation, from 2001 to 2004, but not on the pine peatland plots (Table 1, Fig. 1). The average defoliation degree of spruce and pine on each of the sample plots during 2001–2004, is shown in Figures 2 and 3. On spruce, there was a more than 3%-units increase in the average defoliation degree from 2001 to 2004 on the Juupajoki, Tammela, Uusikaarlepyy and Solböle plots, and on pine on the Juupajoki and Miehikkälä plots. However, the average defoliation degree on these plots was less than 20% for both species (Fig. 2). The maximum site-specific increase from 2001 to 2004 for spruce was 4%-units on the Uusikaarlepyy plot, and for pine 3.7%-units on the Miehikkälä plot. The highest average degree of defoliation on spruce during 2001–2004 occurred on the Evo (ca. 29%, average for 2001–2004) and Oulanka (ca. 27%) plots, and the lowest average degree of defoliation (ca. 10%) on the Uusikarlepyy plot (Fig. 2). The highest average defoliation degree on pine occurred on the Lieksa plot (ca. 25%), and the lowest (ca. 5%) on the Kivalo, Punkaharju and Tammela plots.

The proportion of discoloured Scots pines (proportion of discoloured needles mass more than 10%) was very low during the period 2001–2004 (Table 2). However, the proportion of slightly discoloured Norway spruce was higher than in pine and increased during 2003–2004 (Table 2). The most abundant discoloration symptoms on Norway spruce at Level II were needle tip yellowing and apical yellowing and overall yellowing of more than one-year old needles.

Table 1. The proportion of trees in different defoliation classes (amount of needle loss in assessable crown) on the mineral soil and peatland plots during 2001–2004.
Taulukko 1. Kivennäis- ja turvemailla kasvavien puiden jakautuminen neljään eri harsuuntumisluokkaan vuosina 2001–2004.

Tree species	Year	Number of trees	Needle loss classes, % – *Neulaskatoluokat, %*			
Puulaji	*Vuosi*	*Puiden lkm*	0–10	11–25	26–60	>60
Norway spruce	2001	797	33.9	54.4	11.2	0.5
Kuusi	2002	797	30.5	56.9	12.1	0.5
	2003	797	26.2	62.1	11.1	0.6
	2004	797	24.6	61.5	13.4	0.5
Scots pine	2001	722	74.8	22.3	2.9	0.0
Mänty	2002	722	71.8	25.3	2.9	0.0
	2003	722	69.7	27.4	2.9	0.0
	2004	722	67.5	28.9	3.6	0.0
Scots pine	2001	240	46.3	51.3	2.5	0.0
(peatland plots)	2002	240	50.4	46.7	2.9	0.0
Mänty	2003	240	45.8	52.1	2.1	0.0
(turvealat)	2004	240	52.1	47.1	0.8	0.0

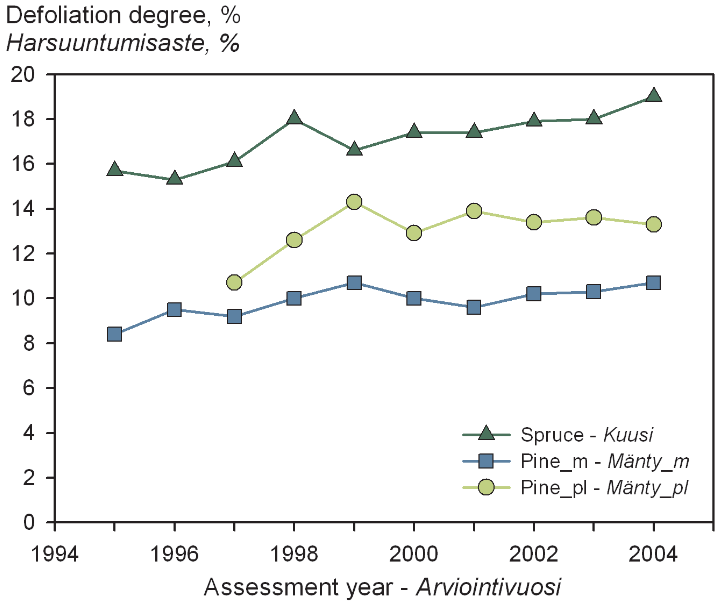

Figure 1. The average defoliation degree of Norway spruce and Scots pine during 1995–2004 on the Level II mineral soil (m) and peatland (pl) plots in Finland.
Kuva 1. Kuusen ja männyn keskimääräinen harsuuntumisaste tason II kivennäis- (m) ja turvemailla (pl) vuosina 1995–2004.

Table 2. The proportion of trees in different discoloration classes (amount of discoloured needle mass in assessable crown) on the mineral soil and peatland plots during 2001–2004.
Taulukko 2. Kivennäis- ja turvemailla kasvavien puiden jakautuminen neljään eri värioireluokkaan vuosina 2001–2004.

Tree species	Year	Number of trees	Discoloration classes, % – *Värioireluokat, %*			
Puulaji	*Vuosi*	*Puiden lkm*	0–10	11–25	26–60	>60
Norway Spruce	2001	792	94.6	5.2	0.2	0.0
Kuusi	2002	792	94.3	5.3	0.3	0.1
	2003	792	95.7	3.7	0.4	0.0
	2004	792	90.7	8.8	0.4	0.1
Scots pine	2001	721	100.0	0.0	0.0	0.0
Mänty	2002	721	99.9	0.1	0.0	0.0
	2003	721	98.9	1.1	0.0	0.0
	2004	721	99.6	0.3	0.0	0.1
Scots pine	2001	240	99.2	0.8	0.0	0.0
(peatland plots)	2002	240	100.0	0.0	0.0	0.0
Mänty	2003	240	99.6	0.4	0.0	0.0
(turvealat)	2004	240	98.7	1.3	0.0	0.0

The proportion of spruces with signs of damaging agents varied from 28% in 2001 to 11% in 2004, and of pine from 29.2% in 2001 to 1.5% in 2003 (Fig. 4). During 2001–2004 the most common biotic damaging agents were fungal pathogens on both tree species and insects on pine. Practically no insect damage was detected on spruce. The proportion of trees with fungal pathogens decreased clearly during the period 2001–2004 in both species. Abiotic (e.g. wind, snow) damage and man-made damage and competition (grouped as “other” damaging agents) were also an important group on both tree species. The proportion of trees with abiotic damage

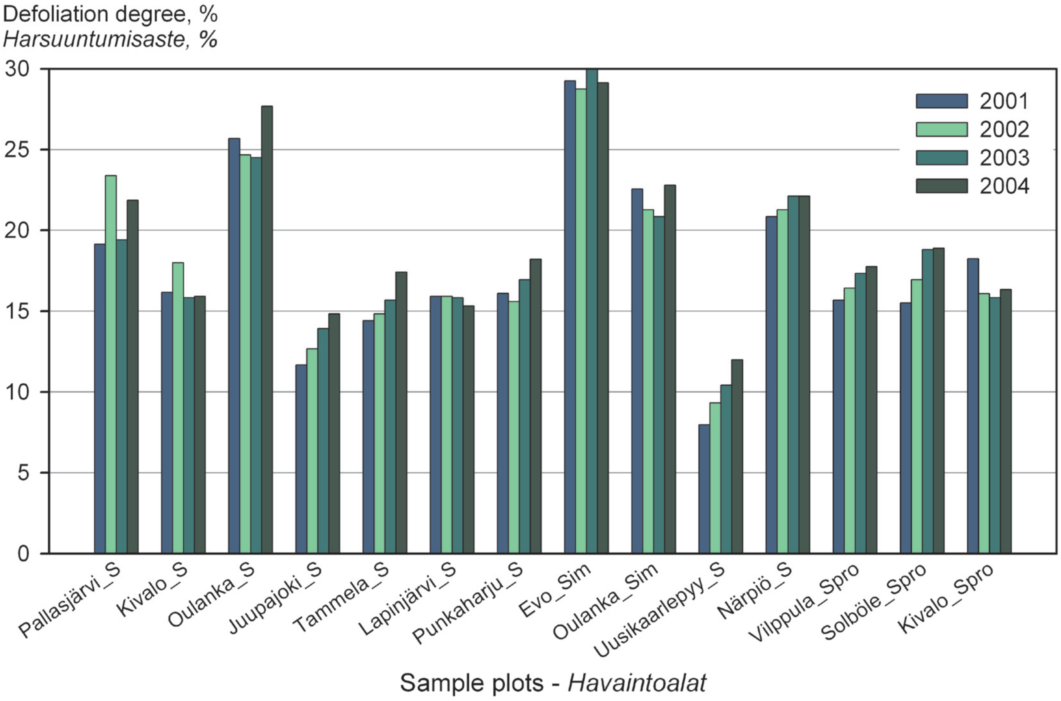

Figure 2. The average defoliation of Norway spruce during 2001–2004 on the Level II plots in Finland.
Kuva 2. Kuusen keskimääräinen harsuuntumisaste havaintoaloittain vuosina 2001–2004.

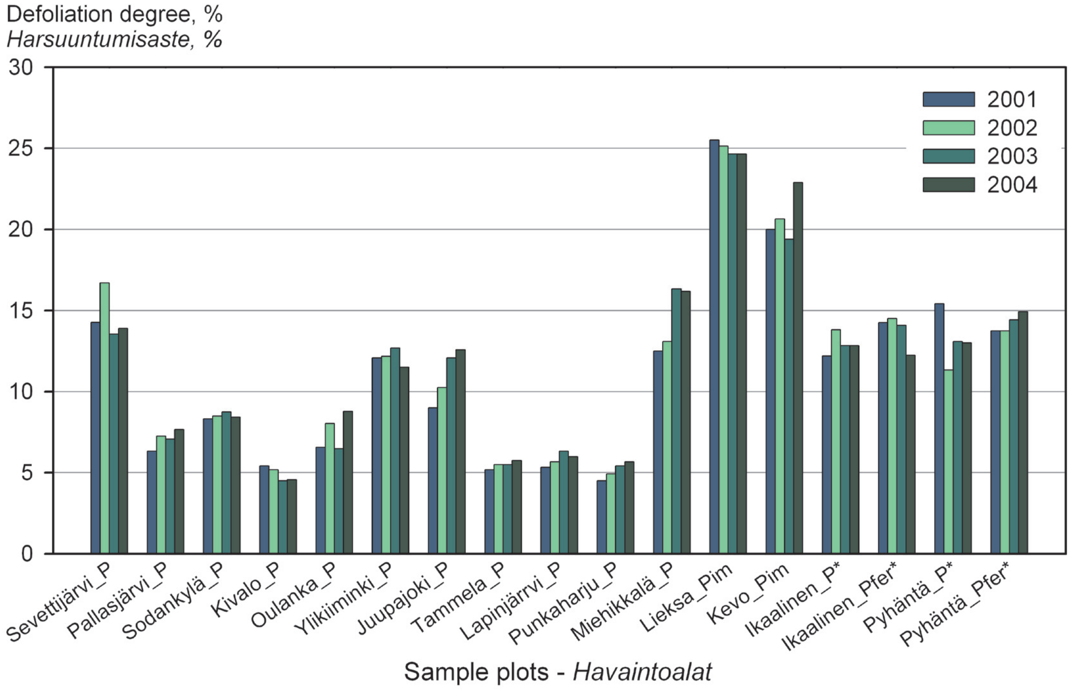

Figure 3. The average defoliation of Scots pine during 2001–2004 on the Level II plots in Finland. Peatland sites are indicated with an asterisk.
*Kuva 3. Männyn keskimääräinen harsuuntumisaste havaintoaloittain vuosina 2001–2004. * = turvemaiden havaintoala.*

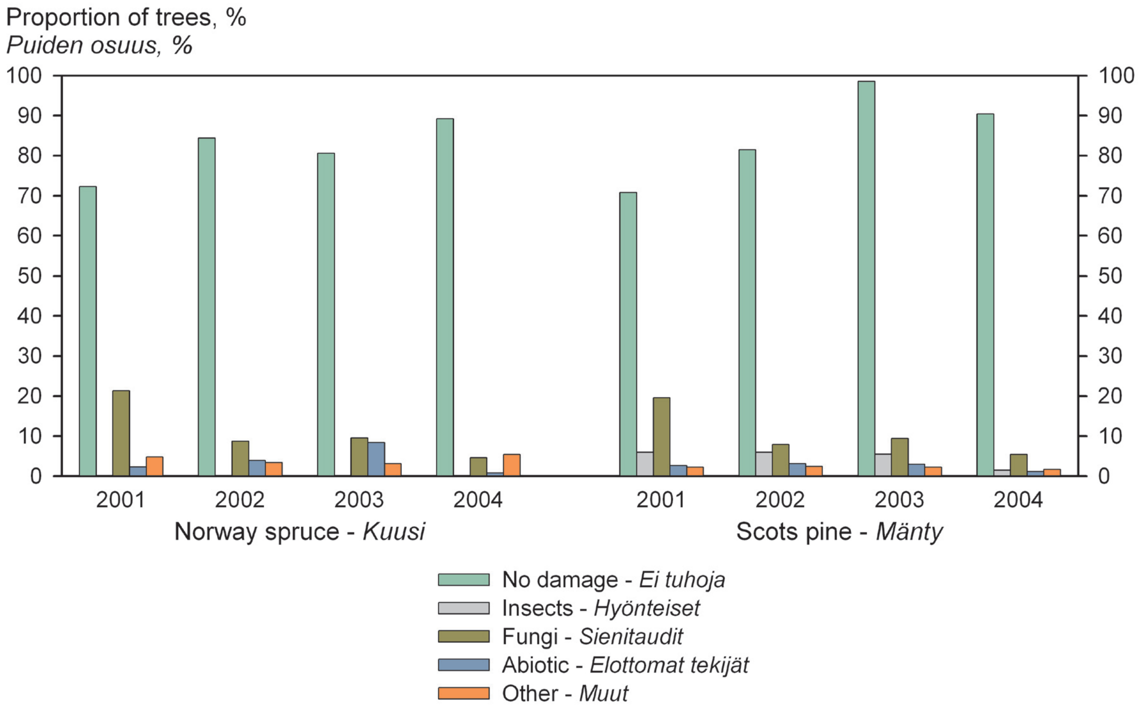

Figure 4. The proportion of trees in different damage classes on the Level II plots during 2001–2004. *Other includes e.g. competition and man-made damage. Due to fact that the assessed trees might have more than one type of damage, the sum of the proportions of trees might be more than 100 % in certain years.
*Kuva 4. Puiden jakautuminen eri tuholuokkiin tason II havaintoaloilla vuosina 2001–2004. *Luokka "Muut" sisältää esim. kilpailun ja ihmisen aiheuttamat tuhot. Koska arvioitavalla puulla voi olla enemmän kuin yksi tuho niin kuvan pylväiden summa saattaa jonakin vuonna ylittää 100 %.*

was highest in 2003 on spruce (ca. 8% of trees) and in 2002 on pine (ca. 3% of trees) (Fig. 4). For more comprehensive information about the abiotic and biotic damage in Finland, see Chapters 2.2, 4.2 and 4.3 in this volume.

References

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 2006. Part II. Visual assessment of crown condition. [Internet site]. UN-ECE. Programme coordination centre, Hamburg. Available at: http://www.icp-forests.org/manual.htm.

3.2 Needle chemistry on the intensive monitoring plots 1995–2003

Neulasten kemiallinen koostumus intensiiviseurannan havaintoaloilla vuosina 1995–2003

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The elemental composition of needles has been monitored bi-annually on all the plots belonging to the Level II intensive monitoring network during 1995–2003. During this period, there were no drastic changes in the nutrient status of the trees on the plots. Consistently with the observed decrease in sulphur deposition, foliar sulphur concentrations showed a slight decreasing trend during the period.

Neulasten alkuainekoostumusta on seurattu joka toinen vuosi metsien intensiiviseurannan (taso II) havaintoaloilla vuosina 1995–2003. Havaintojakson aikana puiden ravinnetilassa ei ole tapahtunut jyrkkiä muutoksia. Rikkilaskeumassa tapahtunut lasku näkyy lievästi laskevana trendinä myös neulasten rikkipitoisuudessa.

Introduction

The elemental composition of foliage represents an important tool when diagnosing nutrient deficiencies, excesses and imbalances in forest trees (Kimmins 1987, Walworth and Sumner 1988). When carefully applied, the chemical composition of leaves may qualify as a competent indicator of health status at the ecosystem level. Changes in the nutrient status of trees may result from several factors affecting nutrient availability and needle mass, such as the occurrence of abiotic and biotic damage, fluctuation in weather conditions, changes in anthropogenic deposition or, in general, changes in the nutrient pools in the ecosystem.

In monitoring studies designed to detect temporal changes in the ecosystem, carefully standardized sampling design and consistent analysis, as well as regularly implemented quality control, are of utmost importance (e.g. Sulkava et al. 2007). In the ICP Forests/Forest Focus monitoring programmes, the analytical quality of needle elemental analysis is constantly monitored by means of method blanks and regular analysis of internal and certified reference samples. In addition, the laboratories participate in international and national inter-laboratory tests. The inter-laboratory comparisons have shown that Metla's laboratories (Parkano and Vantaa), which are responsible for carrying out chemical leaf analysis in the Finnish ICP Forests/Forest Focus programme, are of high quality (e.g. Bartels 2002).

In Finland, the nutritional status of the trees on the 31 Level II plots has been monitored biannually since 1995 (Raitio 1999). In this article we report the results of the surveys carried out in 1995/96, 1997, 1999, 2001 and 2003.

Material and methods

Two sets of 10 predominant or dominant sample trees are selected for needle chemistry analyses on each Level II plot. Sample branches are taken from 10 of these trees every second year. The two tree sets are sampled in rotation, i.e. each set is sampled every 4 years. This arrangement is being employed in order to minimise damage to the trees as a result of branch removal. The first tree set (18 plots) was sampled in 1995 (supplemented by two plots in 1996). Since then, all 31 plots in the Level II network were sampled in 1997, 1999, 2001 and 2003. The sample branches with current (C) and previous-year needles (C+1) were collected from the uppermost third of the living crown with a pruning device during October and November.

The branches were stored in a freezer (-18°C) during the period between sampling and pre-treatment. In the pre-treatment procedure, the branches were cut in order to separate shoot sections bearing different needle-year classes. Shoots with the same needle-year class of each tree were pooled and subsequently treated as a separate sample. The shoots were dried at 40°C for 10 days and the needles then removed from the shoots. The dry needles were milled using an ultracentrifugal mill (Retsch type Zm 1, mesh size 1 mm).

Unwashed needles from each tree (n = 10) from each plot were analysed separately for the nitrogen (N), sulphur (S), phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), and boron (B). The N concentration of the needles were determined without any further pre-treatment on a CHN analyser (1995, 1997 and 1999 samples: LECO CHN-600 Analyser, 2001 and 2003 samples: LECO CHN-2000 Analyser). The S, P, Ca, K, Mg, Zn, Mn, Fe and Cu concentrations in the needles were determined, following wet digestion in HNO_3/H_2O_2, by inductively coupled plasma atomic emission spectroscopy (ICP/AES). For the 1995 and 1997 samples, digestion was performed by the open wet digestion method (Thermolyne 2200 Hot Plate), followed by determination on an ARL 3580 ICP emission spectrometer. For the 1999, 2001 and 2003 samples, the needle samples were digested by the closed wet digestion method in a microwave (CEM MDS 2000) and analysed on a TJA Iris Advantage ICP-emission spectrometer. For the samples of 1995 and 1997, B was determined by azomethin H-reagent on a UV-VIS spectrophotometer, and for samples of 1999 and onwards, B was determined by ICP/AES after CEM digestion. The results are expressed as mean concentrations per plot per 105°C dry weight.

Results and discussion

During the period 1995–2003 the tree nutrient status on the Level II plots showed no drastic changes (Figs. 1–12). The observed annual variation in the nutrient concentrations primarily results from differences in the weather conditions between the years, and analytical variation plays only a minor or negligible role (Table 1). The overall mean ± S.D. (1995–2003) for the concentrations of each element in Scots pine and Norway spruce needles are presented in Table 2.

Consistently with the observed decrease in S deposition (see Chapter 3.5) and in S concentrations in the needles on the Level I plots (Lorenz et al. 2003, Luyssaert et al. 2003), foliar S concentrations showed a slight, decreasing trend from 1995 to 2003 (Figs. 1, 4, 7 and 10). This trend may, however, be strengthened by the fact that there is a slight decreasing trend in the level of the foliar

S concentrations due to analytical reasons (Table 1, see also Luyssaert et al. 2004). In contrast, the foliar Cu concentrations showed an apparent increasing trend on several plots (Figs. 3, 6, 9 and 12). The increasing trend results, at least partly, from the improved accuracy and sensitivity of the analytical method for microelements such as Cu.

The Cu concentrations on Plot nr. 1 (Sevettijärvi) clearly stand out from the concentrations on the other plots (Figs. 3 and 6). The elevated Cu concentrations may be due to Cu deposition originating from the copper-nickel smelter in Nikel, which is located on the Kola Peninsula in Russia at a distance of ca. 70 km from the Sevettijärvi plot. In general, the plots located near the coast show higher B concentrations than those in inland (Figs. 3, 6, 9 and 12). This difference is especially distinct in northern Finland; foliar B concentrations at Sevettijärvi (nr. 1) and Kevo (nr. 22) are clearly higher than on the other pine plots in northern Finland (Figs. 3 and 6), and indicates the significance of sea spray as a source of B deposition.

Table 1. Average value (± 0.5 * 95% confidence interval) of certified reference material (spruce needles, CRM 101) from the Community Bureau of Reference for nitrogen (N), sulphur (S), phosphorus (P), calcium (Ca), magnesium (Mg), zinc (Zn) and manganese (Mn) analysed in conjunction with the needle material of this study. Number of repetitions for nitrogen/other elements is indicated.
*Taulukko 1. Tämän tutkimuksen neulasanalyysien yhteydessä analysoidun sertifioidun vertailumateriaalin (Community Bureau of Reference, kuusen neulaset, CRM101) typpi (N)-, rikki (S)-, fosfori (P)-, kalsium (Ca)-, magnesium (Mg)-, sinkki (Zn)- ja mangaani (Mn)-pitoisuuksien keskiarvot (± 0.5 * 95 % luottamusväli). n = toistojen määrä (typpi/muut alkuaineet).*

	N	S	P	Ca	Mg	Zn	Mn
	mg g^{-1}					mg kg^{-1}	
CRM 101	18.89 ± 0.18	1.70 ± 0.04	1.69 ± 0.04	4.28 ± 0.08	0.619 ± 0.009	35.3 ± 2.3	915 ± 11
1995 n = 10/15	18.6 ± 0.06	1.79 ± 0.08	1.79 ± 0.10	4.20 ± 0.33	0.62 ± 0.04	32.8 ± 1.8	895 ± 51
1997 n = 4/3	18.4 ± 0.26	1.67 ± 0.05	1.84 ± 0.03	4.32 ± 0.07	0.57 ± 0.13	30.9± 1.5	850 ± 3
1999 n = 23/23	19.2 ± 0.10	1.66 ± 0.10	1.79 ± 0.12	4.22 ± 0.32	0.61 ± 0.04	31.5 ± 1.9	913 ± 72
2001 n = 19/13	19.2 ± 0.04	1.70 ± 0.04	1.83 ± 0.06	4.24 ± 0.16	0.61 ± 0.02	32.6 ± 1.4	908 ± 26
2003 n = 11/12	19.2 ± 0.03	1.54 ± 0.06	1.71 ± 0.06	4.12 ± 0.12	0.59 ± 0.02	30.3 ± 1.0	883 ± 49

Table 2. Overall average ± S.D. for nitrogen, sulphur, phosphorus, calcium, potassium, magnesium, zinc, manganese, iron and copper concentrations in current (C) and previous-year (C+1) Scots pine and Norway spruce needles. The samples were taken from Level II observation plots in 1995/96, 1997, 1999, 2001 and 2003. The four plots located on peatland (nrs. 27, 26, 29 and 30) have been excluded.
Taulukko 2. Kuusen ja männyn nuorimpien (C) ja edellisenä kesänä syntyneiden (C+1) neulasten typpi-, rikki-, fosfori-, kalsium-, kalium-, magnesium-, sinkki-, mangaani-, rauta- ja kuparipitoisuuksien keskiarvot keskihajontoineen. Näytteet on kerätty II tason aloilta vuosina 1995/96, 1997, 1999, 2001 ja 2003. Turvemailla sijaitsevien havaintoalojen (no. 27, 26, 29 ja 30) tuloksia ei ole sisällytetty keskiarvoihin.

Element *Alkuaine*	Scots pine – *Mänty* n = 65		Norway spruce – *Kuusi* n = 56	
	C needles *C-neulaset*	C+1 needles *C+1 -neulaset*	C needles *C-neulaset*	C+1 needles *C+1 -neulaset*
N, mg g^{-1}	11.9 ± 1.38	11.7± 1.43	11.8 ± 1.66	10.8 ± 1.30
S, mg g^{-1}	0.85 ± 0.09	0.86 ± 0.10	0.84 ± 0.09	0.83 ± 0.08
P, mg g^{-1}	1.46 ± 0.14	1.31 ± 0.12	1.60 ± 0.22	1.31 ± 0.25
Ca, mg g^{-1}	1.87 ± 0.37	3.08 ± 0.53	3.67 ± 0.75	6.41 ± 1.62
K, mg g^{-1}	5.22 ± 0.34	4.58 ± 0.43	6.65 ± 0.79	4.99 ± 0.65
Mg, mg g^{-1}	1.02 ± 0.13	0.89 ± 0.17	1.14 ± 0.14	1.05 ± 0.15
Zn, mg kg^{-1}	39.1 ± 5.0	48.2 ± 7.1	33.8 ± 6.9	37.0 ± 13.1
Mn, mg g^{-1}	406 ± 114	667 ± 196	673 ± 192	1037 ± 312
Fe, mg kg^{-1}	28.5 ± 5.7	40.1 ± 9.7	26.1 ± 5.3	30.6 ± 6.5
Cu, mg kg^{-1}	2.7 ± 0.5	2.2 ± 0.4	2.0 ± 0.3	1.7 ± 0.3
B, mg kg^{-1}	11.3 ± 4.32	10.3 ± 4.71	11.3 ± 3.75	12.4 ± 6.10

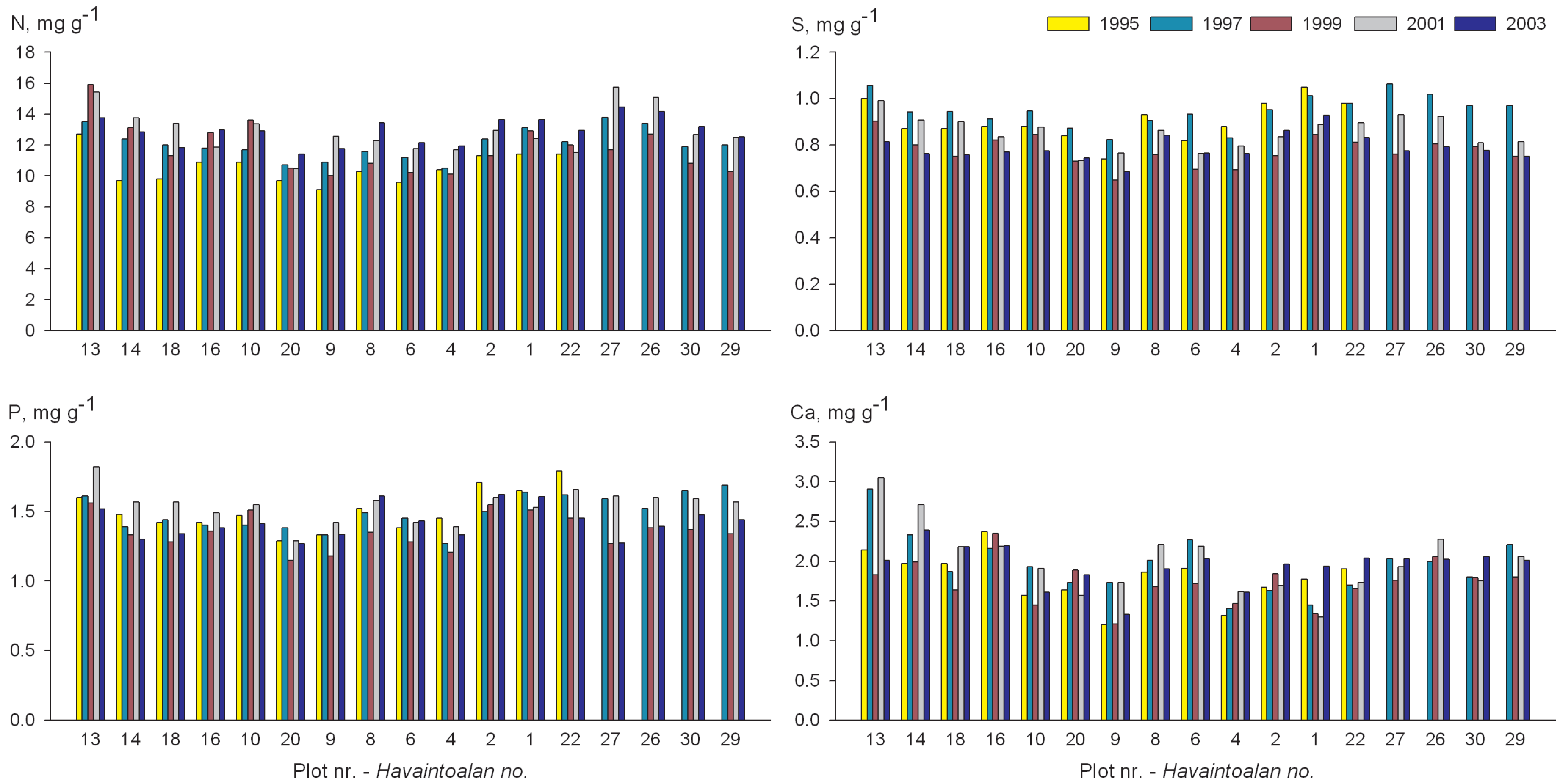

Figure 1. Average nitrogen (N), sulphur (S), phosphorus (P) and calcium (Ca) concentrations in current-year (C) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are located on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).
Kuva 1. Männyn nuorimpien neulasten keskimääräiset typpi (N)-, rikki (S)-, fosfori (P)- ja kalsium (Ca)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

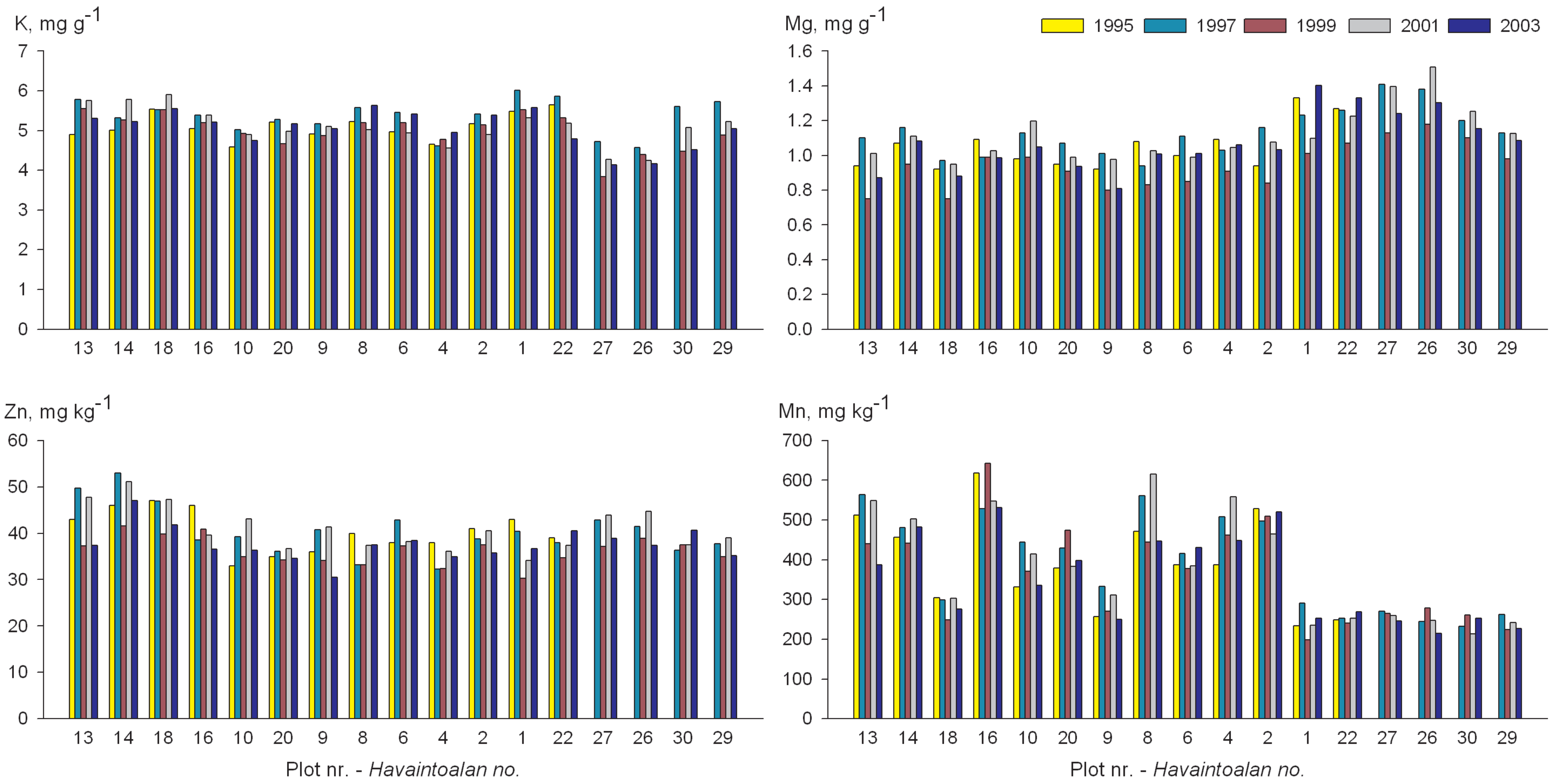

Figure 2. Average potassium (K), magnesium (Mg), zinc (Zn) and manganese (Mn) concentrations in current-year (C) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are located on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).

Kuva 2. Männyn nuorimpien neulasten keskimääräiset kalium (K)-, magnesium (Mg)-, sinkki (Zn)- ja mangaani (Mn)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

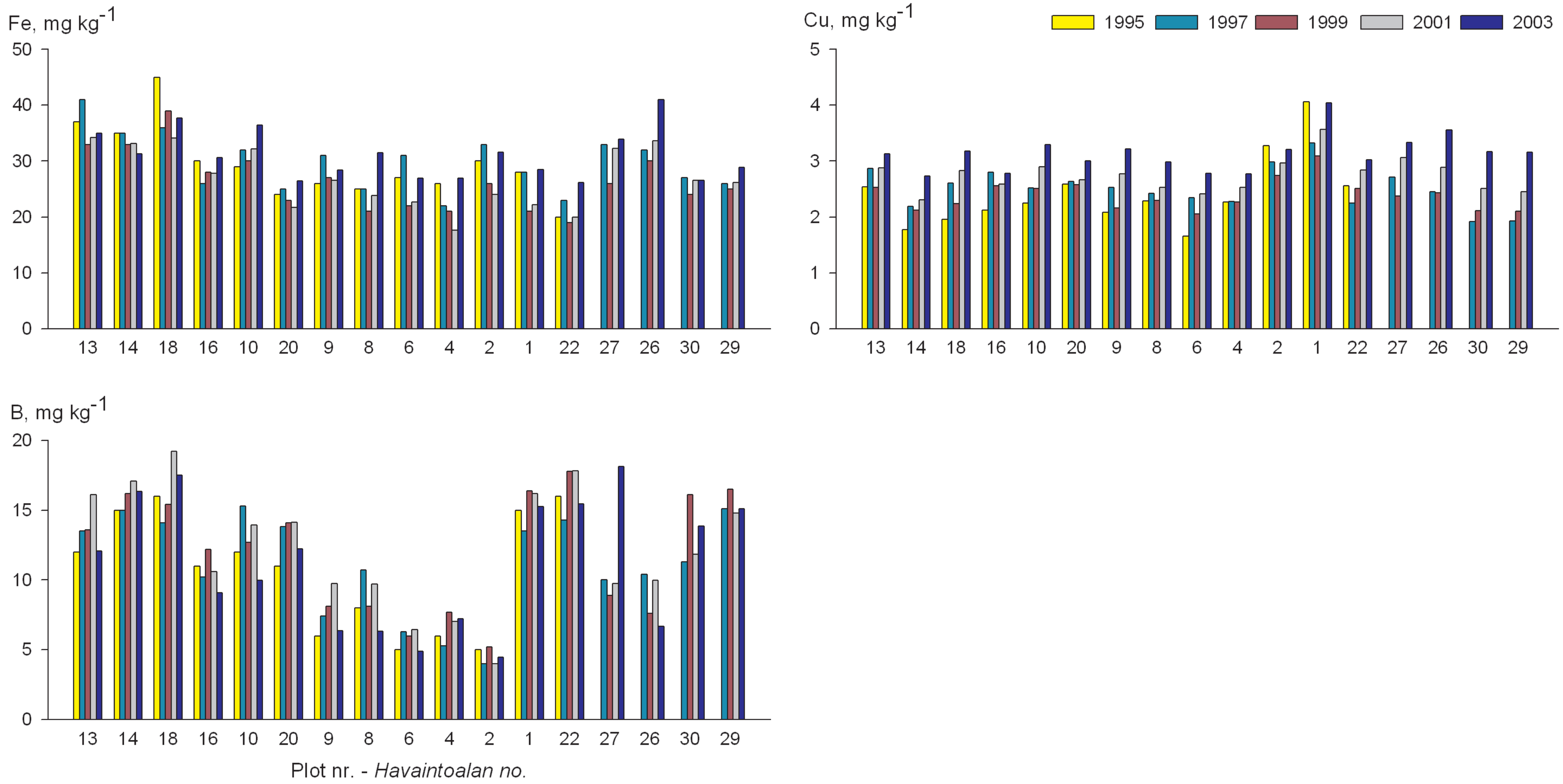

Figure 3. Average iron (Fe), copper (Cu) and boron (B) concentrations in current-year (C) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are located on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).

Kuva 3. Männyn nuorimpien neulasten keskimääräiset rauta (Fe)-, kupari (Cu)- ja boori (B)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

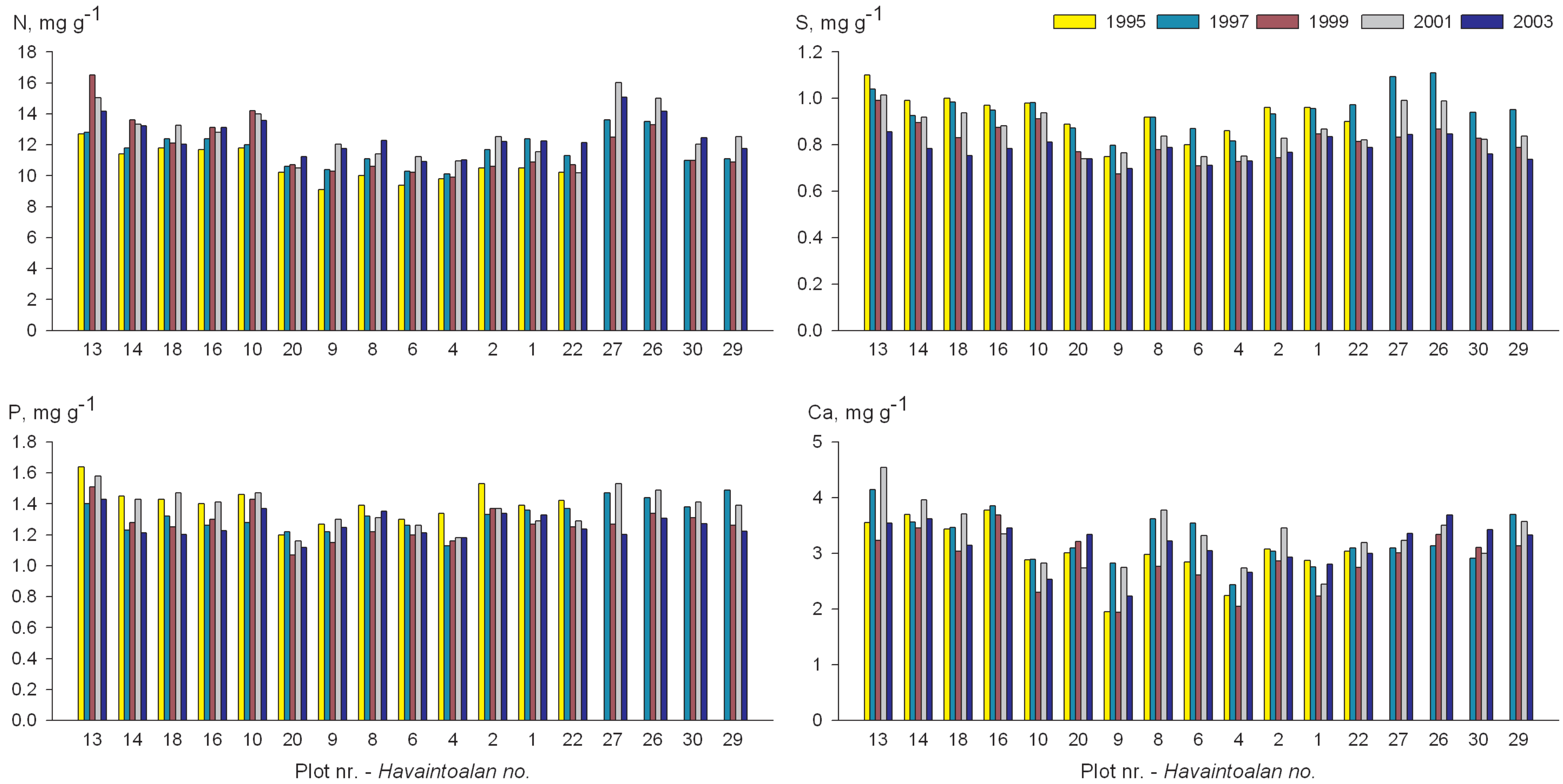

Figure 4. Average nitrogen (N), sulphur (S), phosphorus (P) and calcium (Ca) concentrations in previous-year (C+1) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are located on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).
Kuva 4. Männyn edellisenä kesänä syntyneiden neulasten keskimääräiset typpi (N)-, rikki (S)-, fosfori (P)- ja kalsium (Ca)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

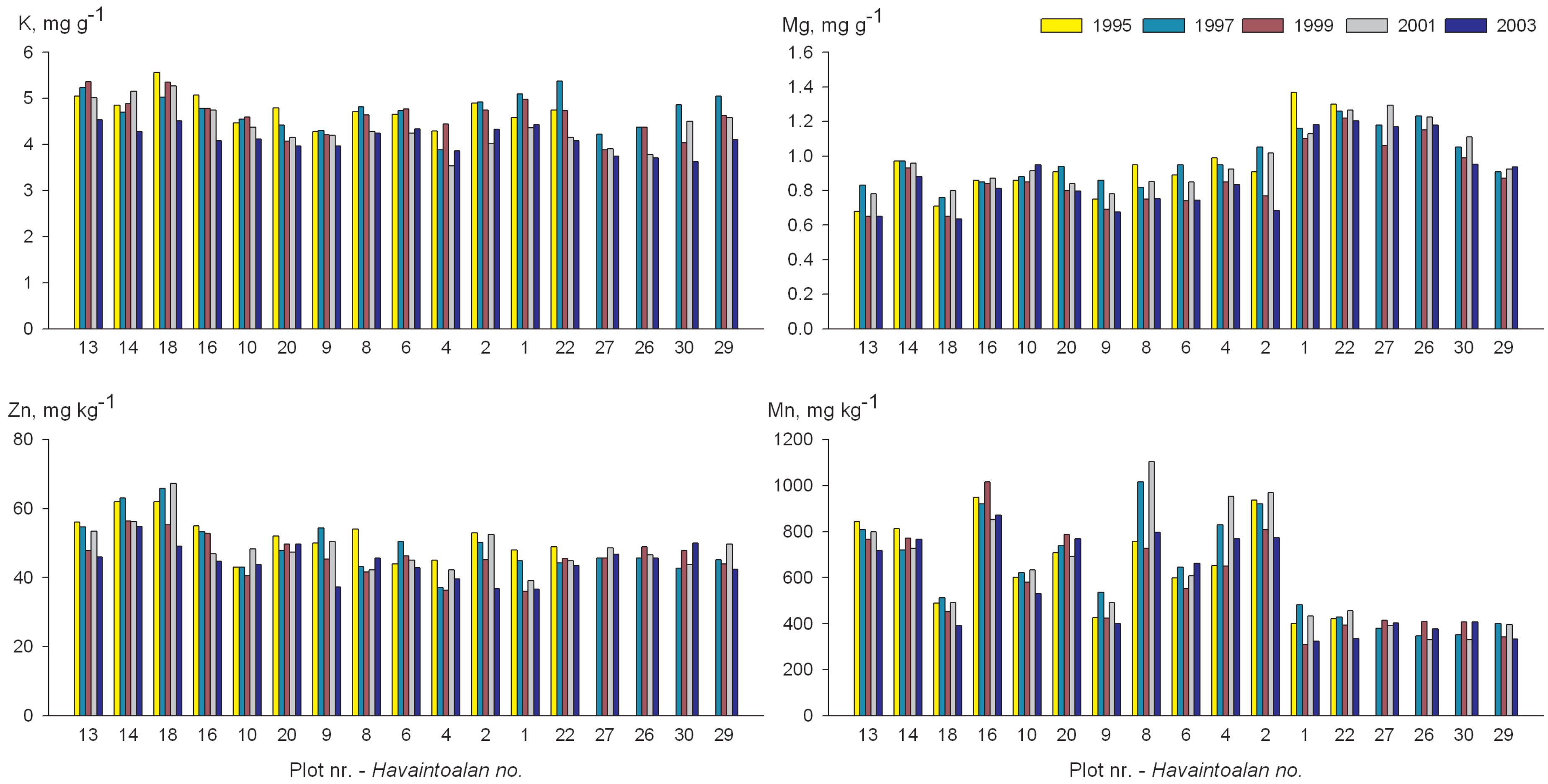

Figure 5. Average potassium (K), magnesium (Mg), zinc (Zn) and manganese (Mn) concentrations in previous-year (C+1) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are locating on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).
Kuva 5. Männyn edellisenä kesänä syntyneiden neulasten keskimääräiset kalium (K)-, magnesium (Mg)-, sinkki (Zn)- ja mangaani (Mn)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

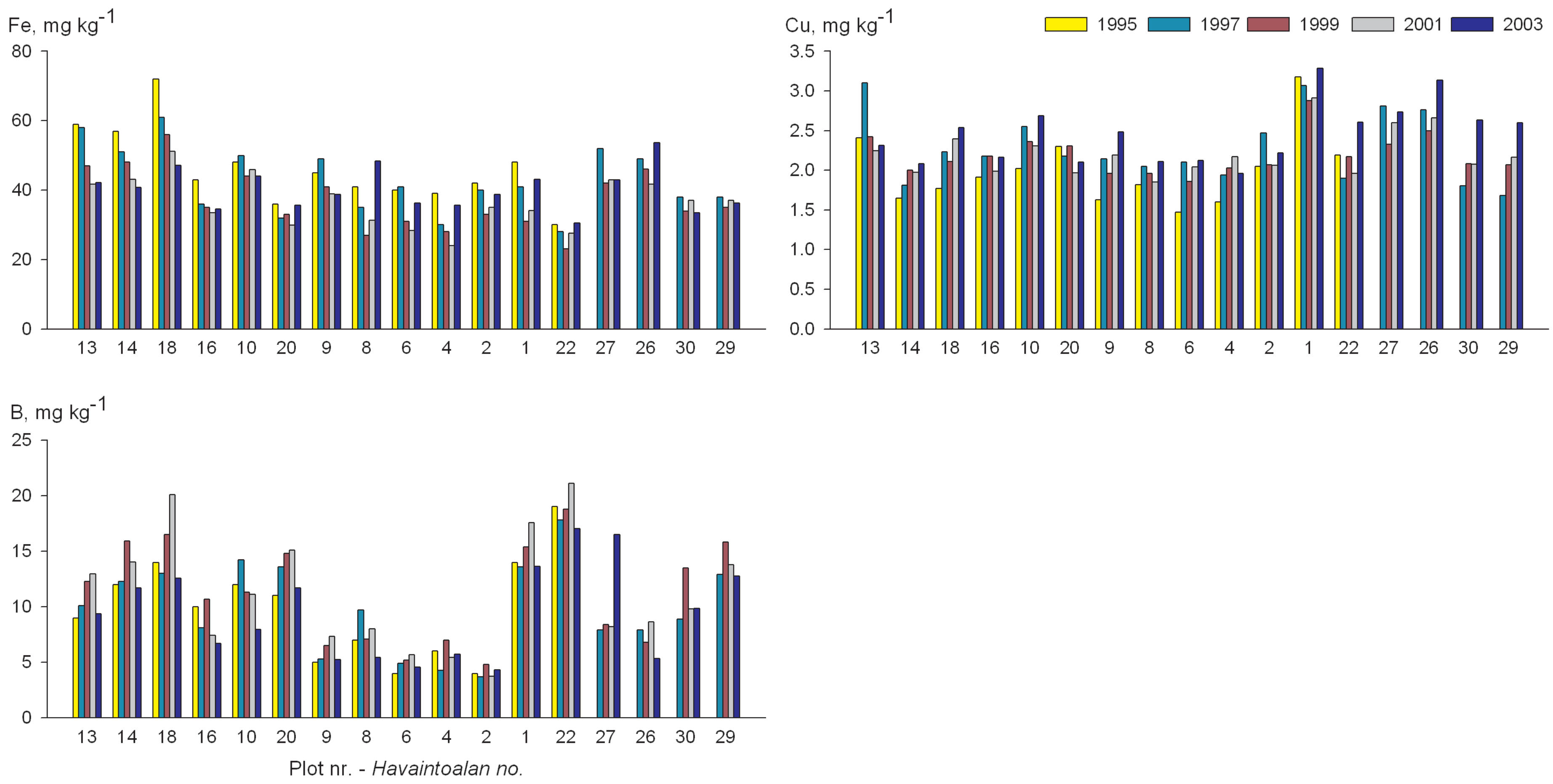

Figure 6. Average iron (Fe), copper (Cu) and boron (B) concentrations in previous-year (C+1) Scots pine needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The last four plots are locating on peatland (nrs. 27, 26, 30 and 29). The plots are arranged in order of latitude (S to N).

Kuva 6. Männyn edellisenä kesänä syntyneiden neulasten keskimääräiset rauta (Fe)-, kupari (Cu)- ja boori (B)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalat no. 27, 26, 30 ja 29 (oik.) sijaitsevat turvemailla. Havaintoalojen järjestys etelästä pohjoiseen.

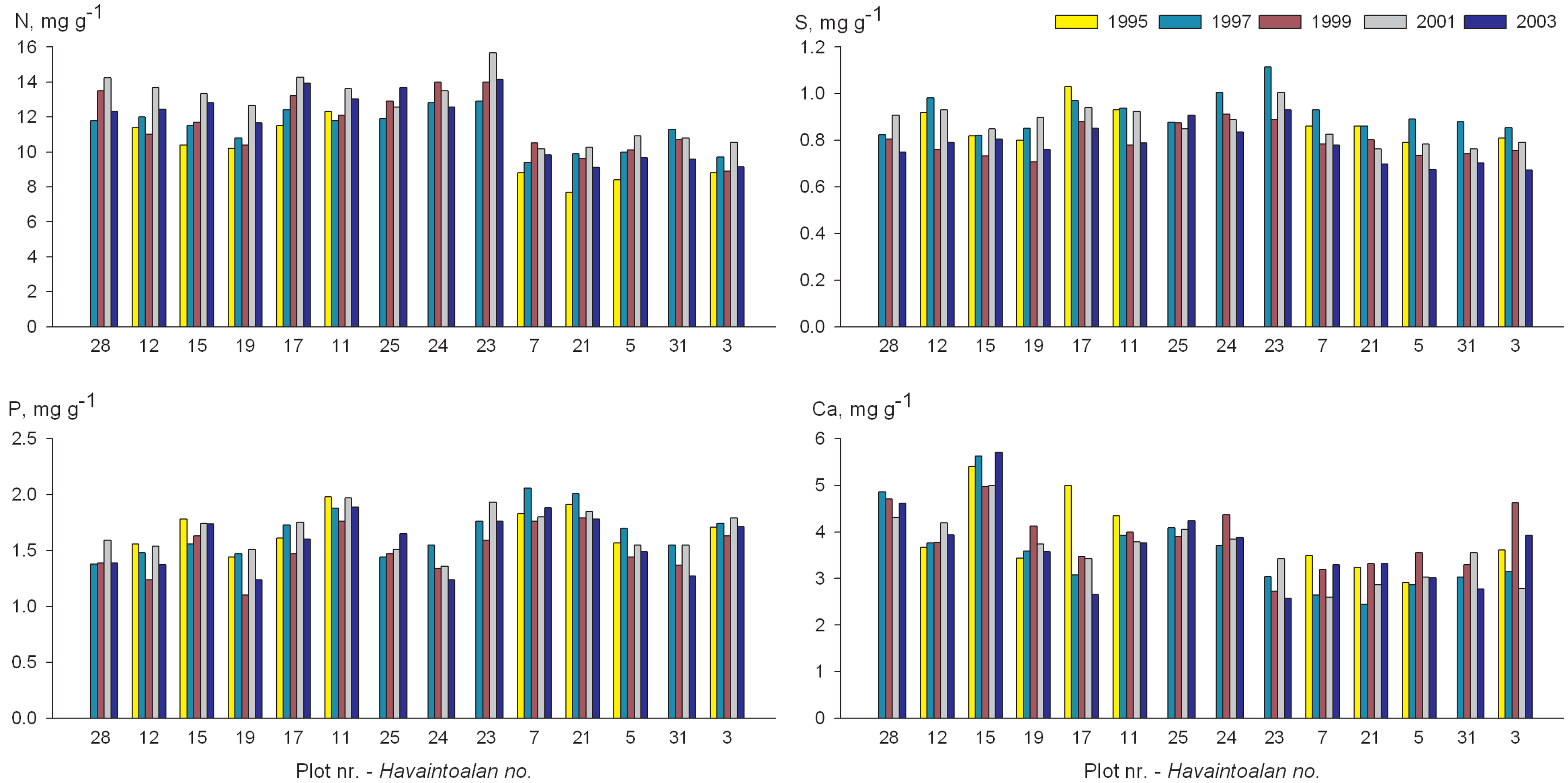

Figure 7. Average nitrogen (N), sulphur (S), phosphorus (P) and calcium (Ca) concentrations in current-year (C) Norway spruce needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged in order of latitude (S to N).
Kuva 7. Kuusen nuorimpien neulasten keskimääräiset typpi (N)-, rikki (S)-, fosfori (P)- ja kalsium (Ca)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

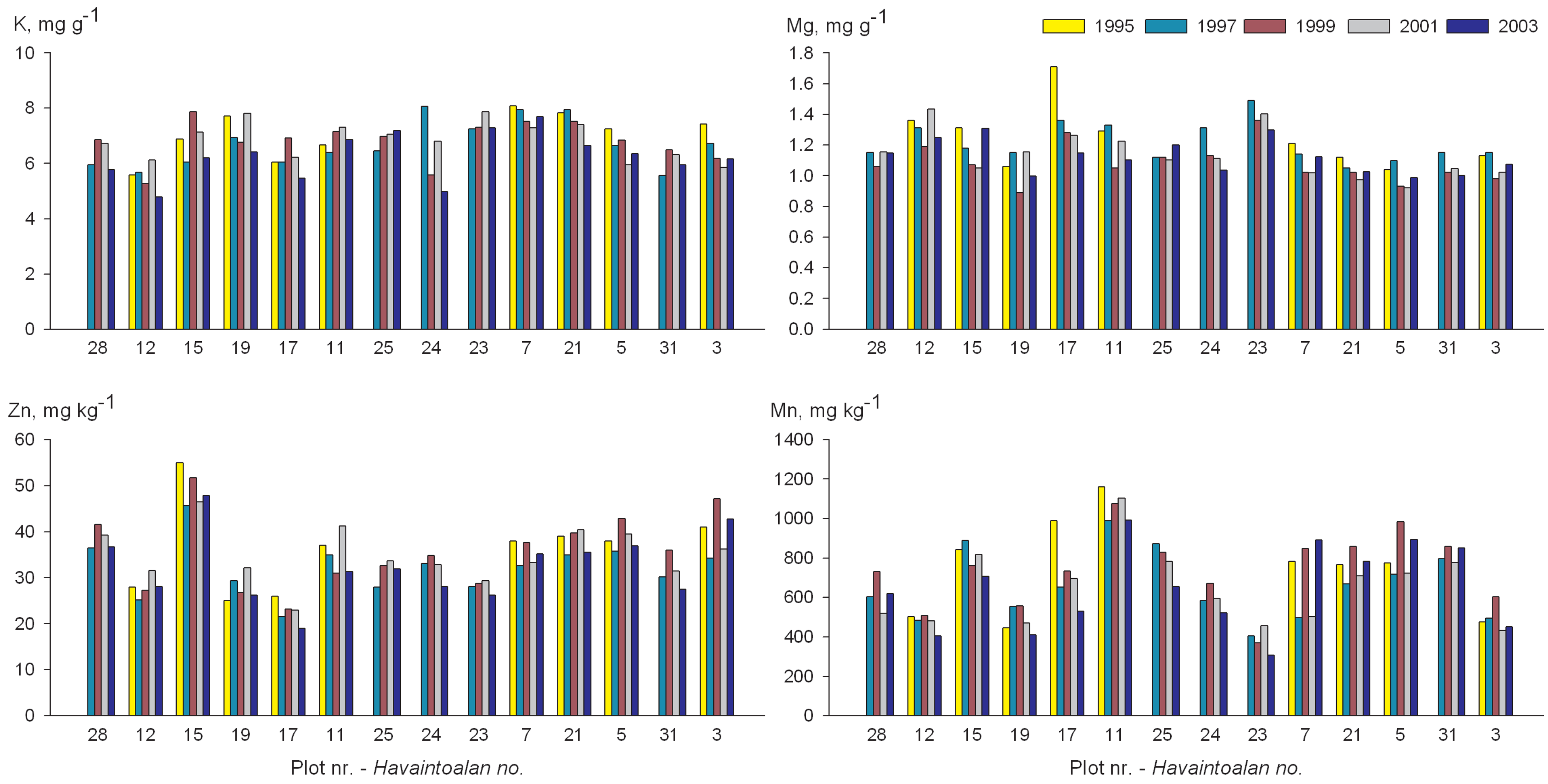

Figure 8. Average potassium (K), magnesium (Mg), zinc (Zn) and manganese (Mn) concentrations in current-year (C) Norway spruce needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged in order of latitude (S to N).

Kuva 8. Kuusen nuorimpien neulasten keskimääräiset kalium (K)-, magnesium (Mg)-, sinkki (Zn)- ja mangaani (Mn)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

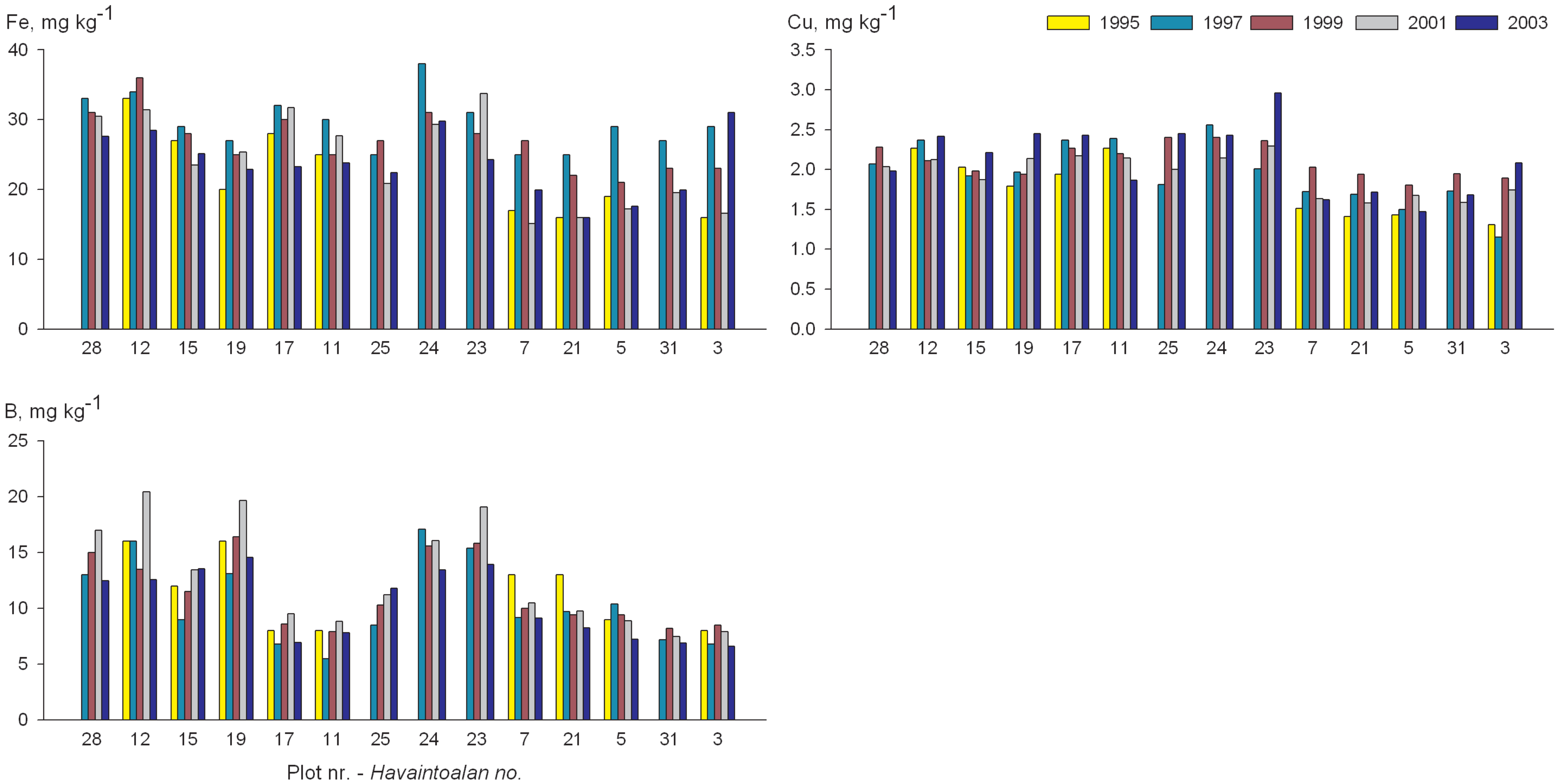

Figure 9. Average iron (Fe), copper (Cu) and boron (B) concentrations in current-year (C) Norway spruce needles taken on the Level II observation plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged in order of latitude (S to N).
Kuva 9. Kuusen nuorimpien neulasten keskimääräiset rauta (Fe)-, kupari (Cu)- ja boori (B)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

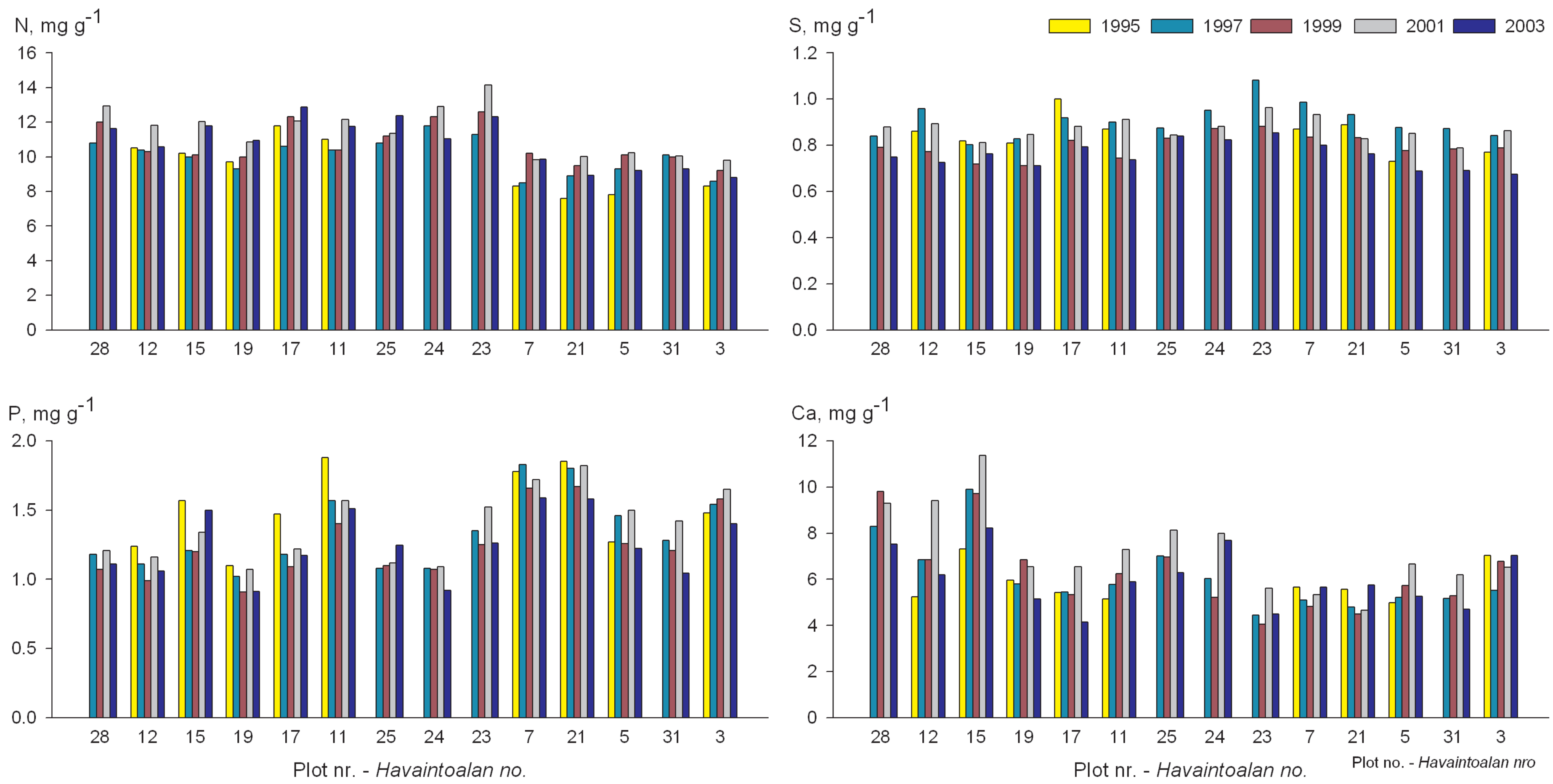

Figure 10. Average nitrogen (N), sulphur (S), phosphorus (P) and calcium (Ca) concentrations in previous-year (C+1) Norway spruce needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged in order of latitude (S to N).
Kuva 10. Kuusen edellisenä kesänä syntyneiden neulasten keskimääräiset typpi (N)-, rikki (S)-, fosfori (P)- ja kalsium (Ca)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

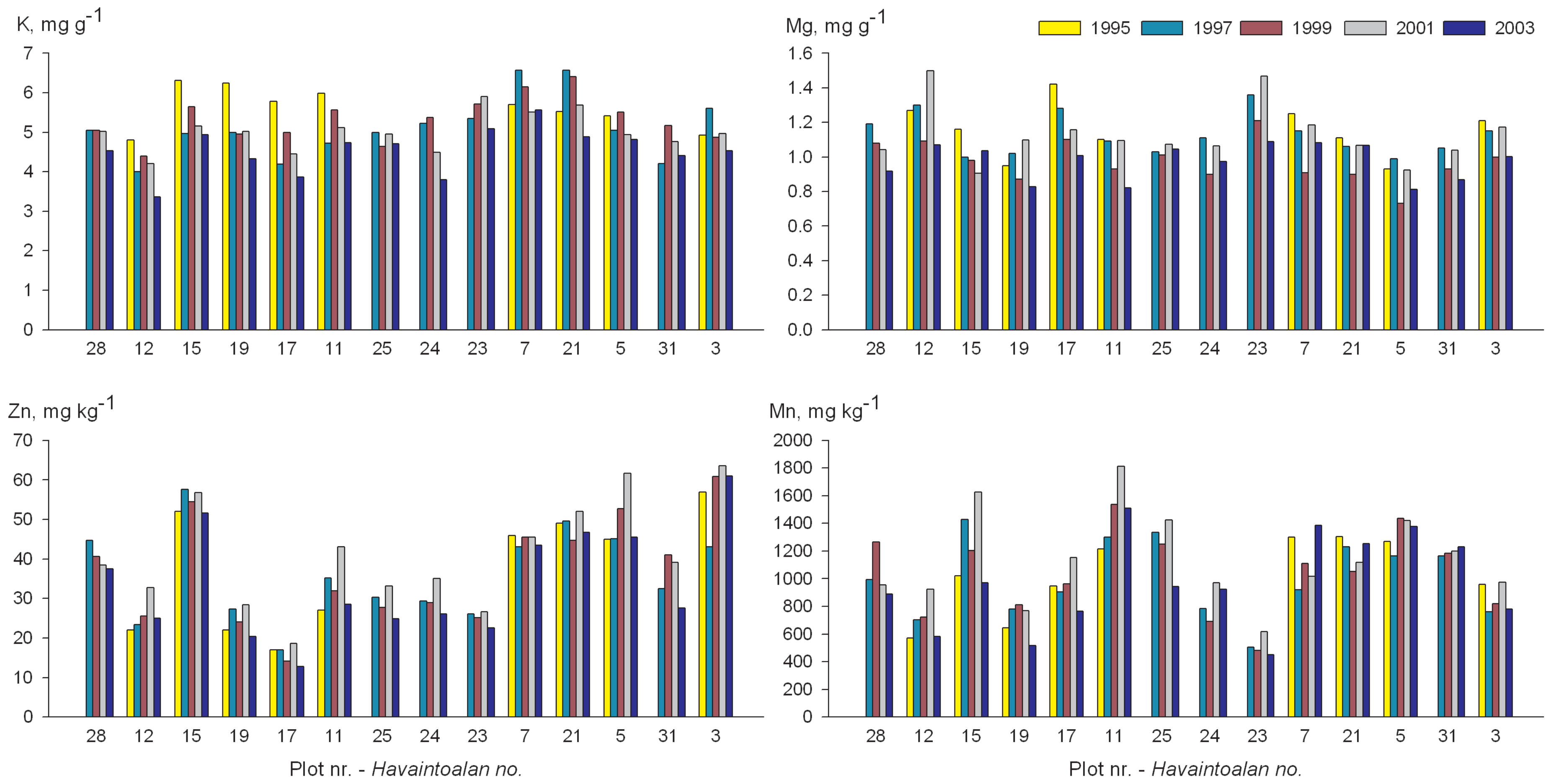

Figure 11. Average potassium (K), magnesium (Mg), zinc (Zn) and manganese (Mn) concentrations in previous-year (C+1) Norway spruce needles on the Level II plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged running from south to north.
Kuva 11. Kuusen edellisenä kesänä syntyneiden neulasten keskimääräiset kalium (K)-, magnesium (Mg)-, sinkki (Zn)- ja mangaani (Mn)-pitoisuudet II tason havaintoaloilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

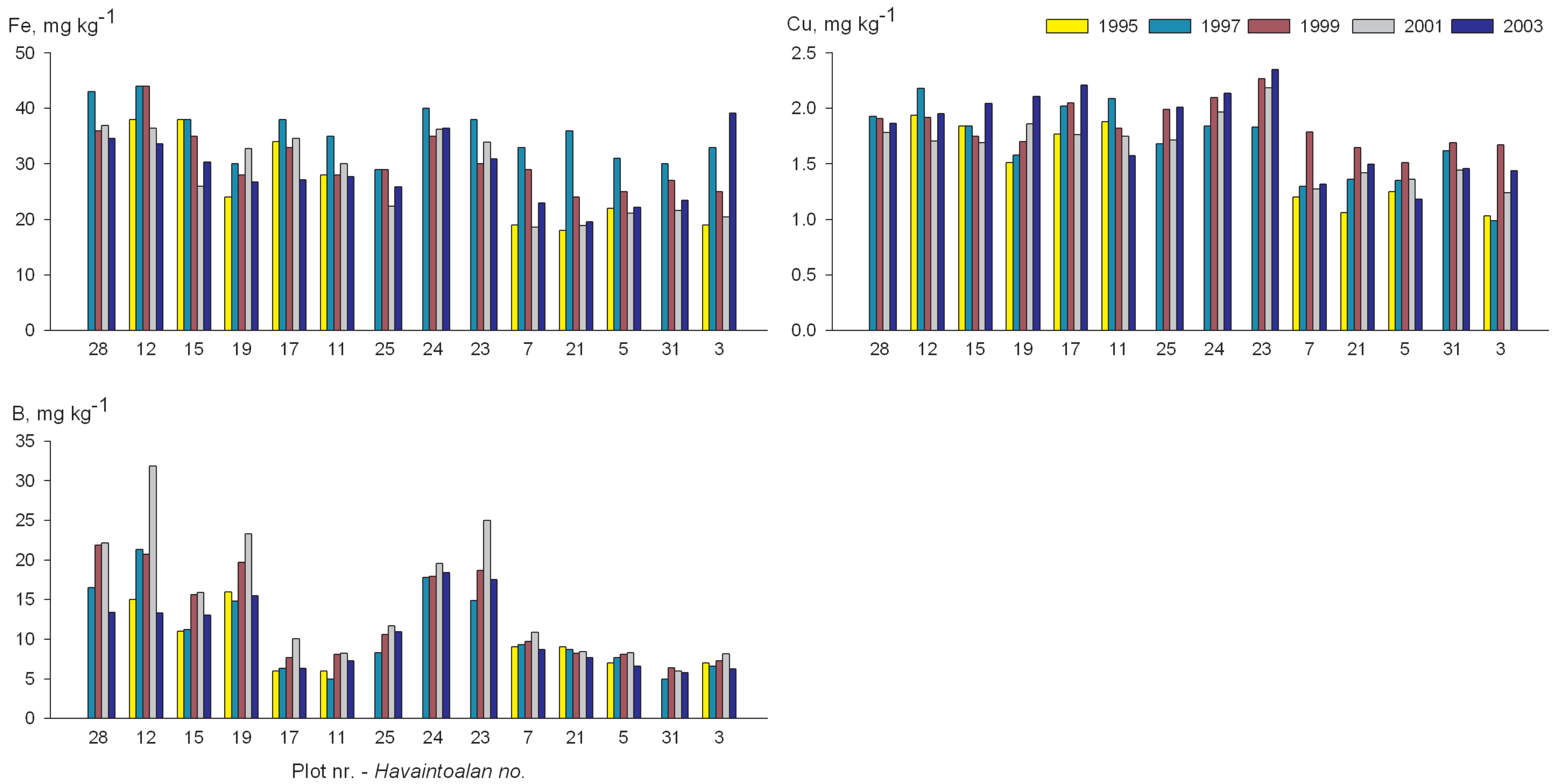

Figure 12. Average iron (Fe), copper (Cu) and boron (B) concentrations in previous-year (C+1) Norway spruce needles on the Level II observation plots in 1995/96, 1997, 1999, 2001 and 2003. The plots are arranged in order of latitude (S to N).

Kuva 12. Kuusen edellisenä kesänä syntyneiden neulasten keskimääräiset rauta (Fe)-, kupari (Cu)- ja boori (B)-pitoisuudet II tason havaintoalöilla vuosina 1995/96, 1997, 1999, 2001 ja 2003. Havaintoalojen järjestys etelästä pohjoiseen.

References

Bartels, U. 2002. ICP-Forests 4th needle/leaf interlaboratory test 2001/2002. Results. North Rhine-Westfalia State Environment Agency, Essen. 128 p.

Kimmins, J.P. 1987. Forest Ecology. Macmillan Publishing Company, New York. 531 p.

Lorenz, M., Mues, V., Becher, G., Müller-Edzards, C., Luyssaert, S., Raitio, H., Fürst, A. & Langouche, D. 2003. Forest condition in Europe. Results of the 2002 large-scale survey. Technical Report. EC, UN/ECE 2003, Brussels, Geneve. 171 p.

Luyssaert, S., Raitio, H. & Fürst, A. 2003. Elemental foliar composition indicates environmental changes. In: The condition of forests in Europe. 2003 Executive Report. Federal Research Centre for Forestry and Forest Protection. p. 21.

Luyssaert, S., Sulkava, M., Raitio, H. & Hollmén, J. 2004. Evaluation of forest nutrition based on large-scale foliar surveys: are nutrition profiles the way of the future? Journal of Environmental Monitoring 6: 160–167.

Raitio, H. 1999. Needle chemistry. In: Raitio, H. & Kilponen, T. (eds.). Forest Condition Monitoring in Finland. National report 1998. The Finnish Forest Research Institute, Research Papers 743: 51.

Sulkava, M., Luyssaert, S., Rautio, P., Janssens, I.A. & Hollmén, J. 2006. Improved data quality can advance trend detection in environmental monitoring by decades. Submitted manuscript.

Walworth, J.L. & Sumner, M.E. 1988. Foliar Diagnosis: A Review. In: Tinker, B. & Läuchli, A. (eds.). Advances in Plant Nutrition 3. Praeger Publishers, New York. p. 193–241.

3.3 Litterfall production on 14 Level II plots during 1996 – 2003

Karikesato 14 havaintoalalla (taso II) vuosina 1996 – 2003

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Litterfall production was monitored on 8 Norway spruce plots and 6 Scots pine plots during 1996–2003. The annual litterfall production varied considerably between the years and plots. The mean annual litterfall sum on the spruce plots ranged from 61 to 503 g m^{-2}, whereas on the pine plots it ranged from 123 to 342 g m^{-2}. The average needle litterfall production varied from 29% to 87% of the total litterfall flux on the spruce plots and from 52% to 69% on the pine plots. The highest litter production on the pine plots occurred in the autumn, while on the spruce plots litterfall production was more evenly distributed throughout the year.

Karikesatoa seurattiin Metsien intensiiviseurannan kahdeksalla kuusi- ja kuudella mäntyalalla vuosina 1996–2003. Karikesato vaihteli runsaasti sekä vuosien että havaintoalojen välillä. Kuusikoissa keskimääräinen vuosittainen karikesato vaihteli 61–503 g m^{-2}, vastaavasti männiköissä 123–342 g m^{-2}. Neulaskarikkeen osuus kokonaiskarikesadosta oli kuusialoilla 29–87 % ja mäntyaloilla 52–69 %. Männiköissä karikesadossa esiintyi selkeä vuodenaikaisvaihtelu määrän ollessa suurimmillaan syksyisin, sen sijaan kuusikoissa karikesato oli tasaisemmin jakautunut ympäri vuoden.

Introduction

A substantial proportion of terrestrial net primary production is removed from the trees as litterfall on the forest floor and subsequently to the detritus food web. Litterfall represents a major pathway through which soils, depleted by nutrient uptake and leaching, are replenished (Morrison 1991). Furthermore, litterfall represents one of the primary links between producer and decomposer organisms (Fyles et al. 1986). Therefore litterfall plays a key role in understanding the dynamics of nutrient cycling within forest ecosystems.

Litterfall production is correlated strongly with site, stand and climate factors. Albrektson (1988), for instance, found that needle litterfall production in Scots pine stands increased with improving site quality and decreased with latitude. Annual litterfall can vary considerably, which is related to the fact that the weather conditions differ year to year. In addition, there is variation between seasons, e.g. deciduous trees shed most of their foliar biomass in the autumn. In boreal coniferous forests, foliar litter comprises the main part of the litterfall flux to the forest floor. This report presents the results of litterfall production on 14 Level II sites during 1996 to 2003.

Material and methods

The study was carried out in 8 Norway spruce (*Picea abies* L. Karst.) and 6 Scots pine (*Pinus sylvestris* L.) plots during 1996 to 2003; sampling on some of the plots started later than 1996. Litterfall was collected using 12 traps located systematically on a 20 x 20 m grid on one plot (30 x 30 m) in each stand. The top of the funnel-shaped traps, with a collecting area of 0.5 m^2,

Figure 1. Photo of a litterfall trap at the Scots pine plot Hietajärvi (nr. 20). (Photo: Johan Stendahl).
Kuva 1. Karikesatokeräin Hietajärven männikköalalla (no. 20). (Kuva: Johan Stendahl).

was located at a height of 1.5 m above the forest floor (Fig. 1). The litterfall was collected in a replaceable cotton bag attached to the bottom of the litterfall trap. Litterfall was sampled at two-week intervals during the snow-free period (May to November, depending on the latitude of the plot), and once at the end of winter. After collection, all the litter samples were air-dried and sorted into at least four fractions: pine green needles/brown needles, spruce needles and the remaining material. The mass of each fraction was weighed and nutrient analyses were performed. Litterfall production (dry mass per unit area) was calculated by dividing the total and needle litterfall masses by the total surface area of the traps.

Results and discussion

The annual litterfall production varied between years and plots considerably (Table 1 and 2, Fig. 2a, b). The mean annual litterfall sum on the spruce plots ranged from 61 to 503 g m^{-2}, whereas for pine it ranged from 123 to 342 g m^{-2} (Table 1 and 2, Fig. 2a, b). The lowest litterfall production in both pine and spruce stands was at the northernmost plots at Kivalo. There was a clearly decreasing south-north gradient in litterfall production, which obviously is related to the stand characteristics, climate and latitude, e.g. the height of the trees is the lowest on the northern plots (see Table 2, p. 18), indicating the impact of tree height on litterfall production. Saarsalmi et al. (in press) found that stand height was the stand characteristic (tree height, breast diameter, basal area, stem volume, age) with the strongest correlation with litterfall production. Litterfall production also showed a slightly increasing trend over time, being greater in 2003 than in the beginning of the sampling period at most of the plots. The amount of needles, branches, bark and cones in litterfall usually increase with stand age (Mälkönen 1974, Flower-Ellis 1985, Finér 1996). This trend was also seen on our plots. The average litterfall production was greater on the spruce plots (282 g m^{-2}) than on the pine plots (222 g m^{-2}). The higher crown ratio of spruce (averaging 0.76 in Finland; Hynynen et al. 2002, Saarsalmi et al. in press) compared to pine partly explains the higher spruce canopy litterfall production.

Table 1. Annual a) total litterfall and b) needle litterfall production on the Norway spruce plots.
Taulukko 1. Vuosittainen a) kokonaiskarikesato ja b) neulaskarikesato kuusialoilla.

Plot *Havaintoala*	Pallas- järvi (3)	Kivalo (5)	Juupa- joki (11)	Tammela (12)	Punka- harju (17)	Evo (19)	Oulanka (21)	Uusikaarle- pyy (23)
a)								
Year – *Vuosi*	Total litterfall, *g m^{-2}* (dw) – *Kokonaiskarikesato, g m^{-2} (kp)*							
1996		114	297	240				
1997		120	372	305				
1998		116	372	318				
1999		124	360	327	293	382	122	482
2000		92	403	342	365	368	104	440
2001		141	434	351	367	316	119	587
2002	61	136	425	362	369	339	128	461
2003	61	127	463	388	476	380	145	548
$\bar{x}$	61	121	391	329	374	357	124	503
sd	0	15	52	45	66	29	15	62
b)								
Year – *Vuosi*	Needle litterfall, *g m^{-2}* (dw) – *Neulaskarike, g m^{-2} (kp)*							
1996		84	172	136				
1997		99	225	198				
1998		91	225	204				
1999		100	231	211	151	149	40	339
2000		69	217	193	162	116	28	277
2001		122	245	166	213	108	41	400
2002	55	107	241	193	212	123	32	254
2003	50	102	301	266	350	179	38	369
$\bar{x}$	53	97	232	196	218	135	36	328
sd	3	16	36	37	79	29	5	61

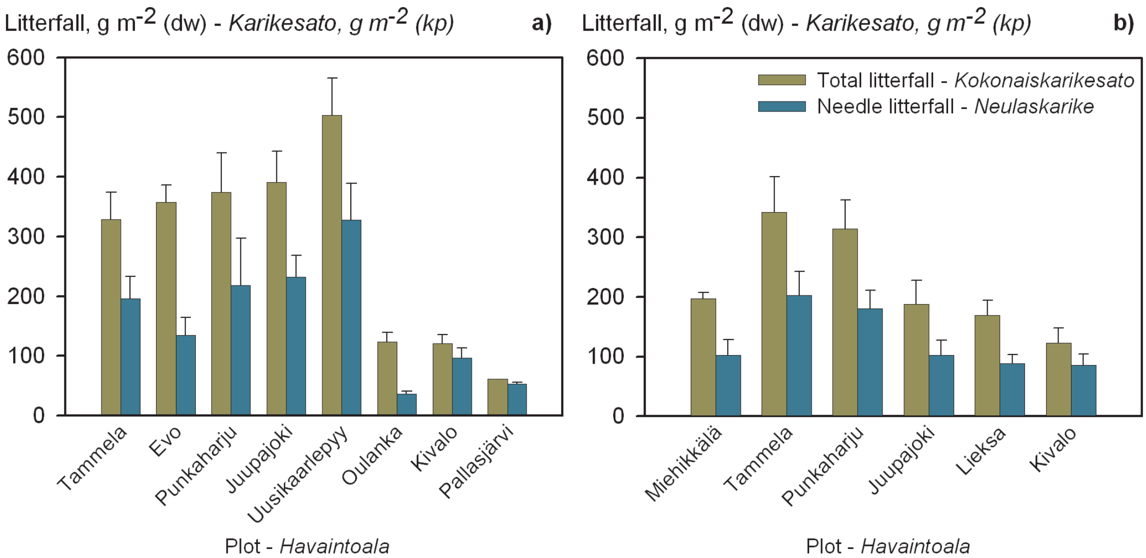

Figure 2. Mean annual sum and standard deviation of total and needle litterfall production on a) the Norway spruce plots, and b) the Scots pine plots during 1996–2003. Note, on the Evo, Oulanka, Punkaharju and Uusikaarlepyy plots sampling was started in 1999 and at Pallasjärvi in 2001.
Kuva 2. Keskimääräinen vuosittainen karikesato ja vuosien välinen keskihajonta a) kuusialoilla ja b) mäntyaloilla vuosina 1996–2003. Huom., Evolla, Oulangalla, Punkaharjulla ja Uudessakaarlepyyssä karikesadon keräys aloitettiin vasta 1999, Pallasjärvellä 2001.

Table 2. Annual a) total litterfall and b) needle litterfall production on the Scots pine plots.
Taulukko 1. Vuosittainen a) kokonaiskarikesato ja b) neulaskarikesato mäntyaloilla.

Plot *Havaintoala*	Kivalo (6)	Juupa- joki (10)	Tammela (13)	Punka- harju (16)	Miehik- kälä (18)	Lieksa (20)
a)						
Year – *Vuosi*	Total litterfall, *g m^{-2} (dw) – Kokonaiskarikesato, g m^{-2} (kp)*					
1996	83	102	229			
1997	157	176	292			
1998	132	168	343			
1999	146	206	388	382		196
2000	117	213	328	255		195
2001	92	223	416	284		161
2002	125	206	373	324	204	141
2003	134	209	365	325	190	154
$\bar{x}$	123	188	342	314	197	169
sd	25	39	59	48	10	25
b)						
Year – *Vuosi*	Needle litterfall, *g m^{-2} (dw) – Neulaskarikesato, g m^{-2} (kp)*					
1996	65	51	139			
1997	85	86	171			
1998	83	96	221			
1999	113	120	222	226		105
2000	89	108	186	143		90
2001	56	139	273	190		101
2002	101	109	205	177	121	74
2003	91	106	207	165	84	75
$\bar{x}$	86	102	203	180	102	89
sd	18	26	40	31	26	14

There were also considerable variation in needle litterfall production between the plots and years. A similar type of decreasing south-north gradient, and an increasing trend over time, was observed in needle litterfall production as in total litterfall production (Table 1 and 2, Fig. 2a, b). However, no clear cycle in needle litter production was found, indicating that there is overlap of different needle age-classes in the trees. The average needle litterfall production varied from 29% (Oulanka) to 87% (Pallasjärvi) of the total litterfall flux on the spruce plots, and from 52% (Miehikkälä) to 69% (Kivalo) on the pine plots. On the average there was a slightly higher needle litterfall production on the spruce plots (59%) than on the pine plots (57%). In boreal coniferous forests needle litter constitutes the main part of the litterfall flux to the forest floor. The rest of the litterfall consisted of leaves, the reproductive organs of trees such as seeds, cones and flower parts, and branches and to a lesser extent dead insects, faeces of animals and, on rare occasions, dead squirrels and birds.

There was a clear seasonal pattern in litterfall production on the pine plots (Fig 3a). The highest litter production occurred in the autumn, which is connected with needle senescence. The oldest needle age-glass of pine is usually shed in August-October (Salemaa and Lindgren 2000). Litter production was lowest during the winter and early summer. A similar seasonal pattern for Scots pine has earlier been reported in many other studies (e.g. Viro 1955, Mälkönen 1974). Spruce litterfall production was more evenly distributed throughout the year than that of pine, and only a small peak was observed in early summer and autumn (Fig. 3b), which is typical of Norway spruce according to earlier studies (Viro 1955, Mälkönen 1974, Finér 1996).

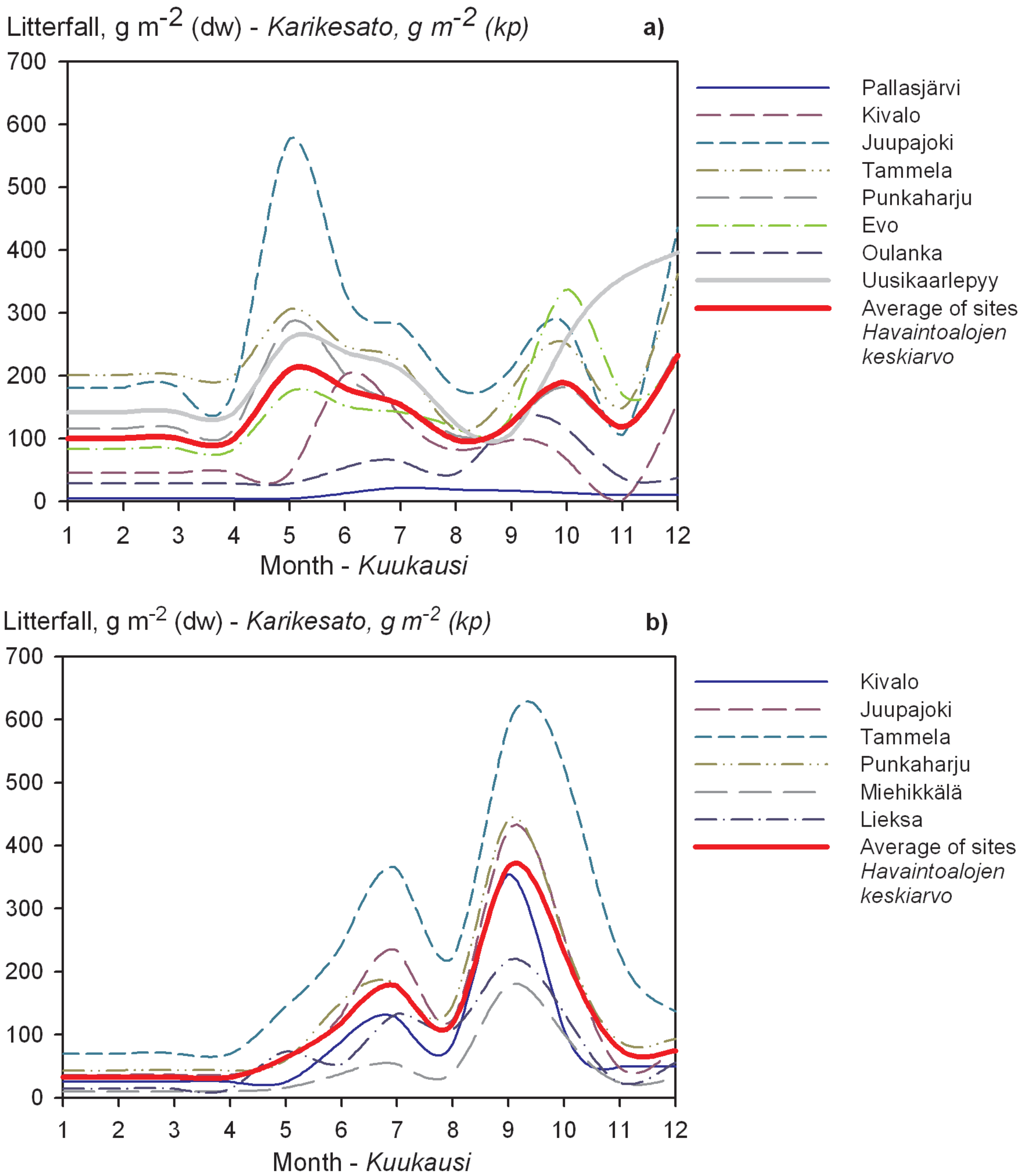

Figure 3. Total monthly litterfall (g m^{-2}) during 1996–2003 on a) the Norway spruce plots, and b) on the Scots pine plots. Note, on the Evo, Oulanka, Punkaharju and Uusikaarlepyy plots sampling was started in 1999 and at Pallasjärvi in 2001.
Kuva 3. Vuosijakson 1996–2003 yhteenlaskettu karikesato (g m^{-2}) kuukausittain a) kuusialoilla ja b) mänty-aloilla. Huom., Evolla, Oulangalla, Punkaharjulla ja Uudessakaarlepyyssä karikesadon keräys aloitettiin vasta 1999, Pallasjärvellä 2001.

Conclusions

Both total and needle litterfall production during 1996–2003 varied substantially between years, plots, tree species and season. There was also a clear increasing trend in litterfall production over time, and a decreasing trend in latitude. The variation in litterfall production is mainly related to latitude, stand characteristics, site type and weather conditions.

References

Albrektson, A. 1988. Needle litterfall in stands of Pinus sylvestris L. in Sweden, in relation to site quality, stand age and latitude. Scandinavian Journal of Forest Research 3: 333–342.

Finér, L. 1996. Variation in the amount and quality of litterfall in a Pinus sylvestris L. stand growing on a bog. Forest Ecology and Management 80: 1–11.

Flower-Ellis, J. 1985. Litterfall in an age series of Scots pine stands: summary results for the period 1973–1983. In: Lindroth, A. (ed.). Klimat, fotosyntes och förnafall I tallskog på Sedimentmark – ekologiska basmätningar i Jädraås. Institutionen för Ekologi och Miljövård, Sveriges Lantbruksuniversitet, Uppsala. Rapport 19: 75–74.

Fyles, J.W., La Roi, G.H. & Ellis, R.A. 1986. Litter production in Pinus banksiana dominated stands in northern Alberta. Canadian Journal of Forest Research 16: 772–777.

Hynynen, J., Ojansuu, R., Hökkä, H., Siipilehto, J., Salminen, H. & Haapala, P., 2002. Models for prediciting stand development in MELA System. The Finnish Forest Research Institute, Research Papers 835. 116 p.

Saarsalmi, A., Starr, M. Hokkanen, T. Ukonmaanaho, L., Kukkola, M., Nöjd, P. & Sievänen, R. Predicting annual canopy litterfall production for Norway spruce (Picea abies (L.) Karst.) stands. Forest Ecology and Management (in press).

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

Morrison, I.K. 1991. Addition of organic matter and elements to the forest floor of an old growth Acer saccharum forest in the annual litter fall. Canadian Journal of Forest Research 21: 462–468.

Salemaa, M. & Lindgren, M. 2000. Crown condition. In: Mälkönen, E. (ed.). Forest Condition in a Changing Environment – The Finnish Case. Forestry Sciences 65. Kluwer Academic Publishers, Dordrecht. p. 121–132.

Viro, P.J. 1955. Investigations in forest litter. Communicationes Instituti Forestalis Fenniae 45(6): 1–65.

3.4 Understorey vegetation on the Level II plots during 1998–2004

Aluskasvillisuus tason II havaintoaloilla vuosina 1998–2004

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A complete vegetation survey of the Level II plots is undertaken every fifth year. Here we present an overview of the second inventory of 31 Level II plots (year 2003) and a new birch plot, which was inventoried for the first time in 2004. The main compositional gradient represented the site fertility gradient, combined with the variation in soil moisture and location along the south-north axis in Non-metric Multidimensional Scaling (NMDS) of the vegetation of the mineral soil plots (year 2003). The number of vascular plant species decreased towards the north in both the pine and spruce stands. In contrast, the number of bryophyte and lichen species increased from south to north on the pine plots, whereas there was no south-north trend on the spruce plots. The cover percentages of the understorey plant species have remained relatively constant on six of the Level II plots that were surveyed every year during the period 1998–2003. The largest annual changes in the coverage of vascular plants and bryophytes were 10–15%-units. An increasing trend in the coverage of dwarf shrubs was found on two of the southern plots, but the cover of bryophytes simultaneously decreased. Between-year variation in the amount of precipitation and needle/leaf litter appeared to regulate the coverage of the bryophyte layer. Positive correlation between the cover of bilberry (*Vaccinium myrtillus*) and annual precipitation was also found on two of the northern plots.

Metsäekosysteemien intensiiviseurannan (ICP metsäohjelma/taso II) havaintoalojen aluskasvillisuus tutkitaan viiden vuoden välein. Tässä raportissa esitämme yhteenvedon toisesta inventoinnista (v. 2003) sekä tuloksia uudelta koivualalta, joka inventoitiin ensimmäisen kerran vuonna 2004. Kivennäismaiden havaintoalojen aineistossa (v. 2003) tärkein kasvillisuuden rakennetta kuvaava vaihtelusuunta ilmensi kasvupaikan ravinteisuutta, maaperän kosteutta ja havaintoalan sijaintia etelä-pohjoissuunnassa (ei-metrinen moniuloitteinen skaalaus, NMDS). Putkilokasvilajien lukumäärä vähentyi pohjoiseen päin sekä männiköissä että kuusikoissa. Toisaalta sammal- ja jäkälälajien lukumäärä lisääntyi männiköissä pohjoiseen päin, mutta vastaavaa vaihtelua ei havaittu kuusikoissa. Kasvilajien peittävyysprosentit ovat pysyneet suhteellisen vakaina kuudella vuosittain tutkitulla taso II:n havaintoalalla seurantajakson 1998–2003 aikana. Putkilokasvien ja sammalten peittävyyksien vuosittaiset muutokset ovat olleet suurimmillaan 10–15 %-yksikköä. Varpujen peittävyydet lisääntyivät kahdella eteläisellä havaintoalalla, mutta samanaikaisesti sammalten peittävyys pieneni. Vuosien väliset erot sade- ja neulas/lehtikarikkeen määrissä näyttivät säätelevän sammalkerroksen peittävyyttä. Myös mustikan (*Vaccinium myrtillus*) peittävyyden ja sademäärän välillä havaittiin positiivinen korrelaatio kahdella pohjoisella havaintoalalla.

Introduction

Understorey vegetation makes an important contribution to the annual biomass production (Havas and Kubin 1983), nutrient cycling (Mälkönen 1974) and biodiversity (Reinikainen et al. 2000) of boreal forests. Changes in plant populations and communities have great indicative value in the monitoring of forest ecosystems. Long time series on the occurrence and abundance of plant species, connected to relevant environmental variables, offer the possibility to relate changes in vegetation to e.g. climatic and anthropogenic-derived changes (Økland 1995, Seidling 2005).

The main aims of vegetation monitoring in the Level II programme are 1) to characterize the current state of forest vegetation on the basis of the floristic composition, and 2) to detect temporal changes in the vegetation in relation to natural and anthropological environmental factors. A complete vegetation survey of the 31 sample plots was carried out for the first time in 1998 and repeated in 2003. In this report we present the general state (mean coverage of species groups and the number of species) of the understorey vegetation on all of the plots in 2003. A summary of the vegetation on a new birch plot at Punkaharju (surveyed in 2004) is also given. The vegetation pattern on the mineral soil plots was related to the chemical composition of the organic layer and a number of stand characteristics. In addition, we analyse annual changes in the coverage of the understorey vegetation on six plots during 1998–2003.

Methods

In 2003 there was a total of 31 Level II plots: 27 plots on mineral soil sites and 4 on peatland (Table 1). The sampling design for monitoring understorey vegetation is based on a pilot study carried out in 1996 (Salemaa et al. 1999). In general, the vegetation inventory is carried out according to the methods of the ICP Forests monitoring programme (Manual on methods... 2002).

One of the three sub-plots was selected for vegetation monitoring (see Fig. 3, p. 15). The size of the sub-plot is 30 x 30 m. Altogether 16 sample quadrats, each 2 m^2 (1.41 x 1.41 m) in area, were marked out systematically (4 x 4 design) on the sub-plot. The location of the quadrat was moved only in cases where there was an exceptional surface (e.g. path or large stone) occupying more than 20% of the area. In addition, four 10 x 10 m quadrats (A–D) were marked out to give four 100 m^2 areas (Fig. 1). These areas provide vegetation data representing the Common Sample Area (= 400 m^2), which is used in all countries participating in the ICP Forest monitoring programme.

Estimation of plant species coverage %

The vegetation inventory was carried out during July–August. The cover percentage of the individual plant species was assessed visually using the following scale: 0.01 (solitary or very sparsely growing shoots), 0.1, 0.2, 0.5, 1, 2, …99, 100%. The bottom layer (mosses, liverworts and lichens), the field layer (< 50 cm vascular plants: herbs, grasses, sedges, dwarf shrubs and tree seedlings) and the shrub layer (50–150 cm) were inventoried. Plants growing on stones, stumps or fallen stems were excluded. The cover of needle and leaf litter, dead plant material, dead branches, fallen tree stems, stumps, bare soil and stones was also assessed. Additional species, i.e. species occurring on the monitoring area (400 m^2 and 900 m^2) but not on the sample quadrats, were recorded. One team (2–4 botanists) performed the surveys on all the plots. Field tests were carried out to check the between-observer assessment level, and to calibrate it when necessary.

A 2 m^2 frame divided into 100 small quadrats by a net of elastic strings was used in the assessment of the plant cover (Fig. 2). “An open frame” without a net was placed on sites where a tree, shrubs or high vegetation were growing (Fig. 3). The cover of withered early summer species (e.g. *Anemone nemoralis*) was assessed according to their probable maximum biomass. The height of the field and shrub layers was measured at 10 points in different parts of the monitoring sub-plot. Samples of unknown plant species (mainly bryophytes and lichens) were later identified on the basis of microscopic characteristics.

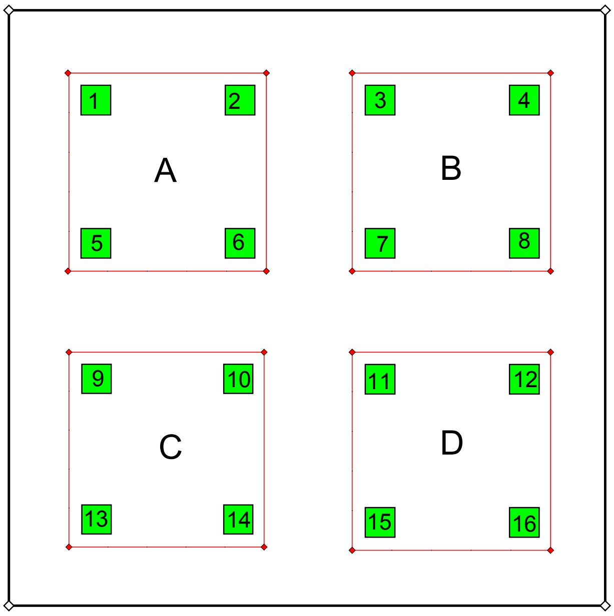

Figure 1. The sub-plot (30 x 30 m = 900 m^2) used for the inventory of understorey vegetation. Coverage (%) of the plant species was assessed on the small sample quadrats (16 x 2 m^2). The larger quadrats (A–D) were 10 x 10 m =100 m^2 in area. Additional plant species growing outside the small quadrats were recorded within areas of 4 x 100 m^2 (A–D) and 900 m^2 (whole plot).
Kuva 1. Metsäekosysteemin intensiiviseurannan kasvillisuusala (30 x 30 m = 900 m^2). Kasvilajien peittävyydet arvioitiin pieniltä näyteruuduilta (16 x 2 m^2). Suuremmat ruudut (A–D) olivat kooltaan 10 x 10 m = 100 m^2. Näyteruutujen ulkopuolella kasvavat lajit kirjattiin 4 x 100 m^2:n (A–D) ja 900 m^2:n alueelta.

Figure 2. The frame with a net of small quadrats used in vegetation analysis (1.41 x 1.41 m) (Sevettijärvi_P Nr. 1 in 2003). (Photo: Maija Salemaa).
Kuva 2. Kasvillisuuden inventoinnissa käytettävä verkkokehikko (Sevettijärvi_P no. 1 vuonna 2003). (Kuva: Maija Salemaa).

Table 1. The number of species occurring on the common sample area (CSA = 400 m^2) of the vegetation subplots, and the evenness (E) and diversity (Shannon H') indices of the plant communities. Add. = additional species found outside CSA, but inside the area of 900 m^2. Data from 2003, except for plot Nr. 33 (Punkaharju_B) from 2004.
Taulukko 1. Lajien lukumäärät kasvillisuusaloille perustetuilla 400 m^2 suuruisilla näytealoilla (CSA), sekä kasviyhteisöjen tasaisuus- (E) ja diversiteetti- (Shannon H') indeksit. Ylim. = ylimääräiset lajit, jotka kasvoivat CSA:n ulkopuolella, mutta 900 m^2:n sisällä. Aineisto vuodelta 2003, paitsi havaintoala no. 33 (Punkaharju_B) vuodelta 2004.

Plot *Havaintoala*	Heath site type *Kasvup. tyyppi*	Vascular plants – *Putkilokasvit* (<50 cm): Trees & shrubs *Puut & pensaat*	Dwarf shrubs *Varvut*	Herbs *Ruohot*	Grasses & sedges *Heinät & sarat*	Tot *Tot*	Bryophytes – *Sammalet*: Hepatics *Maksa-samm.*	Mosses *Lehti-samm.*	Tot *Tot*	Lichens – *Jäkälät*: Cladonia *Torvi-jäkälät*	Other *Muut*	Tot *Tot*	All *Kaikki*	E	H'	Add. *Ylim.*
1 Sevettijärvi_P	xeric	1	4	0	0	5	9	11	20	15	6	21	46	0.573	2.195	1
2 Pallasjärvi_P	sub-xeric	2	8	2	1	13	7	14	21	15	6	21	55	0.551	2.208	3
3 Pallasjärvi_S	mesic	3	5	3	1	12	4	13	17	2	4	6	35	0.480	1.707	7
4 Sodankylä_P	sub-xeric	3	6	0	0	9	9	10	19	13	4	17	45	0.454	1.727	0
5 Kivalo_S	mesic	1	3	3	1	8	12	13	25	9	3	12	45	0.497	1.891	2
6 Kivalo_P	sub-xeric	4	6	2	1	13	3	13	16	6	5	11	40	0.406	1.498	0
7 Oulanka_S	mesic	1	4	5	3	13	6	12	18	1	0	1	32	0.527	1.825	2
8 Oulanka_P	mesic	6	9	6	2	23	3	12	15	0	0	0	38	0.481	1.749	1
9 Ylikiiminki_P	xeric	2	4	0	0	6	2	9	11	11	5	16	33	0.494	1.728	0
10 Juupajoki_P	sub-xeric	4	3	6	3	16	0	13	13	8	2	10	39	0.455	1.668	4
11 Juupajoki_S	herb-rich	4	2	15	7	28	11	20	31	1	0	1	60	0.621	2.543	5
12 Tammela_S	mesic	3	2	11	4	20	3	17	20	1	0	1	41	0.527	1.957	4
13 Tammela_P	sub-xeric	5	6	7	3	21	0	6	6	8	2	10	37	0.508	1.833	1
14 Lapinjärvi_P	sub-xeric	1	3	5	3	12	1	8	9	3	2	5	26	0.383	1.248	3
15 Lapinjärvi_S	herb-rich	5	3	27	7	42	4	16	20	2	0	2	64	0.619	2.576	1
16 Punkaharju_P	sub-xeric	2	5	4	0	11	0	5	5	1	0	1	17	0.452	1.281	8
17 Punkaharju_S	herb-rich	5	3	12	4	24	2	20	22	1	0	1	47	0.397	1.530	6
18 Miehikkälä_P	xeric	2	4	1	0	7	0	6	6	15	4	19	32	0.413	1.430	2
19 Evo_Sim	herb-rich	3	3	16	4	26	9	23	32	5	0	5	63	0.411	1.701	4
20 Lieksa_Pim	sub-xeric	3	4	1	0	8	0	8	8	1	5	6	22	0.569	1.757	3
21 Oulanka_Sim	mesic	3	6	5	1	15	5	12	17	5	1	6	38	0.434	1.580	1
22 Kevo_Pim	sub-xeric	1	7	0	1	9	13	14	27	18	9	27	63	0.599	2.482	0
23 Uusikaarlepyy_S	herb-rich	4	0	6	2	12	4	9	13	0	0	0	25	0.484	1.559	0
24 Närpiö_S	mesic	9	4	10	5	28	2	17	19	1	2	3	50	0.548	2.143	2
25 Vilppula_Spro	herb-rich	4	3	19	8	34	2	18	20	1	0	1	55	0.688	2.758	1
26 Ikaalinen_P	(peatland)	4	6	1	2	13	2	9	11	6	1	7	31	0.648	2.227	2
27 Ikaalinen_Pfer	(peatland)	4	9	2	2	17	1	11	12	6	2	8	37	0.566	2.042	1
28 Solböle_Spro	herb-rich	6	2	24	12	44	2	20	22	0	0	0	66	0.579	2.425	2
29 Pyhäntä_P	(peatland)	4	9	1	2	16	4	20	24	7	5	12	52	0.478	1.887	1
30 Pyhäntä_Pfer	(peatland)	4	9	1	2	16	5	17	22	4	3	7	45	0.540	2.054	1
31 Kivalo_Spro	mesic	3	3	4	3	13	5	16	21	1	1	2	36	0.430	1.542	3
33 Punkaharju_B	herb-rich	5	2	27	10	44	2	17	19	0	0	0	63	0.612	2.534	5
Total number		19	14	59	23	115	35	66	101	21	13	34	250			

Figure 3. An open frame (1.41 x 1.41 m) is used in sites where trees or high vegetation are growing (Tammela_P Nr. 13 in 2000). (Photo: Maija Salemaa).
Kuva 3. Kulmasta auki olevaa verkotonta avokehikkoa käytetään paikoissa, jossa kasvaa puita tai aluskasvillisuus on korkeaa (Tammela_P no. 13 vuonna 2000). (Kuva: Maija Salemaa).

Data analysis

The number of species (S) and the mean coverage of the species groups were calculated for each vegetation plot. The diversity of the plant communities was measured by the Shannon diversity ($H' = -\sum_{i=1}^{S} p_i \ln p_i$, i = proportion of the ith species of the total coverage) and the evenness ($E = H'/\ln S$) indices. The data of all plots on mineral soil sites (year 2003) were ordinated by global non-metric multidimensional scaling (NMDS) in order to find the main compositional gradients of the vegetation (R programme version 2.4.1, Vegan package, Oksanen 2007). Two-dimensional solution using the Wisconsin squareroot transformation and Bray-Curtis coefficients as a measure of dissimilarity in floristic composition between the sample plots was chosen for the final method. Environmental vectors depicting the chemical properties of the organic layer (year 2003) and stand variables (years 1999–2000) were fitted to the ordination configuration.

Results and discussion

Vegetation surveys in 2003 and 2004

The number of species varied from 25 to 66 in the mesic and herb-rich spruce heaths, and from 17 to 63 in the xeric and sub-xeric pine heaths (Table 1). A total of 44 vascular plant and 19 bryophyte species were found in the birch stand at Punkaharju (Nr. 33). The number of species, Shannon diversity, as well as the evenness indices, were highest in the herb-rich spruce heaths (Table 1). The two exceptions were Uusikaarlepyy (Nr. 23) and Punkaharju (Nr. 17), where the number of species was low due to shading of the dense canopy of the spruce stands. The most northern plot Kevo (Nr. 22) formed an interesting case in the sub-xeric pine heaths: here the diversity of the species ($H' = 2.482$) rose to the same level as that found in southern herb-rich heaths. Although the number of vascular plants was low (9) on this plot, the number of liverwort (13), moss (14) and lichen (27) species was high. The number of vascular plant species in the pine stands decreased, whereas that of bryophytes and lichens increased towards the north (Fig. 4a). In the spruce stands the number of vascular plants species was also higher in southern than in northern Finland, but there was no clear south-north trend in the species number of the bottom layer (Fig. 4b). In addition to the latitude and site fertility level, the species number is affected by the successional age of the stand (Tonteri 1994), and many other biotic and abiotic factors.

The sum coverage of all species in the bottom and field layers exceeded 100% on almost all the plots (Table 2). Clear exceptions to this were the spruce plots at Uusikaarlepyy (Nr. 23), Evo (Nr. 19) and Juupajoki (Nr. 11), as well as the birch plot at Punkaharju (Nr. 33). On all these plots the large amounts of needle or leaf litter on the ground suppressed the growth of bryophytes especially.

Plot and species scores of NMDS were displayed in two separate diagrams, but they were examined together in order to interpret the ordination (Fig. 5a, b). The more similar the plant species composition in the plots, the closer they were located to each other in the ordination diagram (Fig. 5a). Species scores were calculated as cover-weighted averages of the sample scores. As a result, the species points were located in the same part of the ordination space as the plots on which they were most likely to have a high abundance (Fig. 5b). The main compositional gradient in the ordination of the mineral soil plots ($n = 27$) represented the change in site fertility, combined with the variation in soil moisture and location along the south-north axis. The plots were located in accordance with the fertility level of the forest site types (Fig. 5a). Herb-rich heaths were located on the right, mesic heaths in the centre, followed by sub-xeric and xeric heaths on the left. In general, the ordination configuration was strongly related to the C/N ratio in the organic layer ($r = 0.823$, $P < 0.01$), which increased towards the north. The second gradient in the ordination indicated the combined effect of soil moisture and latitude. The northern plots, rich in bryophyte species, (upper part of the configuration), were divided from the drier southern stands. The exchangeable Ca concentrations and pH of the organic layer increased towards the southern herb-rich heaths (Fig. 5a).

The arrangement of the species scores corresponded to the general pattern of fertility and moisture level of the plots. The demanding bryophyte species (e.g. *Rhodobryum roseum* and *Brachythecium spp.*) on the right were replaced by generalist bryophytes in the middle (e.g. *Pleurozium schreberi* and *Dicranum polysetum*) and by drought-tolerant lichens (e.g. *Cladina rangiferina*) on the left in the species ordination (Fig. 5b). The number and abundance of liverworts (e.g. *Barbilophozia* spp.) increased towards the northern plots, indicating increasing soil moisture. Plot-wise differences were mainly based on the variation in the vascular plant communities in the fertile, but in bryophytes and lichens at the infertile end of the site-type gradient (c.f. Tonteri et al. 2005). This confirms the importance of including all vegetation groups in the monitoring programmes of boreal forests.

Vegetation change on six plots during 1998–2003

The annual variation in the total cover of vascular plants during 1998–2003 was relatively small (Table 3). The change in the cover of woody plants (dwarf shrubs and tree seedlings < 50 cm) was greatest on the Tammela plots (Nrs. 12 and 13): about 14% units higher in 2003 than in 1998. This was mainly caused by the increase in the cover of *Vaccinium myrtillus* at Tammela_S (Nr. 12) and *Vaccinium vitis-idaea* at Tammela_P (Nr. 13) (Fig. 6). Slight decreasing trend in the cover of *V. myrtillus* was found on the Pallasjärvi plots (Nrs. 2 and 3) (Fig. 6). Annual bulk precipitation

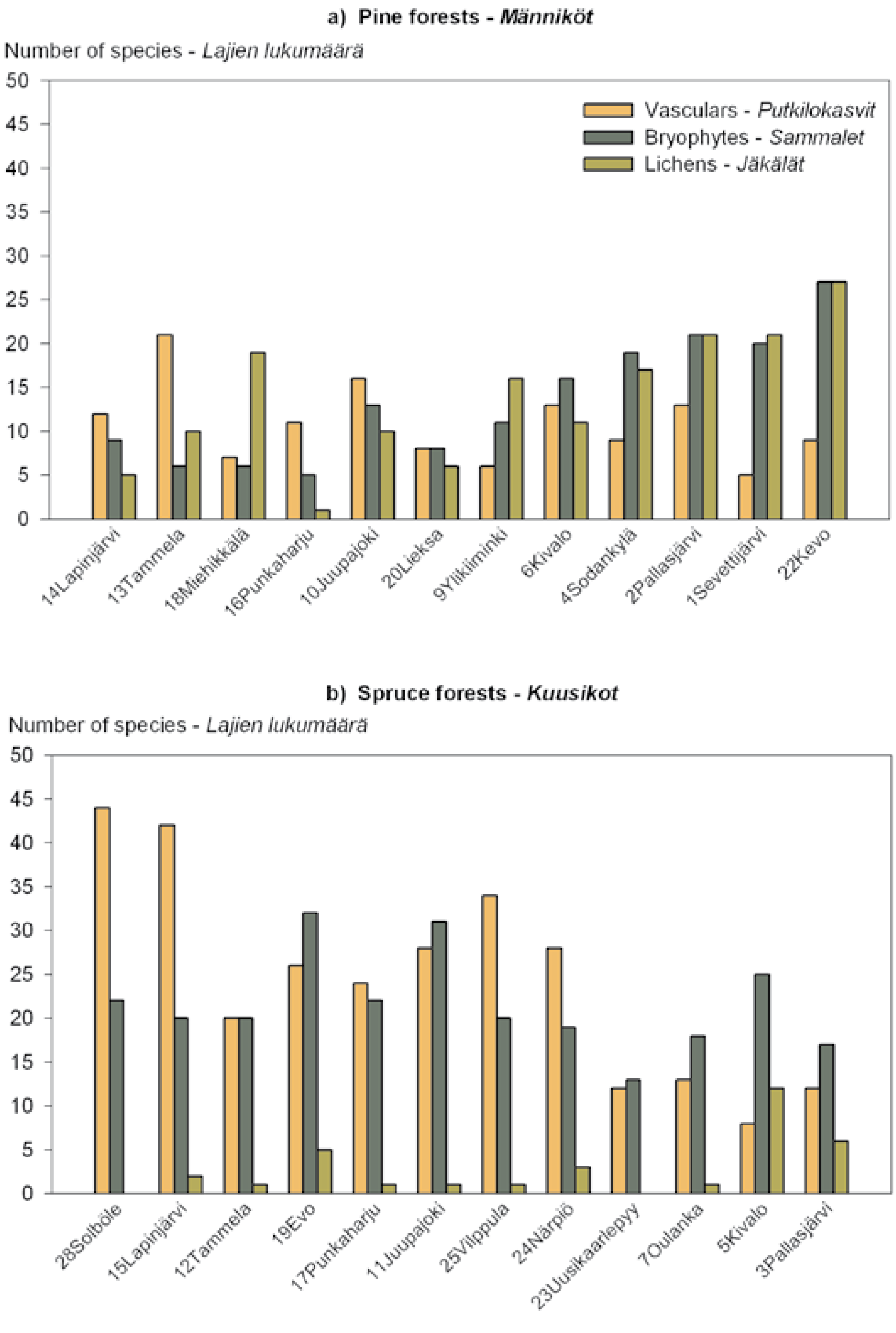

Figure 4. The number of species in the understorey vegetation (CSA = 400 m^2) in heath forests in 2003. The plots run from left to right in accordance with the South-North gradient. a) Scots pine stands represent sub-xeric and xeric heaths, and b) Norway spruce stands mesic and herb-rich heaths. The Solböle and Närpiö sites are no longer part of the Level II network.

Kuva 4. Aluskasvillisuuden lajimäärät kangasmetsien havaintoaloilla (CSA = 400 m^2) vuonna 2003. Havainto-alat järjestetty vasemmalta oikealle vastaamaan etelä-pohjoisgradienttia Suomessa. a) Männiköt edustavat kuivahkoja ja kuivia kankaita, b) kuusikot lehtomaisia ja tuoreita kankaita. Solböle ja Närpiö eivät ole enää mukana tason II seurannassa.

Table 2. The mean cover (%) of the species groups, decaying wood and needle/leaf litter on the vegetation plots. Data from 2003, except for plot Nr. 33 (Punkaharju_B) from 2004.

Taulukko 2. Kasvilajiryhmien, lahopuun, neulas- ja lehtikarikkeen keskimääräiset peittävyydet (%) kasvillisuuden havaintoaloilla. Aineisto on vuodelta 2003, paitsi havaintoala no. 33. (Punkaharju_B), joka inventoitiin vuonna 2004.

Plot	Vasc. plants	Bryophytes - *Sammalet*			Lichens - *Jäkälät*				All	Wood	Litter - *Karike*	
Havaintoala	*Putkilokasvit*	Hepatics *Maksasamm.*	Mosses *Lehtisamm.*	Sum *Summa*	*Cladina Poronjäk.*	Cladonia *Torvijäk.*	Other *Muut*	Sum *Summa*	*Kaikki*	debris *Lahopuu*	Needles *Neulaset*	Leaves *Lehdet*
1 Sevettijärvi_P	46.7	4.1	11.6	15.7	38.3	4.0	0.4	42.7	105.0	2.0	29.3	0.8
2 Pallasjärvi_P	37.2	2.3	47.0	49.3	6.9	3.4	0.8	11.0	97.5	3.5	33.3	3.1
3 Pallasjärvi_S	57.3	2.0	84.5	86.6	0.0	0.0	0.1	0.2	144.0	3.1	7.3	0.0
4 Sodankylä_P	37.2	0.1	74.0	74.1	4.4	1.2	0.5	6.1	117.4	5.0	15.0	0.0
5 Kivalo_S	32.0	8.6	76.1	84.6	0.0	0.1	0.0	0.1	116.7	5.6	11.0	0.0
6 Kivalo_P	35.5	0.0	91.5	91.5	1.8	0.1	0.2	2.1	129.2	4.2	9.5	0.0
7 Oulanka_S	68.0	1.8	86.1	87.9	0.0	0.0	0.0	0.0	155.9	3.6	1.4	20.8
8 Oulanka_P	79.6	0.1	86.3	86.4	0.0	0.0	0.0	0.0	166.0	2.8	13.3	3.4
9 Ylikiiminki_P	33.3	0.0	51.3	51.3	16.4	5.2	0.2	21.9	106.5	2.7	23.9	0.0
10 Juupajoki_P	47.4	0.0	91.2	91.2	0.0	0.1	0.0	0.2	138.9	4.1	7.2	0.4
11 Juupajoki_S	34.1	0.7	43.6	44.3	0.0	0.0	0.0	0.0	78.4	16.4	26.8	18.0
12 Tammela_S	53.9	0.0	51.7	51.8	0.0	0.0	0.0	0.0	105.7	6.2	15.4	26.3
13 Tammela_P	45.2	0.0	46.9	46.9	0.1	0.2	0.0	0.4	92.5	6.1	39.6	4.4
14 Lapinjärvi_P	31.1	0.0	73.8	73.8	0.0	0.0	0.0	0.1	104.9	7.1	23.3	1.8
15 Lapinjärvi_S	50.6	3.5	66.5	70.0	0.0	0.0	0.0	0.0	120.6	2.6	7.3	25.4
16 Punkaharju_P	21.8	0.0	89.0	89.0	0.0	0.0	0.0	0.0	110.8	7.1	16.9	0.2
17 Punkaharju_S	17.7	0.0	68.3	68.3	0.0	0.0	0.0	0.0	86.0	11.0	28.9	0.2
18 Miehikkälä_P	23.4	0.0	70.1	70.1	3.1	0.4	0.3	3.9	97.3	5.9	14.8	2.8
19 Evo_Sim	18.9	0.1	41.3	41.3	0.0	0.2	0.0	0.2	60.4	6.7	12.3	50.0
20 Lieksa_Pim	62.3	0.0	93.2	93.2	0.5	0.0	0.2	0.7	156.1	4.1	2.5	10.8
21 Oulanka_Sim	59.1	0.3	89.3	89.6	0.0	0.0	0.0	0.0	148.7	5.2	5.4	16.1
22 Kevo_Pim	42.0	3.1	42.0	45.1	4.7	3.2	4.9	12.7	99.8	3.0	24.0	13.8
23 Uusikaarlepyy_S	4.6	0.1	15.8	15.9	0.0	0.0	0.0	0.0	20.5	21.9	85.1	0.0
24 Närpiö_S	25.5	0.0	69.2	69.2	0.1	0.0	0.0	0.1	94.8	7.0	22.5	0.6
25 Vilppula_Spro	70.9	6.0	37.2	43.2	0.0	0.0	0.0	0.0	114.1	9.6	18.5	0.2
26 Ikaalinen_P	59.4	0.0	84.9	84.9	0.0	0.1	0.0	0.2	144.5	2.0	8.4	0.2
27 Ikaalinen_Pfer	31.8	0.0	78.3	78.4	0.2	0.5	0.0	0.7	110.8	3.2	8.1	2.0
28 Solböle_Spro	73.1	0.0	69.3	69.3	0.0	0.0	0.0	0.0	142.4	2.8	12.4	1.6
29 Pyhäntä_P	70.7	0.0	82.4	82.5	1.8	0.3	0.3	2.3	155.4	4.0	3.6	0.9
30 Pyhäntä_Pfer	76.6	0.1	91.1	91.1	0.4	0.0	0.1	0.6	168.2	3.4	3.8	1.5
31 Kivalo_Spro	56.7	2.2	79.2	81.4	0.0	0.0	0.0	0.0	138.1	7.5	8.9	0.8
33 Punkaharju_B	44.9	0.0	2.6	2.6	0.0	0.0	0.0	0.0	47.5	8.1	0.2	82.2

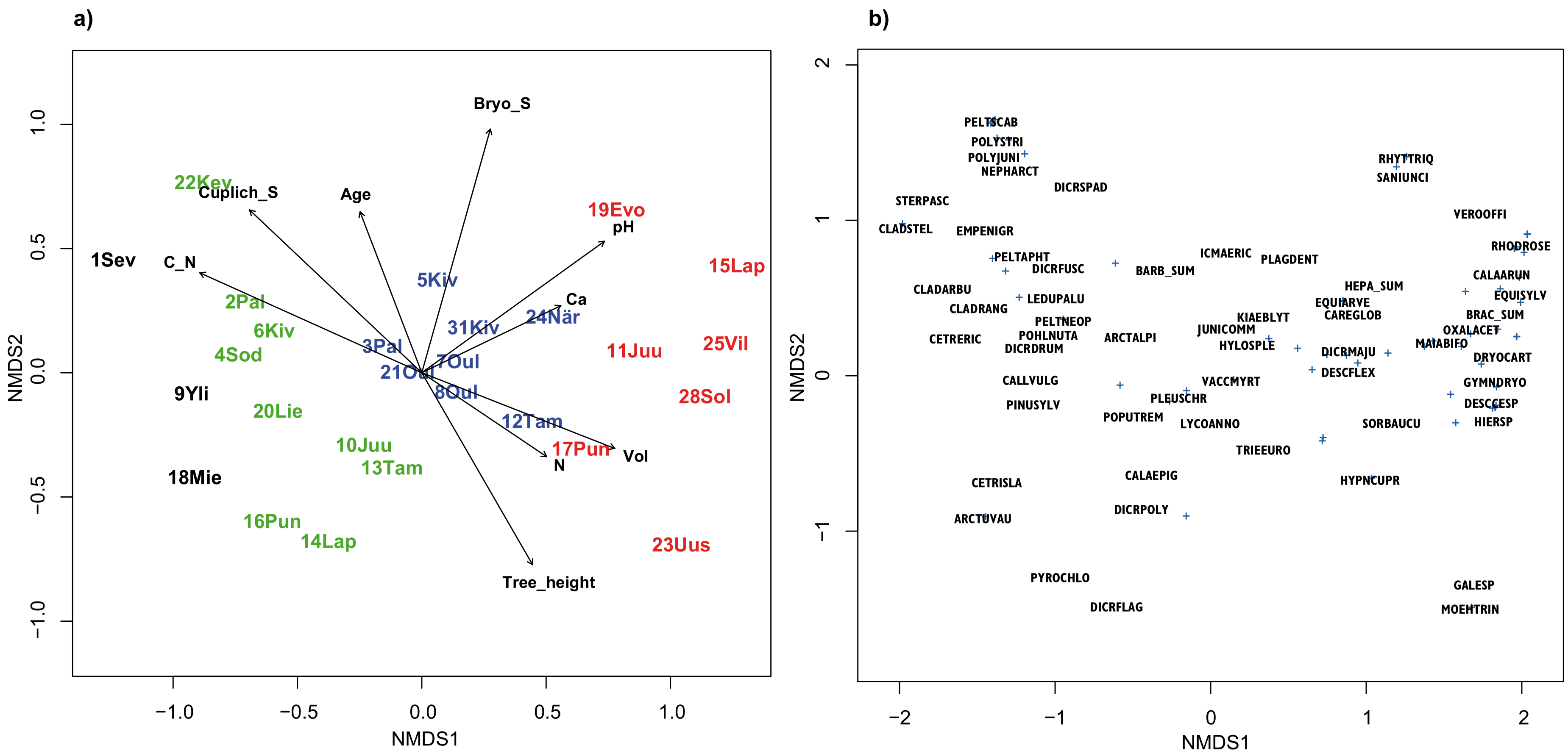

Figure 5. Global nonmetric multidimensional scaling (NMDS) of the vegetation data on the mineral soil plots (n = 27) in 2003. a) Ordination of the sample plots and the fitted vectors of selected environmental variables. C_N = C/N in organic soil, Cuplich_S = number of cup lichen species, Bryo_S = number of bryophyte species, Vol = Stem volume). Site types: red = herb-rich heaths, blue = mesic heaths, green = sub-xeric heaths and black = xeric heaths. b) Weighted averages of the species. Abbreviation of the species names = first four letters from generic and species names. The most abundant species labeled with names, other marked as crosses.

Kuva 5. Globaali ei-metrinen moniuloitteinen skaalaus (NMDS) kivennäismaiden näytealojen kasvillisuudesta vuodelta 2003. a) Näytealojen ordinaatio ja eräiden ympäristömuuttujien sovitetut vektorit. C_N = C/N orgaanisessa kerroksessa, Cuplich_S = torvijäkälälajien lukumäärä, Bryo_S = sammalajien lukumäärä, Vol = runkotilavuus. Kasvupaikkatyypit: punainen = lehtomaiset, sininen = tuoreet, vihreä = kuivahkot ja musta = kuivat kankaat. b) Lajien painotetut keskiarvot. Lajinimien lyhenteet = neljä ensimmäistä kirjainta suvun ja lajin tieteellisistä nimistä. Runsaimmat lajit merkitty nimellä, muut ristillä.

at Pallasjärvi_S (Nr. 3) was lower during the years 2001–2003 (mean 482 mm) than in 1998 (647 mm) (Lindroos et al. 2000, and pages 84, 86 and 88 in this volume), and this may have restricted the growth of *V. myrtillus*. In fact, positive correlation was found between the cover of *V. myrtillus* and the amount of precipitation ($r = 0.857$, $p = 0.029$, $n = 6$).

Table 3. The mean cover (%) of the woody species (dwarf shrubs and tree seedlings), herbs and grasses, bryophytes, lichens, needle and leaf litter during 1998–2003 on the six vegetation plots.
Taulukko 3. Puuvartisten (varvut ja puiden taimet), ruohojen ja heinien summan, sammalten, jäkälien ja neulas- ja lehtikarikkeen peittävyydet (%) kuudella kasvillisuuden havaintoalalla vuosina 1998–2003.

Plot *Havaintoala*	Year *Vuosi*	Woody species *Puu-vartiset*	Herbs & grasses *Ruohot & heinät*	Bryophytes sum *Sammalet summa*	Lichens sum *Jäkälät summa*	Needle litter *Neulas-karike*	Leaf litter *Lehti-karike*
2 Pallasjärvi_P	1998	45.1	0.3	35.5	13.9	51.0	5.6
	1999	42.9	0.1	46.2	14.2	33.4	5.0
	2000	53.8	0.2	41.3	11.5	36.5	3.6
	2001	43.1	0.2	37.5	10.0	30.4	2.5
	2002	42.2	0.3	49.5	9.6	36.8	2.8
	2003	37.0	0.2	49.1	11.0	33.3	3.1
3 Pallasjärvi_S	1998	67.2	2.9	87.3	0.4	6.8	0.1
	1999	56.8	1.2	84.0	0.2	6.4	0.1
	2000	69.4	1.6	89.4	0.1	9.5	0.0
	2001	63.7	2.1	87.0	0.1	5.1	0.1
	2002	58.8	3.3	85.2	0.2	6.8	0.1
	2003	55.2	2.2	86.5	0.2	7.3	0.0
7 Oulanka_S	1998	66.3	5.8	88.0	0.0	4.7	28.4
	1999	64.9	3.9	90.8	0.0	1.5	25.9
	2000	69.3	6.2	99.3	0.0	2.9	29.4
	2001	64.5	6.2	85.9	0.0	1.0	18.2
	2002	66.8	6.3	88.4	0.0	1.9	16.6
	2003	62.0	6.0	87.8	0.0	1.4	20.8
8 Oulanka_P	1998	76.0	7.3	82.5	0.0	23.9	6.8
	1999	74.9	4.9	87.4	0.0	9.9	7.0
	2000	79.8	7.5	89.3	0.0	11.2	7.6
	2001	74.0	5.5	90.5	0.0	5.1	3.6
	2002	77.7	5.1	88.5	0.0	9.1	2.7
	2003	75.8	3.8	86.4	0.0	13.3	3.4
12 Tammela_S	1998	31.2	16.1	77.4	0.0	15.7	8.4
	1999	33.4	16.3	71.5	0.0	13.9	5.7
	2000	30.6	15.8	68.7	0.0	12.5	12.9
	2001	36.7	19.6	73.4	0.0	9.4	9.1
	2002	47.2	16.0	65.8	0.0	13.1	13.3
	2003	43.9	9.9	51.7	0.0	15.4	26.3
13 Tammela_P	1998	22.4	11.1	86.1	0.6	21.4	1.1
	1999	25.4	14.8	80.9	0.6	19.8	1.1
	2000	31.6	14.4	72.0	0.4	20.3	0.5
	2001	36.0	14.5	65.2	0.3	20.3	0.3
	2002	38.2	19.4	62.9	0.3	35.8	2.0
	2003	36.3	8.9	46.9	0.3	39.6	4.4

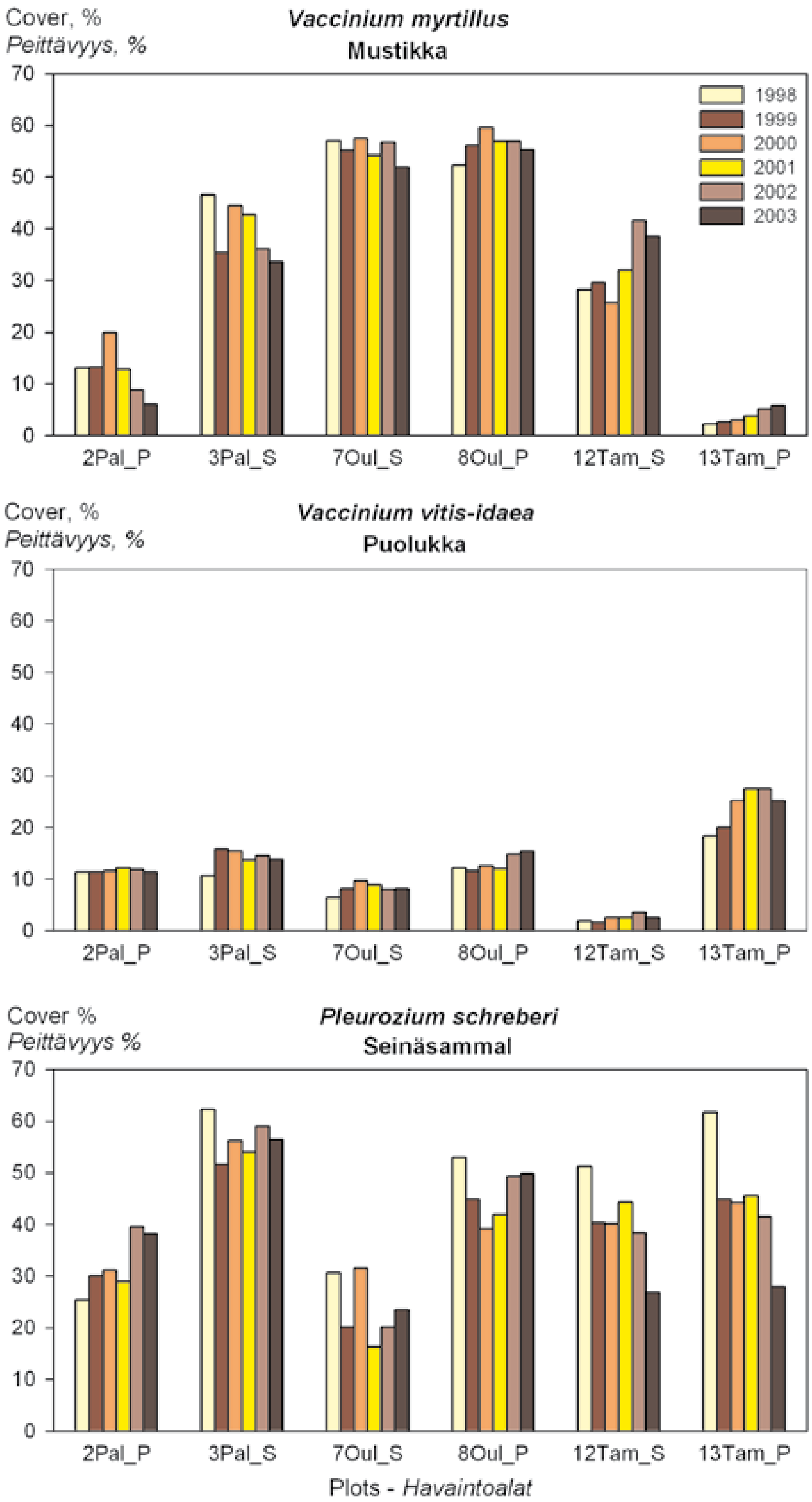

Figure 6. The change in the mean cover of *Vaccinium myrtillus* (bilberry), *V. vitis-idaea* (cowberry) and a bryophyte *Pleurozium schreberi* on the six vegetation plots during 1998–2003.
Kuva 6. Mustikan (Vaccinium myrtillus), puolukan (V. vitis-idaea) sekä seinäsammalen (Pleurozium schreberi) keskimääräisten peittävyyksien muutos kuudella kasvillisuuden havaintoalalla jaksolla 1998–2003.

The total cover of bryophytes and lichens changed only slightly on the northern plots (Nrs. 2, 3, 7, 8), whereas the cover of bryophytes decreased on the plots at Tammela (Nrs. 12, 13) during 1998–2003 (Table 3). The decreasing trend was expressed especially in the dominant moss species *Pleurozium schreberi* at Tammela (Fig. 6). At the same time the cover of dwarf shrubs, as well as the cover of needle and leaf litter on the forest floor, increased which may have suppressed the moss layer. The cover of bryophytes correlated negatively with the cover of needle litter at Tammela_P (Nr. 13) ($r = -0.805$, $p = 0.053$, $n = 6$) and with the cover of leaf litter at Tammela_S (Nr. 12) ($r = -0.940$, $p = 0.005$, $n = 6$). In addition, a positive correlation was found between the annual precipitation and the cover of bryophytes in the combined data of the two plots at Tammela ($r = 0.592$, $p = 0.043$, $n = 12$).

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References

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

Lindroos, A.-J., Derome, J., Derome, K. & Niska, K. 2000. Deposition. In: Ukonmaanaho, L. & Raitio, H. (eds.) Forest condition monitoring in Finland. National Report 1999. The Finnish Forest Research Insitute, Research Papers 782: 61–69.

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

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 2002. Part VIII. Assessment of ground vegetation. 19 p. [Internet site]. UN-ECE. Programme coordination centre, Hamburg. Available at: http://www.icp-forests.org/manual.htm.

Økland, R.H. 1995. Changes in the occurrence and abundance of plant species in a Norwegian boreal coniferous forest, 1988–1993. Nordic Journal of Botany 15: 415–438.

Oksanen, J. 2007. Multivariate Analysis of Ecological Communities in R: vegan tutorial. 39 p. [Internet site]. Available at: http://cc.oulu.fi/~jarioksa/softhelp/vegan.html.

Reinikainen, A., Mäkipää, R., Vanha-Majamaa, I. & Hotanen, J.-P. (eds.) 2000. Kasvit muuttuvassa metsäluonnossa. (English summary: Changes in the frequency and abundance of forest and mire plants in Finland since 1950). Tammi, Helsinki. 384 p.

Salemaa, M., Monni, S., Royo Peris, F. & Uhlig, C. 1999. Sampling strategy for the assessment of temporal changes in ground vegetation in boreal forests. In: Raitio, H. & Kilponen, T. (eds.). Forest condition monitoring in Finland. National report 1998. The Finnish Forest Research Institute, Research Papers 743: 117–127.

Seidling, W. 2005. Ground floor vegetation assessment within the intesive (Level II) monitoring of forest ecosystems in Germany: chances and challenges. European Journal of Forest Research 124: 301–312.

Tonteri, T. 1994. Species richness of boreal understorey forest vegetation in relation to site type and successional factors. Annales Zoologici Fennici 31: 53–60.

Tonteri, T., Hotanen, J.-P., Mäkipää, R., Nousiainen, H., Reinikainen, A. & Tamminen, M. 2005. Metsäkasvit kasvupaikoillaan – kasvupaikkatyypin, kasvillisuusvyöhykkeen, puuston kehitysluokan ja puulajin yhteys kasvilajien runsaussuhteisiin. Metsäntutkimuslaitoksen tiedonantoja 946. 106 p.

3.5 Open area bulk deposition and stand throughfall in Finland during 2001–2004

Avoimen paikan ja metsikkösadannan laskeuma Suomessa vuosina 2001–2004

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The results of deposition (open area bulk and stand throughfall) monitoring on 8 Norway spruce and 8 Scots pine Level II plots during 2001–2004 are presented in this report. Mean total N and SO_4-S deposition were clearly higher in southern Finland than in northern Finland. Sulphur deposition in the open and in stand throughfall during 2001–2004 was clearly lower than that measured in earlier years (monitoring started in 1996), especially on the plots in southern Finland. There was no corresponding decrease in the deposition of nitrogen compounds in either bulk deposition or in stand throughfall. The lowest SO_4-S deposition in stand throughfall was recorded on the spruce plot at Pallasjärvi (N Finland), 94 mg m^{-2} in 2002, and the highest value on the spruce plot in Tammela (S Finland), 507 mg m^{-2} in 2003. The lowest total N deposition in the open occurred on the pine plot at Sevettijärvi (N Finland), 62 mg m^{-2} in 2002, while the corresponding highest deposition load was recorded on the plot at Miehikkälä (S Finland), 456 mg m^{-2} in 2004. The annual values for many of the other deposition parameters were also higher in the southern part of Finland compared to the north.

Tässä raportissa esitetään avoimen paikan ja metsikkösadannan laskeuman tulokset kahdeksalle kuusi- ja mäntyalalle vuosille 2001–2004. Totaalitypen ja SO_4-S:n keskiarvolaskeumat olivat selvästi suurempia Etelä-Suomessa verrattuna Pohjois-Suomeen vuosina 2001–2004. Verrattaessa vuosien 2001–2004 tuloksia aikaisempiin vuosiin (seuranta alkoi 1996) havaittiin, että avoimen paikan ja metsikkösadannan rikkilaskeuma on alentunut etenkin Etelä-Suomen havaintoaloilla. Vastaavaa laskeuman vähentymistä ei ollut havaittavissa typen yhdisteille avoimella paikalla tai metsikkösadannassa. Alhaisin metsikkösadannan SO_4-S -laskeuma mitattiin Pallasjärven kuusikkoalalla Pohjois-Suomessa, 94 mg m^{-2} vuonna 2002, ja suurin laskeuma Tammelan kuusikkoalalla Etelä-Suomessa, 507 mg m^{-2} vuonna 2003. Alhaisin avoimen paikan totaalitypen laskeuma mitattiin Sevettijärven alalla Pohjois-Suomessa, 62 mg m^{-2} vuonna 2002, ja suurin laskeuma Miehikkälän havaintoalalla Etelä-Suomessa, 456 mg m^{-2} vuonna 2004. Myös useiden muiden laskeumatunnusten arvot olivat suurimmat maan eteläosissa pohjoiseen verrattuna.

Introduction

Deposition monitoring started in Finland as a part of the EU/ICP Forests programmes in 1995. During the first year, 18 Level II intensive monitoring plots were established for this purpose in different parts of Finland. The number of the Level II plots with deposition monitoring increased to 24 plots during 1996 but, from 1998 onwards, the number of intensively monitored plots was reduced to 16. In 2004, one plot was replaced with two new plots, i.e. the total number of the plots was 17.

The results concerning deposition on the forests and forest floor have been published in the national reports (Lindroos et al. 1999, 2000, 2001, 2002). The deposition monitoring was carried out according to the relevant sub-manual of the EU-funded Forest Focus programme. In this report, the deposition results of the 16 monitoring plots for the years 2001–2004 are presented.

Material and methods

Deposition on the forests (bulk deposition in the open area, BD) and on the forest floor (stand throughfall, TF) were monitored in 8 Norway spruce and 8 Scots pine stands during 2001–2003. In 2004, deposition was monitored on 8 Norway spruce, 7 Scots pine and 2 birch plots. The BD and TF samples were collected at 4-week intervals during the winter, and at 2-week intervals during the snow-free period.

There were 20 systematically located bulk deposition collectors (ø = 20 cm, h = 0.4 m) within the stand (TF) during the snow-free period, and 6–10 snow collectors (ø = 36 cm, h = 1.8 m) during the wintertime depending on the structure of the stand. The number of snow collectors in each stand was based on a pre-study using 20 snow collectors located systematically on each plot. From this 20-collector network, 6–10 collectors were selected for sampling such that the mean deposition value was approximately the same as the result obtained with the 20 collectors. The number of collectors in the open area was 3 (bulk deposition) and 2 (snow collectors). The samples were pre-treated and analysed according to the sub-manual of the ICP Forests Programme (current version: Manual on methods... 2006).

Results and discussion

The amount of precipitation in the open area varied from 278 to 822 mm/year during 2001–2004. The corresponding range for the amount of stand throughfall was 191–731 mm/year. The lowest annual SO_4-S deposition load in the open was recorded on the Oulanka plot in northern Finland, 81 mg m^{-2} in 2003, and the highest load on the Miehikkälä plot in southern Finland, 320 mg m^{-2} in 2004. The corresponding lowest value in stand throughfall was recorded on the spruce plot at Pallasjärvi (N Finland), 94 mg m^{-2} in 2002, and the highest value on the spruce plot at Tammela (S Finland), 507 mg m^{-2} in 2003. For the total N deposition in the open, the lowest value occurred on the plot at Sevettijärvi (N Finland), 62 mg m^{-2} in 2002, while the corresponding highest deposition load on the plot at Miehikkälä (S Finland), 456 mg m^{-2} in 2004 (Tables 1–8).

The annual deposition values for many of the parameters were higher in the southern part of Finland than in the north. Throughfall deposition was generally higher than that in the open for all the parameters except for nitrogen compounds. The bulk deposition values for NH_4-N, NO_3-N and N_{tot} were generally higher than those in stand throughfall (Tables 1–8).

There were two exceptions to these general trends: the pine plot at Sevettijärvi and the spruce plot at Uusikaarlepyy. On the Sevettijärvi plot in NE Finland, the Na and Cl deposition values were very high due to the proximity of the Barents Sea. On the Uusikaarlepyy plot, located on the west coast of Finland, local NH_3 emissions were reflected in deposition, and the stand throughfall values for nitrogen compounds were generally higher than those in the open (Tables 1–8).

Sulphur deposition in bulk deposition and stand throughfall in 2003 and 2004 were lower than the values recorded in earlier years (monitoring started in 1996), especially on the plots in southern Finland (Lindroos et al. 2006). This decrease is in accordance with the results for the whole European monitoring network (The Condition of...2005). On the other hand, there was no corresponding decrease in the deposition of nitrogen compounds in either bulk deposition or in stand throughfall. Mean total N in bulk deposition and SO_4-S deposition in stand throughfall were clearly higher in southern Finland compared to northern Finland during 2001–2004 (Figs. 1 and 2).

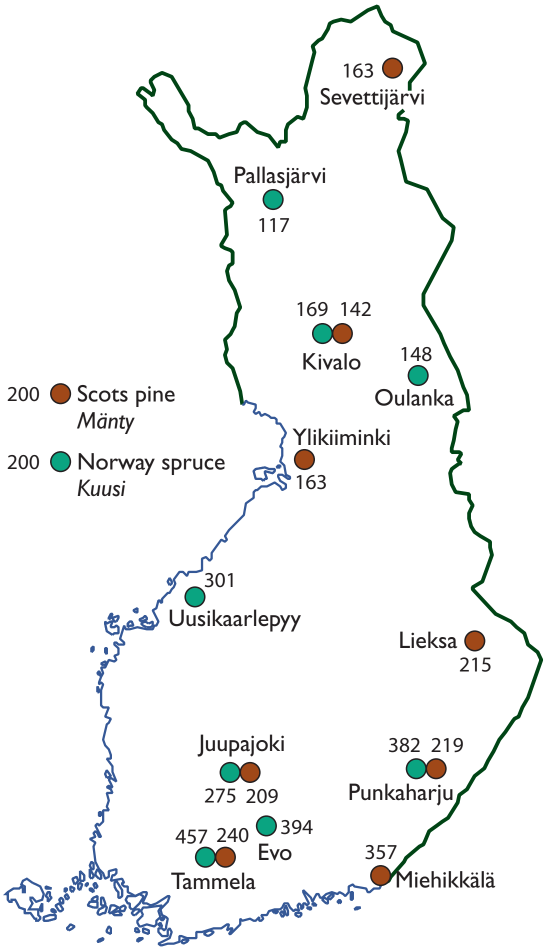

Figure 1. Mean SO_4-S deposition (mg m^{-2} yr^{-1}) in stand throughfall for the period 2001–2004.
Kuva 1. Keskimääräinen SO_4-S -laskeuma (mg m^{-2} v^{-1}) metsikkösadannassa tutkimusjaksolla 2001–2004.

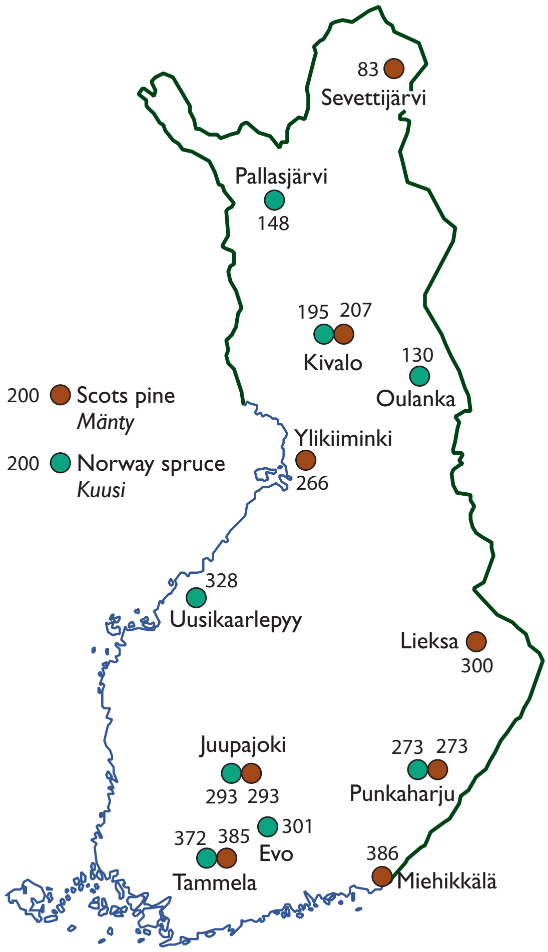

Figure 2. Mean total N deposition (mg m^{-2} yr^{-1}) in bulk deposition for the period 2001–2004.
Kuva 2. Keskimääräinen totaali-N -laskeuma (mg m^{-2} v^{-1}) avoimella paikalla tutkimusjaksolla 2001–2004.

Table 1. Bulk deposition in the open (BD) and deposition in stand throughfall (TF) on 8 Norway spruce plots in 2001. The plots are listed in the table from north to south Finland.
Taulukko 1. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla kuusialalla (plot) vuonna 2001. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot	Lat.		Prec.	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
	nr.			mm						mg m^{-2}					
Pallasjärvi	3	67	BD	575	115	109	61	69	142	61	20	31	76	66	1041
			TF	487	131	146	21	41	127	96	34	377	94	141	3013
Kivalo	5	66	BD	561	156	177	66	96	203	81	27	23	65	59	1036
			TF	500	174	195	24	55	135	102	35	435	87	105	3536
Oulanka	21	66	BD	394	121	133	46	62	123	58	19	17	62	62	787
			TF	388	158	163	24	35	96	103	37	291	97	112	2414
Uusikaarlepyy	23	63	BD	543	167	177	169	122	369	97	34	70	126	131	1028
			TF	340	310	386	221	104	572	141	75	1388	201	536	7157
Juupajoki	11	61	BD	727	247	269	121	168	347	149	37	63	115	120	1326
			TF	495	287	364	33	58	250	207	67	1397	147	291	7401
Punkaharju	17	61	BD	487	185	203	85	133	266	126	29	43	65	65	1021
			TF	313	383	432	24	62	209	195	77	1006	87	270	5069
Evo	19	61	BD	642	218	243	123	160	341	126	33	40	90	92	1247
			TF	441	364	424	33	93	264	303	94	1063	184	466	6724
Tammela	12	60	BD	632	231	260	127	176	353	146	39	52	119	141	1288
			TF	420	461	496	23	80	298	295	107	1241	271	684	8206

Table 2. Bulk deposition in the open area (BD) and deposition in stand throughfall (TF) on 8 Scots pine plots in 2001. The plots are listed in the table from north to south Finland.

Taulukko 2. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla mäntyalalla (plot) vuonna 2001. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
										mg m^{-2}					
Sevettijärvi	1	69	BD	454	113	119	18	39	68	37	36	24	277	449	704
			TF	414	193	201	13	35	81	88	56	115	376	628	1982
Kivalo	6	66	BD	561	151	159	87	97	224	67	20	29	97	62	1087
			TF	432	149	158	34	60	147	87	30	201	81	92	2967
Ylikiiminki	9	64	BD	548	168	191	113	116	316	92	26	40	84	83	1160
			TF	442	165	184	39	79	195	125	44	205	94	124	3691
Lieksa	20	63	BD	501	171	249	94	118	278	97	20	38	88	73	940
			TF	444	212	238	126	93	354	147	51	252	93	120	3817
Juupajoki	10	61	BD	727	247	269	121	168	347	149	37	63	115	120	1326
			TF	600	262	297	38	105	239	186	61	552	168	244	5313
Punkaharju	16	61	BD	487	185	203	85	133	266	126	29	43	64	65	1021
			TF	341	231	260	30	74	183	170	48	370	99	132	4327
Tammela	13	60	BD	680	249	284	144	192	395	142	37	46	124	122	1271
			TF	499	256	303	34	120	281	221	73	535	167	269	5963
Miehikkälä	18	60	BD	677	305	331	132	178	359	180	31	36	97	111	1247
			TF	538	393	428	80	163	362	286	63	327	132	203	4621

Table 3. Bulk deposition in the open (BD) and deposition in stand throughfall (TF) on 8 Norway spruce plots in 2002. The plots are listed in the table from north to south Finland.

Taulukko 3. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla kuusialalla (plot) vuonna 2002. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
										mg m^{-2}					
Pallasjärvi	3	67	BD	417	82	93	57	49	132	84	80	46	66	77	856
			TF	381	94	106	21	32	86	95	81	292	122	191	2604
Kivalo	5	66	BD	498	108	120	64	70	155	101	58	65	87	99	1077
			TF	443	119	147	11	37	108	123	64	403	117	129	3069
Oulanka	21	66	BD	351	90	105	66	50	166	83	57	41	60	77	589
			TF	389	127	141	9	34	74	145	71	264	118	118	2457
Uusikaarlepyy	23	63	BD	278	134	148	103	88	284	134	71	103	271	355	674
			TF	234	283	350	136	120	526	167	86	1772	291	860	7201
Juupajoki	11	61	BD	487	147	166	102	120	238	120	65	54	71	96	883
			TF	357	224	275	18	50	171	195	82	1001	115	229	4654
Punkaharju	17	61	BD	463	154	173	69	114	231	135	73	95	79	114	950
			TF	290	344	406	24	56	205	230	101	1169	125	285	5852
Evo	19	61	BD	539	180	203	135	140	304	186	74	63	98	127	2324
			TF	386	373	455	29	109	281	329	116	1107	267	441	6827
Tammela	12	60	BD	545	214	239	207	175	416	199	90	59	132	188	1168
			TF	406	451	554	55	92	323	384	160	1357	330	604	8991

Table 4. Bulk deposition in the open area (BD) and deposition in stand throughfall (TF) on 8 Scots pine plots in 2002. The plots are listed in the table from north to south Finland.

Taulukko 4. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla mäntyalalla (plot) vuonna 2002. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
					mg m^{-2}										
Sevettijärvi	1	69	BD	357	117	126	27	32	62	81	101	40	501	814	576
			TF	301	154	163	13	24	60	131	103	120	647	1092	1683
Kivalo	6	66	BD	480	99	110	46	68	135	89	52	57	71	81	1084
			TF	389	107	128	31	49	119	106	51	187	109	125	2615
Ylikiiminki	9	64	BD	506	125	139	60	98	214	101	42	56	78	95	940
			TF	428	128	156	33	65	165	157	59	244	120	142	3764
Lieksa	20	63	BD	549	158	176	101	114	267	111	54	58	95	117	1142
			TF	447	172	204	49	77	194	222	79	319	130	169	4668
Juupajoki	10	61	BD	487	147	166	102	120	238	120	65	54	71	96	883
			TF	398	161	193	54	102	227	161	78	384	119	175	4067
Punkaharju	16	61	BD	463	154	173	69	114	231	135	73	95	79	114	950
			TF	311	187	219	27	72	185	182	57	387	105	130	3836
Tammela	13	60	BD	536	215	250	214	172	434	195	86	57	129	177	1119
			TF	404	228	269	111	130	315	255	103	483	165	267	5431
Miehikkälä	18	60	BD	539	268	297	144	171	352	175	52	62	111	153	1260
			TF	402	310	353	78	162	329	245	81	319	150	236	3785

Table 5. Bulk deposition in the open (BD) and deposition in stand throughfall (TF) on 8 Norway spruce plots in 2003. The plots are listed in the table from north to south Finland.
Taulukko 5. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla kuusialalla (plot) vuonna 2003. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
					mg m^{-2}										
Pallasjärvi	3	67	BD	454	82	90	61	48	170	62	21	52	69	103	735
			TF	425	102	116	5	27	77	72	27	281	143	228	3224
Kivalo	5	66	BD	572	152	162	99	96	195	69	23	33	68	94	780
			TF	562	210	245	42	62	157	107	38	428	127	168	4397
Oulanka	21	66	BD	363	81	81	32	52	97	53	27	26	41	59	420
			TF	403	146	158	15	33	93	78	37	348	104	163	3201
Uusikaarlepyy	23	63	BD	326	121	119	163	81	311	58	32	58	74	100	656
			TF	191	352	400	198	128	503	115	74	1726	223	796	6991
Juupajoki	11	61	BD	578	191	195	157	146	309	85	23	49	64	99	957
			TF	408	352	377	24	42	206	179	51	1410	155	364	7913
Punkaharju	17	61	BD	595	193	188	128	141	279	128	48	59	70	105	992
			TF	378	414	466	39	55	232	208	99	1432	138	431	9312
Evo	19	61	BD	588	193	186	116	150	282	148	55	47	72	111	1002
			TF	470	475	520	55	164	327	315	94	1383	268	487	8893
Tammela	12	60	BD	517	234	224	228	157	340	102	35	67	164	161	883
			TF	346	507	557	30	89	278	284	102	1175	283	620	9345

Table 6. Bulk deposition in the open area (BD) and deposition in stand throughfall (TF) on 8 Scots pine plots in 2003. The plots are listed in the table from north to south Finland.

Taulukko 6. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla mäntyalalla (plot) vuonna 2003. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat. = leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
										mg m^{-2}					
Sevettijärvi	1	69	BD	397	100	103	32	43	93	54	53	24	235	404	600
			TF	375	134	143	17	33	82	97	68	117	447	670	2198
Kivalo	6	66	BD	590	147	149	94	98	215	73	20	39	77	95	850
			TF	463	164	180	38	66	150	86	27	215	103	141	3493
Ylikiiminki	9	64	BD	540	181	176	115	133	267	58	19	42	71	100	901
			TF	451	197	217	61	92	199	98	41	215	110	158	3549
Lieksa	20	63	BD	581	191	201	140	130	340	93	25	49	77	113	983
			TF	496	228	243	61	88	236	142	45	256	121	171	4470
Juupajoki	10	61	BD	578	191	195	157	146	309	85	23	49	64	99	957
			TF	473	233	247	57	126	259	154	39	390	130	207	5295
Punkaharju	16	61	BD	595	193	188	128	141	279	128	48	59	70	105	992
			TF	393	242	251	75	99	216	159	42	446	113	170	5633
Tammela	13	60	BD	531	226	229	176	172	350	121	32	34	114	154	877
			TF	368	259	265	96	119	268	209	61	455	160	322	5334
Miehikkälä	18	60	BD	668	290	302	173	188	378	122	26	47	129	166	1063
			TF	496	348	372	96	172	343	236	77	362	208	231	5149

Table 7. Bulk deposition in the open (BD) and deposition in stand throughfall (TF) on 8 Norway spruce plots in 2004. The plots are listed in the table from north to south Finland.
Taulukko 7. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla kuusialalla (plot) vuonna 2004. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat.= leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
										mg m^{-2}					
Pallasjärvi	3	67	BD	712	130	113	42	72	148	82	29	42	79	79	1121
			TF	656	142	151	29	51	149	117	35	380	144	178	4131
Kivalo	5	66	BD	645	149	148	63	93	228	73	23	60	82	102	1106
			TF	604	173	180	23	67	182	95	36	476	125	149	4336
Oulanka	21	66	BD	490	124	106	47	66	132	69	24	33	69	80	667
			TF	525	159	163	49	51	133	106	34	267	91	122	2692
Uusikaarlepyy	23	63	BD	453	132	139	167	100	347	78	42	110	144	181	775
			TF	262	257	306	165	93	467	143	74	1608	242	707	6904
Juupajoki	11	61	BD	640	168	143	100	131	278	92	28	43	96	120	895
			TF	475	235	273	28	62	224	151	46	1051	199	311	5965
Punkaharju	17	61	BD	637	191	202	111	143	317	130	42	85	95	102	1038
			TF	397	387	399	53	58	264	198	74	1099	172	277	7196
Evo	19	61	BD	769	173	169	104	127	278	164	56	44	111	122	1110
			TF	530	362	387	27	92	273	286	92	1113	302	439	6963
Tammela	12	60	BD	821	220	225	137	200	380	149	49	49	168	206	1108
			TF	544	409	462	33	76	309	264	91	1041	382	574	8327

Table 8. Bulk deposition in the open area (BD) and deposition in stand throughfall (TF) on 8 Scots pine plots in 2004. The plots are listed in the table from north to south Finland.

Taulukko 8. Avoimen paikan laskeuma (BD) ja metsikkösadantalaskeuma (TF) kahdeksalla mäntyalalla (plot) vuonna 2004. Havaintoalat on järjestetty taulukossa vastaamaan etelä-pohjoisgradienttia Suomen läpi (Lat.= leveysaste). Prec. = sademäärä.

Sample plot	Plot nr.	Lat.		Prec. mm	SO_4-S	S_{tot}	NH_4-N	NO_3-N	N_{tot}	Ca	Mg	K	Na	Cl	DOC
										mg m^{-2}					
Sevettijärvi	1	69	BD	465	114	116	31	52	107	67	34	24	153	232	607
			TF	405	171	183	28	42	109	98	50	130	332	522	2196
Kivalo	6	66	BD	634	148	134	81	107	252	73	22	42	73	87	1002
			TF	500	149	144	49	70	174	90	29	250	97	127	3695
Lieksa	20	63	BD	822	216	193	113	138	313	142	36	85	120	134	1409
			TF	731	247	246	146	115	317	177	52	285	158	160	4656
Juupajoki	10	61	BD	640	168	143	100	131	278	92	28	43	96	120	895
			TF	515	181	196	59	94	239	148	49	326	160	225	4693
Punkaharju	16	61	BD	637	191	202	111	143	317	130	42	85	95	102	1038
			TF	415	214	225	49	74	221	139	38	457	116	154	4772
Tammela	13	60	BD	758	212	217	139	197	359	131	41	49	175	216	998
			TF	541	216	230	79	113	264	166	53	460	214	315	5725
Miehikkälä	18	60	BD	817	320	307	207	217	456	203	53	54	185	250	1135
			TF	600	378	384	126	183	403	276	76	422	281	424	4751

References

Lindroos, A-J., Derome, J., Derome, K. & Niska, K. 1999. Deposition. In: Raitio, H. & Kilponen, T. (eds.). Forest Condition Monitoring in Finland. National Report 1998. The Finnish Forest Research Institute, Research Papers 743: 72–77.

Lindroos, A-J., Derome, J., Derome, K. & Niska, K. 2000. Deposition. In: Ukonmaanaho, L. & Raitio, H. (eds.). Forest Condition Monitoring in Finland. National Report 1999. The Finnish Forest Research Institute, Research Papers 782: 61–69.

Lindroos, A-J., Derome, J., Derome, K. & Niska, K. 2001. Deposition on the forests and forest floor in 1999. In: Ukonmaanaho,L. & Raitio, H. (eds.). Forest Condition Monitoring in Finland. National Report 2000. The Finnish Forest Research Institute, Research Papers 824: 78–88.

Lindroos, A-J., Derome, J., Derome, K. & Niska, K. 2002. Deposition on the forests and forest floor in 2000. In: Rautjärvi, H., Ukonmaanaho, L. & Raitio, H. (eds.). Forest Condition Monitoring in Finland. National Report 2001. The Finnish Forest Research Institute, Research Papers 879: 63–69.

Lindroos, A-J., Derome, J., Derome, K. & Lindgren, M. 2006. Trends in sulphate deposition on the forests and forest floor and defoliation degree in 16 intensively studied forest stands in Finland during 1996–2003. Boreal Environment Research 11(6): 451–461.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 2006. Part VI. Sampling and analysis of deposition. 78 p. [Internet site]. UN-ECE. Programme coordination centre, Hamburg. Available at: http://www.icp-forests.org/manual.htm.

The Condition of Forests in Europe. 2005. Executive Report. United Nations Economic Commission for Europe. Federal Research Centre for Forestry and Forest Products (BFH). 33 p.

3.6 Soil percolation water quality during 2001–2004 on 11 Level II plots

Vajoveden kemiallinen koostumus 11 havaintoalalla (taso II) vuosina 2001–2004

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This report presents the results of monitoring carried out on percolation water quality during 2001–2004 on 6 Level II plots located in Scots pine stands and 5 plots in Norway spruce stands. Percolation water was collected at 4-week-intervals during the snowfree period in 2001, 2002, 2003 and 2004 using zero tension lysimeters located at a depth of 5 cm from the ground surface. Overall, there were no signs of an increase in acidification caused by the deposition of acidifying sulphur and nitrogen compounds during the period 2001–2004, nor of a decrease in sulphate concentrations resulting from the decrease in sulphur deposition during the past decade. Nitrate concentrations were extremely low, indicating that there are currently no signs of nitrogen saturation in these ecosystems. DOC concentrations increased strongly on most of the plots in 2003, which was an extremely hot and dry summer, and therefore DOC concentrations could potentially be used as a relatively sensitive indicator of the effects of climate change on carbon fluxes. Concentrations of important base cations (Ca, Mg and K) remained relatively constant throughout the monitoring period on most of the plots.

Tässä raportissa esitetään maavesiseurannan tuloksia tason II kuudelta mänty- ja viideltä kuusialalta jaksolta 2001–2004. Vesinäytteet kerättiin 5 cm:n syvyydelle asennetuilla vajovesilysimetreillä lumettomana aikana neljän viikon välein. Jaksolla 2001–2004 ei havaittu merkkejä rikki- ja typpilaskeuman aiheuttamasta happamoitumisesta, eikä toisaalta merkkejä vajoveden sulfaattipitoisuuksien alenemisesta, vaikka rikkilaskeuma on vähentynyt viime vuosikymmenen aikana. Nitraattipitoisuudet olivat erittäin alhaisia, mikä osoittaa, ettei kyseisissä ekosysteemeissä ole tällä hetkellä nähtävissä viitteitä typpikyllästymisestä. Liukoisen hiilen (DOC) pitoisuudet kohosivat voimakkaasti suurimmalla osalla seuranta-aloista vuonna 2003, jolloin kesä oli erittäin lämmin ja kuiva. Vajoveden DOC-pitoisuutta voitaisiin mahdollisesti käyttää suhteellisen herkkänä indikaattorina osoittamaan hiilivirroissa ilmastomuutoksen seurauksena tapahtuvia muutoksia. Suurimmalla osalla havaintoaloista tärkeiden emäskationien (kalsium, magnesium ja kalium) pitoisuudet pysyivät seurantajakson aikana suhteellisen vakaina.

Introduction

Soil solution has been monitored on 16 Level II plots since 1998. The results of percolation water quality monitoring using zero-tension lysimeters located at 5 cm depth on 6 pine plots and 5 spruce plots in different parts of Finland during 2001–2004 are presented in the report. The chemical composition of percolation water sampled with zero-tension lysimeters provides important information about the passage of ions and dissolved organic carbon down the soil profile and, together with information about the chemical composition of throughfall, enables fluxes to be calculated for the most important elements (e.g. carbon and nitrogen) in forest ecosystems. The main purpose of the report is to provide forest researchers with an overall view of the range of percolation water parameters in pine and spruce stands in different parts of the country.

Material and methods

Percolation water was collected at 4-week-intervals during the snowfree period in 2001–2004 using zero tension lysimeters (diam. 20 cm) located at a depth of 5 cm from the ground surface. The installation and construction of the lysimeters have been described in detail in Derome et al. (1991). There were 5 replicate lysimeters at a depth of 5 cm on each plot. The soil type on the plots is podzolic; most of the pine plots are located on sorted glaciofluvial material, and the spruce plots on till soils. The pH was measured on unfiltered samples. The samples were filtered through membrane filters (0.45 µm) under positive pressure by means of a peristaltic pump. An aliquot of the filtrate was preserved with concentrated HNO_3 prior to the determination of Al_{tot} by inductively coupled plasma atomic emission spectrometry (ICP-AES). Dissolved organic carbon (DOC) was determined on the unpreserved filtrate on a TOC analyser, and Ca, Mg, K, SO_4 and NO_3 by ion chromatography (IC).

Results and discussion

Acidity parameters (pH, Al_{tot}, SO_4 and NO_3)

The average pH on the pine plots was relatively constant during 2001–2004 (Fig. 1), and percolation water pH was clearly the highest on the northernmost plot (P_1). On two of the spruce plots (S_3, S_17), on the other hand, there was a statistically significant decrease in pH over time. One of the plots (S_3) is located in northern Finland where the load of acidifying deposition is the lowest, and also biomass accumulation in the stand is relatively slow owing to the low stand density and slow growth rate. Thus neither acidifying deposition nor higher uptake of base cations is likely to be the explanation for the decrease in pH. The other plot is located in south-east Finland in an area which receives considerable amounts of acidifying deposition from the St. Petersburg area. The percolation water on this site was also the most acidic. However, the relatively high acidity on this plot may be related to the fact that it is relatively paludified, and the site was subjected to slash-and-burn agriculture during the late 19th century.

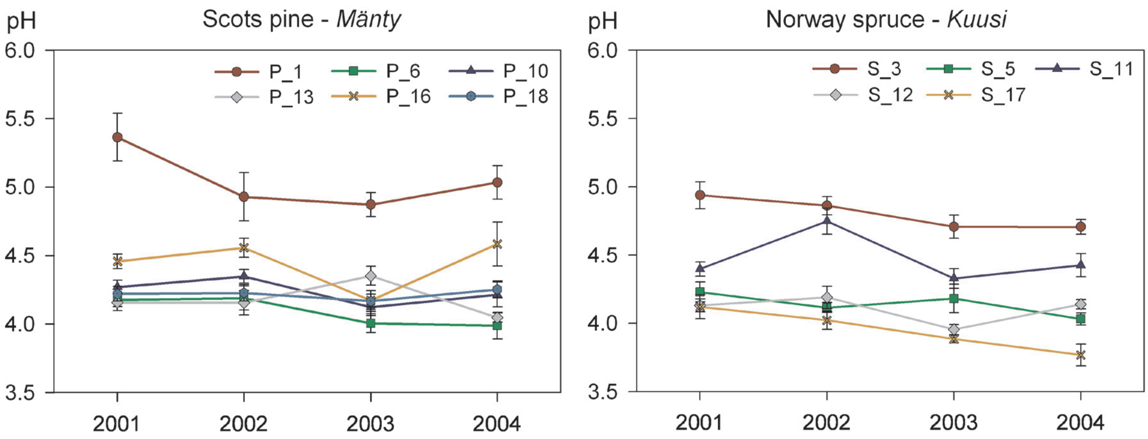

Figure 1. Average (S.E.) annual pH in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.

Kuva 1. Keskimääräinen vajoveden pH 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

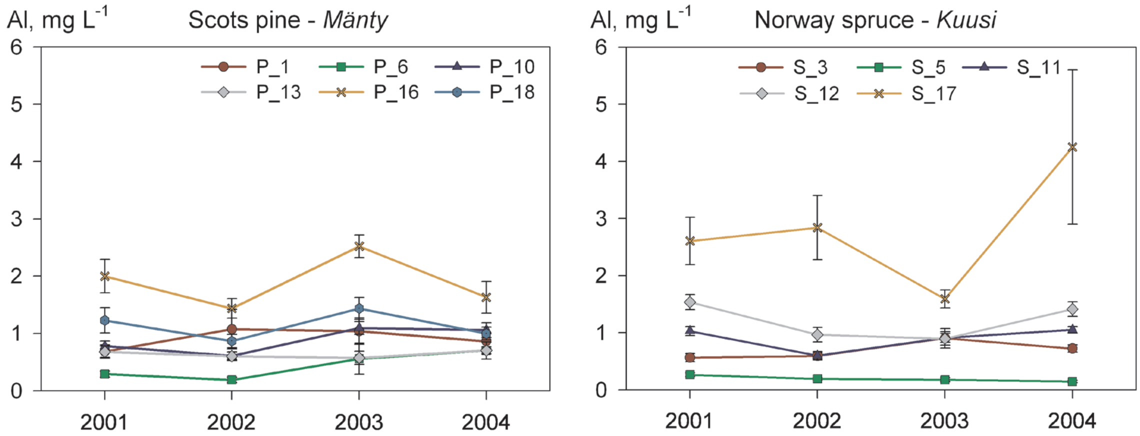

Figure 2. Average (S.E.) annual total aluminium (Al_{tot}) concentration in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.

Kuva 2. Keskimääräinen vajoveden kokonaisalumiinipitoisuus (Al_{tot}) 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

The total aluminium (Al_{tot}) concentration on the pine plots, as well as all but one (S_17) of the spruce plots, were relatively constant throughout the period (Fig. 2). The average Al concentration was the highest on the two plots (P_16 and S_17) in Punkaharju in southern Finland, and the year-to-year variation was also very large on one of these plots (S_17). Aluminium concentrations are usually strongly correlated with pH, and in fact Plot S_17 was the most acidic of all the plots. It has been proposed that Al concentrations above a threshold value of 1.8 mg L^{-1} may cause damage to the fine root systems of trees (de Vries et al. 1995). The annual average Al_{tot} concentration on only two of the plots (P_16 and S_17) exceeded this critical value. However, the percolation water collected under the organic layer on these two plots also had the highest DOC concentrations, and there are strong grounds to assume that only a relatively small proportion of the aluminium was in the form (Al^{3+}) toxic to plant roots.

The average sulphate concentration on all the pine plots and all but one (S_17) of the spruce plots remained extremely constant throughout the period, with no apparent decreasing trend (Fig. 3).

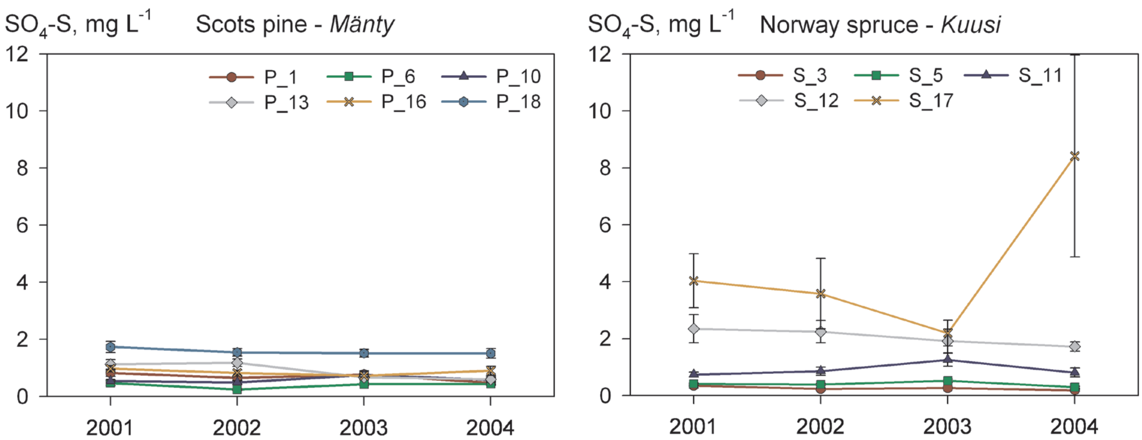

Figure 3. Average (S.E.) annual sulphate concentration (SO_4-S) in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.

Kuva 3. Keskimääräinen vajoveden sulfaattipitoisuus (SO_4-S) 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

The nitrate concentrations on all the plots were extremely low (below 0.25 mg NO_3-N L^{-1}), thus indicating that the leaching of nitrate derived from nitrification is of little importance on these plots (Fig. 4).

Dissolved organic carbon (DOC)

The average DOC concentrations on the pine and spruce stands did not show any clear trends as regards the location of the plots (e.g. north, central and south Finland), nor between the type of tree species on the plots (Fig. 5). There was a clear increase in the DOC concentrations in percolation water on 8 of the 11 plots in 2003. This year had an exceptionally warm and dry summer, and the increase may have been caused by a higher rate of decomposition in the organic layer, with resulting higher DOC concentrations in autumn when precipitation as rain was at a

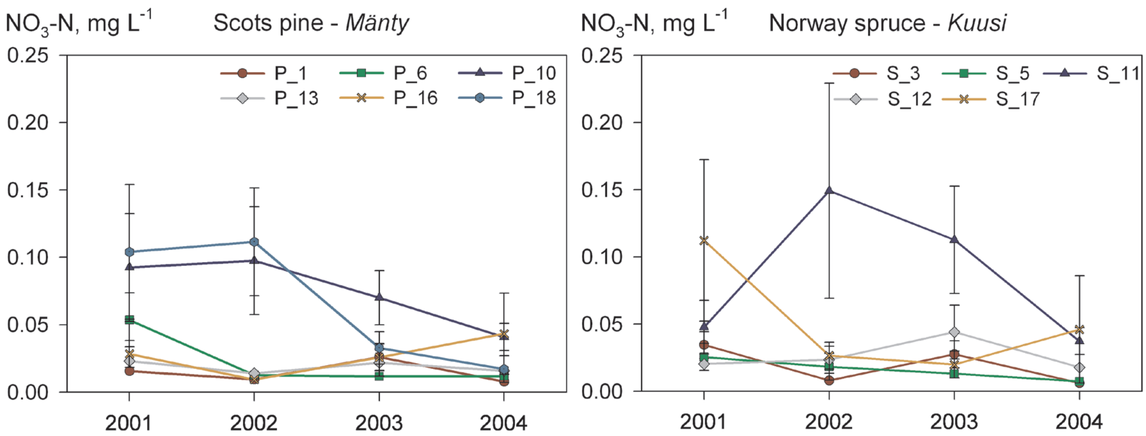

Figure 4. Average (S.E.) annual nitrate concentration (NO_3-N) in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001– 2004. The number of the plots runs in ascending order from north to south.

Kuva 4. Keskimääräinen vajoveden nitraattipitoisuus (NO_3-N) 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

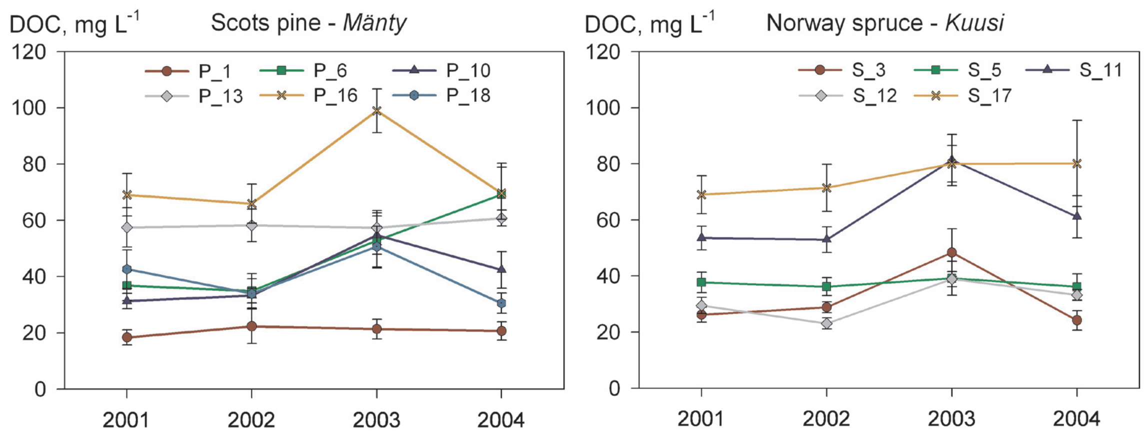

Figure 5. Average (S.E.) annual dissolved organic carbon (DOC) concentration in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.

Kuva 5. Keskimääräinen vajoveden liuenneen orgaanisen hiilen pitoisuus (DOC) 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

peak. This is an interesting finding, and further work should be carried out on the relationship between soil temperature, precipitation and DOC concentrations below the organic layer, as DOC concentrations could potentially be a relatively sensitive indicator of the effects of climate change on carbon fluxes.

Fertility parameters (Ca, Mg, K)

The year-to-year variation in the average Ca, Mg and K concentrations were relatively small (apart from plot S_11 for Ca and K, and S_17 for Mg), and there were no clear trends as regards the overall level of the Ca, Mg and K concentrations in different parts of the country nor for the type of tree species (Figs. 6, 7 and 8). There were no logical explanations for the large year-to-year variation on two of the plots.

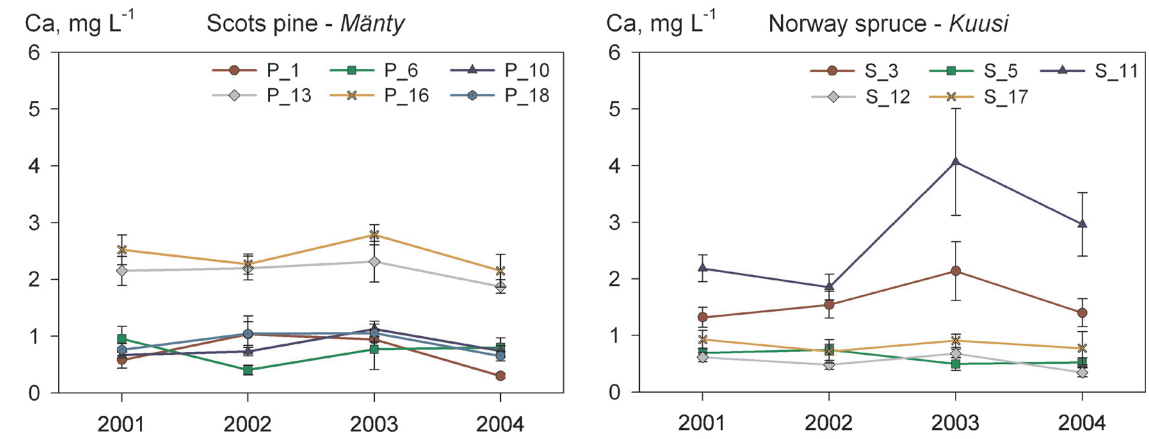

Figure 6. Average (S.E.) annual calcium concentration in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.
Kuva 6. Keskimääräinen vajoveden kalsiumpitoisuus 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

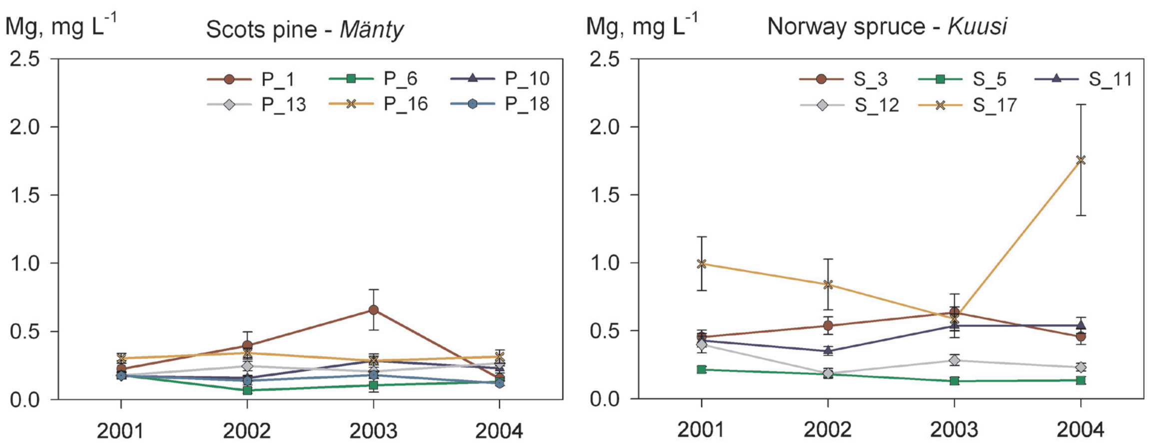

Figure 7. Average (S.E.) annual magnesium concentration in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.
Kuva 7. Keskimääräinen vajoveden magnesiumpitoisuus 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

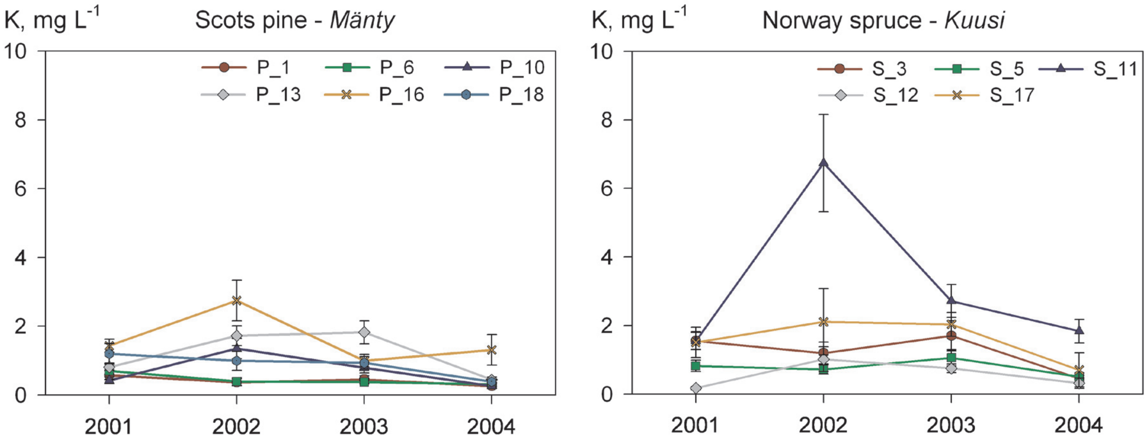

Figure 8. Average (S.E.) annual potassium concentration in percolation water sampled using zero-tension lysimeters at a depth of 5 cm on 6 Scots pine plots and 5 Norway spruce plots during 2001–2004. The number of the plots runs in ascending order from north to south.
Kuva 8. Keskimääräinen vajoveden kaliumpitoisuus 5 cm:n syvyydessä kuudella männikköalalla ja viidellä kuusikkoalalla eri vuosina 2001–2004. Alojen numerointi pohjoisesta etelään. Kuvissa esitetty keskiarvon keskivirhe (S.E.).

References

Derome, J., Niska, K., Lindroos, A.-J. & Välikangas, P. 1991. Ion-balance monitoring plots and bulk deposition in Lapland during July 1989 – June 1990. In: Tikkanen, E. & Varmola, M. (eds.). Research into forest damage connected with air pollution in Finnish Lapland and the Kola Peninsula of the U.S.S.R. The Finnish Forest Research Institute, Research Papers 373: 49–76.

de Vries, W., van Grinsven, J.J.M., van Breemen, N., Leeters, E.E.J.M. & Jansen, P.C. 1995. Impacts of acid deposition on concentrations and fluxes of solutes in acid sandy forest soils in the Netherlands. Geoderma 67: 17–43.

3.7 Phenological assessments on the intensive monitoring plots

Fenologinen seuranta intensiiviseurannan havaintoaloilla

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Phenological observations have been conducted on four of the intensive monitoring plots since 2000. Ten trees per plot were observed and growth onset was recorded on a 5-point scale. Data on environmental variables were obtained from weather stations installed on the plots. The onset of growth was correlated to several environmental parameters (temperature sum, photoperiod, accumulated photoperiod, soil temperature and night frost). Differences between the sites and years were found for all the parameters, indicating the variability of weather conditions on a spatial and temporal scale. The results clearly showed that the trees on the northern plots flushed later than those on the southern plots, but did so at a lower temperature sum. Furthermore, the results also showed that Norway spruce (*Picea abies*) flushed earlier and at a lower temperature sum than Scots pine (*Pinus sylvestris*). No correlation was found between growth onset and any of the tested environmental parameters, indicating that a 5-year series covers too short a time to predict shifts in growth onset and that the measurements should be continued.

Suomessa fenologista havainnointia on tehty neljällä intensiiviseurannan havaintoalalla vuodesta 2000 lähtien. Kullakin havaintoalalla on seurattu kasvuunlähtöä, ts. silmujen puhkeamista kymmenellä puulla käyttäen asteikkoa 0–5. Säähavainnot on saatu havaintoaloille asennetuilta sääasemilta. Kasvuunlähdön yhteisvaihtelua tutkittiin useiden säätekijöiden kanssa (lämpösumma, valoperiodi, kertynyt valoperiodi, maan lämpötila ja yöpakkaset). Kaikissa säämuuttujissa ilmeni koealojen ja vuosien välistä vaihtelua. Pohjoisilla havaintoaloilla silmut puhkeavat selvästi myöhemmin kuin etelässä, mutta silmujen puhjetessa lämpösummakertymä on pohjoisessa alhaisempi kuin etelässä. Kasvuunlähtö tapahtuu aikaisemmin kuusella kuin männyllä. Kasvuunlähdön ja säätekijöiden välillä ei havaittu merkitsevää yhteisvaihtelua, mikä osoittaa, että viiden vuoden aikasarja on liian lyhyt kasvuunlähdon ennustamiseksi. Havainnointia tulisi siis jatkaa.

Introduction

Phenology has been included in the intensive monitoring programme as an optional activity since 2000. Knowledge about the timing and duration of certain life cycle events provides valuable information about the condition of the trees and the effects of climate fluctuations and changes on trees (Beuker 2002). Two levels of phenological observations are included in the programme, monitoring at the plot level and at the individual tree level.

This chapter summarizes the results obtained at the individual tree level and focuses on 1) trends in growth onset over the years, 2) correlations between growth onset and environmental parameters, and 3) the identification of differences between species with respect to growth onset.

Material and methods

Phenological observations from 3 Norway spruce (*Picea abies*) plots (Pallasjärvi, Punkaharju and Solböle) and on one Scots pine (*Pinus sylvestris*; Punkaharju) plot were used. The plot at Pallasjärvi was classified as a northern site, while the plots at Punkaharju and Solböle were classified as southern sites. Data availability for each plot can be found in Table 1.

Ten trees per plot were selected following a stratified random sampling method. Only trees where the upper two-thirds of the living crown were visible from the ground were selected. During the period of shoot development the trees were observed three times a week (Monday, Wednesday and Friday). The same trees were observed in all the years. Binoculars were used to assess the development of growth onset. The development was assessed on a 5-point scale ranging from 0 (none of the buds are open) to 4 (100% of the buds are open). Growth onset was assumed to have started when development had reached stage 1. For spruce, stage 1 is reached when the new growth is visible outside the bud. Pine has reached stage 1 when the orientation of the needles changes from along the axis of the shoot to perpendicular to the axis of the shoot. To prevent bias due to different observers, the same observers conducted the observations on each plot as much as possible.

The meteorological data were collected from weather stations installed on the plots. Minimum, mean and maximum air temperature were recorded above and within the crown (heights ranging from 6 to 20 m for within crown measurements, and from 16.5 to 29 m for above crown measurements) on an hourly basis and corrected for missing values using data from the Finnish Meteorological Institute. Temperature data on a daily basis, corrected for missing values, were available for all years, except 2005. For 2005 uncorrected data were available up until the 14th of November. Missing values had a negligible influence on the temperature sum before the date of bud burst and therefore the data could be used. Temperature data corrected for missing values (on a daily basis) from the above crown measurements were used to calculate the temperature sum for different thresholds. Temperature data on an hourly basis were used to estimate night frost parameters (e.g. difference in days between the last night frost and the start of growth onset, difference in days between first frost free period (>0 days, >3 days and >14 days) and the start of growth onset and the total number of frost free days (counted from the first of January) before the start of growth onset). See Table 2 for an overview.

Soil temperature was measured within the plot at various depths (ranging from 10 to 100 cm below ground level) on an hourly basis. Most of the root mass of spruce and pine occurs at depths of between 0 and 30 cm (Makkonen and Helmisaari 1999, Cronan 2003). Therefore, the data for a depth of 20 cm were used in the analysis. Three replicates were available at this depth on each

Table 1. Years with growth onset observations on Level II observation plots.
Taulukko 1. Kasvuunlähdön havainnointivuodet tason II havaintoaloilla.

Tree species *Puulaji*	Plot *Havaintoala*	2000	2001	2002	2003	2004	2005
Norway spruce – *Kuusi*	Pallasjärvi	X	X	X		X	X
	Punkaharju		X	X	X	X	X
	Solböle	X	X	X	X	X	
Scots pine – *Mänty*	Punkaharju			X	X	X	X

Table 2. Overview of the variables used in the analysis for growth onset of Norway spruce and Scots pine.
Taulukko 2. Kuusen ja männyn kasvuunlähdön analysoinnissa käytetyt taustamuuttujat. Valosumma = kertynyt valoisten tuntien summa.

Species *Laji*	Sample plot *Havaintoala*	Year *Vuosi*	Temperature sum *Lämpö-summa* dd (>5°C)	Soil temperature sum *Maan lämpösumma* dd	Photoperiod at bud burst, h *Valojakso silmujen puhjetessa, t*	Accumulated photoperiod at bud burst, h *Valosumma silmujen puhjetessa, t*	Frost free days per year *Pakkasetto-mien päivien lkm vuodessa*	Days from latest frost free period (length in parentheses) at bud burst *Päiviä edellisestä pakkasetto-masta jaksosta (pituus suluissa) silmujen puhjetessa*			Days from last frost at bud burst *Päiviä viimeisestä pakkasesta silmujen puhjetessa*
								(>0d)	(>3d)	(>14d)	
Norway spruce *Kuusi*	Pallasjärvi	2000	797	150	24	2125	27	85	56	42	17
		2001	800	154	24	2096	37	149	149	51	18
		2002	887	138	24	1874	45	145	70	45	10
		2003	840	154							
		2004	753	158	24	2198	54	117	62	51	29
		2005	620	158	24	2144	46	82	51	34	29
	Punkaharju	2000	1445	112							
		2001	1535	113	18	1696	59	136	55	39	39
		2002	1601	113	18	1601	67	131	41	31	41
		2003	1459		19	1746	56	130	62	48	29
		2004	1370	121	19	1761	62	97	61	54	33
		2005	1444	129	19	1847	65	145	63	39	32
	Solböle	2000	1513	96	18	1691	86	143	65	50	50
		2001	1619		18	1683	77	140	75	55	38
		2002	1683		17	1522	80	123	44	37	37
		2003	1496	102	18	1840	75	137	70	53	36
		2004		96	18	1534	56	123	61	40	32
Scots pine *Mänty*	Punkaharju	2002	1601	112	19	1812	76	140	50	40	50
		2003	1459		19	1948	66	140	72	58	39
		2004	1370	121	18	1638	57	92	56	49	28
		2005	1444	129	19	1973	70	150	68	44	37

site. The difference in days between the date of an exponential increase in soil temperature and the date of growth onset was evaluated. Due to technical problems not all the data were available for the analysis (Table 2).

Accumulated photoperiod was calculated from light measurements made above the crown level using a LI-200SZ photometer. The height varied from 16.5 to 29 m depending on the plot. The data were available on an hourly basis. Calculations were carried out in the same way as for the temperature sum calculations, but without a threshold value. The length of the photoperiod (day length) was calculated as the time difference in hours between sunrise and sunset (Table 2). Sunrise and sunset data for the individual plots were obtained using a sunset calculator (Mundall 2002).

All the parameters were evaluated on a temperature sum as well as a Julian day (the running number of the day from January 1st) basis.

Statistical analysis

The likelihood of a normal distribution was evaluated using a Shapiro-Wilcoxon test or a Kolmogorov-Smirnov test, depending on the number of available cases. Most of the data did not follow a normal distribution even after transformation. In these cases, differences between groups were evaluated using a Kruskal-Wallis test, followed by a Duncan post-hoc test. When there were only two groups a Mann-Whitney-U test was used. A one-way ANOVA followed by a Tukey post-hoc test was used to evaluate differences between groups in cases where the data followed a normal distribution and the requirements for homogeneity of variance were met. A non-parametric (two tailed) Spearman r test was used to evaluate trends. Due to the non-normal distribution of the data and the small number of observations, it was not possible to build regression models allowing evaluation of the relative importance of all the factors together. For pair-wise comparisons between the deviation from the average for Julian day and temperature sum, the independent samples t-test was used for years (normal distribution). A Mann-Whitney U test (non-parametric) was used with respect to the sites.

Results

An attempt was made to predict the date of bud burst on the basis of the average date of bud burst over all five years following Rousi and Pusenius (2005). No agreement between the plots was obtained for any of the calculated thresholds (–2 to +5 °C with a 1 °C increase). Likewise, predicting the date of bud burst on the basis of the average temperature sum at bud burst over all five years did not result in any agreement between the plots. Since no agreement between the plots was obtained, the widely accepted threshold for bud burst of +5 °C (Sarvas 1972) was used for further analysis.

Spruce

When all the plots were pooled, it became clear that there were significant differences between years on both a Julian day ($p < 0.001$) and temperature sum ($p < 0.001$) scale (Fig. 1). The difference between the earliest and the latest year was 9.8 days and 67.3 temperature units. Annual variation in the temperature sum and Julian day at bud burst clearly followed a different pattern, but a significant trend over the years was not found for either parameter.

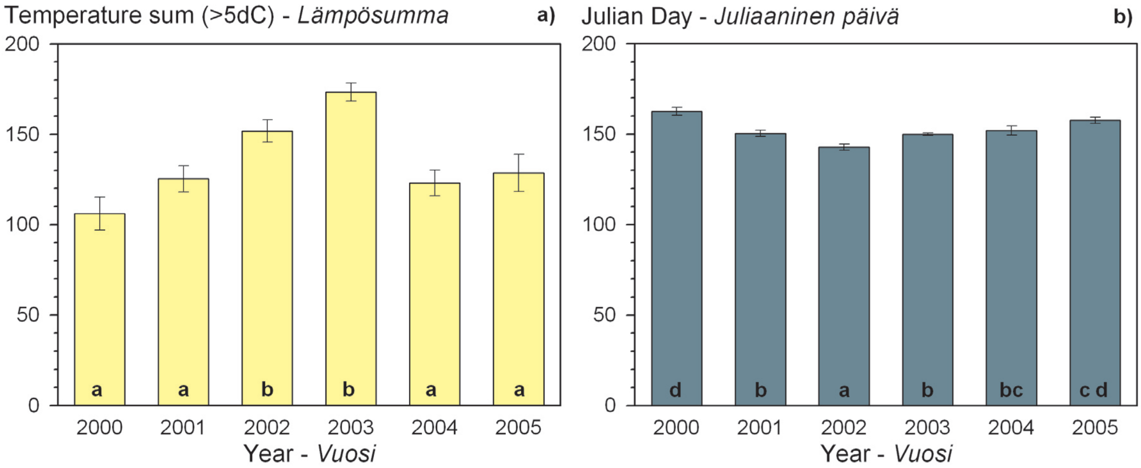

Figure 1. Average temperature sum (a) and Julian day (b) at bud burst over all the plots. Bars show means. Error bars show SEM. Letters indicate significantly different groups.
Kuva 1. Keskimääräinen lämposumma (a) ja juliaaninen päivä (b), jolloin silmut puhkeavat (havaintoalojen keskiarvo ± keskarvon keskivirhe). Tilastollisesti merkisevästi poikkeavat ryhmät on osoitettu eri kirjaimin.

Further analysis showed a significant influence of plot ($p < 0.001$) and plot * year ($p < 0.001$) in both the temperature sum and Julian day. The temperature sum at bud burst over the years for each plot is shown in Fig. 2. Due to missing values, year 2000 at Solböle had to be omitted from the analysis. Figure 2 shows that, with respect to temperature sum, the patterns over the years were different for each plot. The differences between the years were significant at $p < 0.001$.

A significant, but weak, negative trend over the years was found for the plot at Punkaharju ($r = –0.292$, $p = 0.044$), indicating that bud burst started at a lower temperature sum each year. For the plots at Pallasjärvi and Solböle there was no significant trend.

Significant differences between trees with respect to the temperature sum at bud burst were only found for the trees in Punkaharju ($p = 0.007$). Three groups could be separated, but the differences between the groups were small. For Pallasjärvi and Solböle there were no differences between trees.

Analysis of bud burst on a Julian day basis over the years for each plot showed that the patterns were different for each plot (Fig. 3). The differences between the years were all significant at $p < 0.001$.

With respect to Julian day there was a significant, but weak, positive trend over the years for the plots at Pallasjärvi and Punkaharju ($r = 0.313$, $p = 0.036$ and $r = 0.571$, $p < 0.001$, respectively), indicating that bud burst started at a later date each year. No trend was found for Solböle. Based on Julian day at bud burst, there were no differences between trees at any of the plots. Although the differences between trees were not significant, ranking of individual trees over the years showed that the same trees were among the first or last to start flushing each year.

Figures 2 and 3 show that temperature sum and Julian day at bud burst followed a different pattern over the years when analysed at the plot level. Furthermore, the variation in temperature sum at bud burst between the plots seemed to be larger than the variation in Julian day at bud burst over the plots (Table 3).

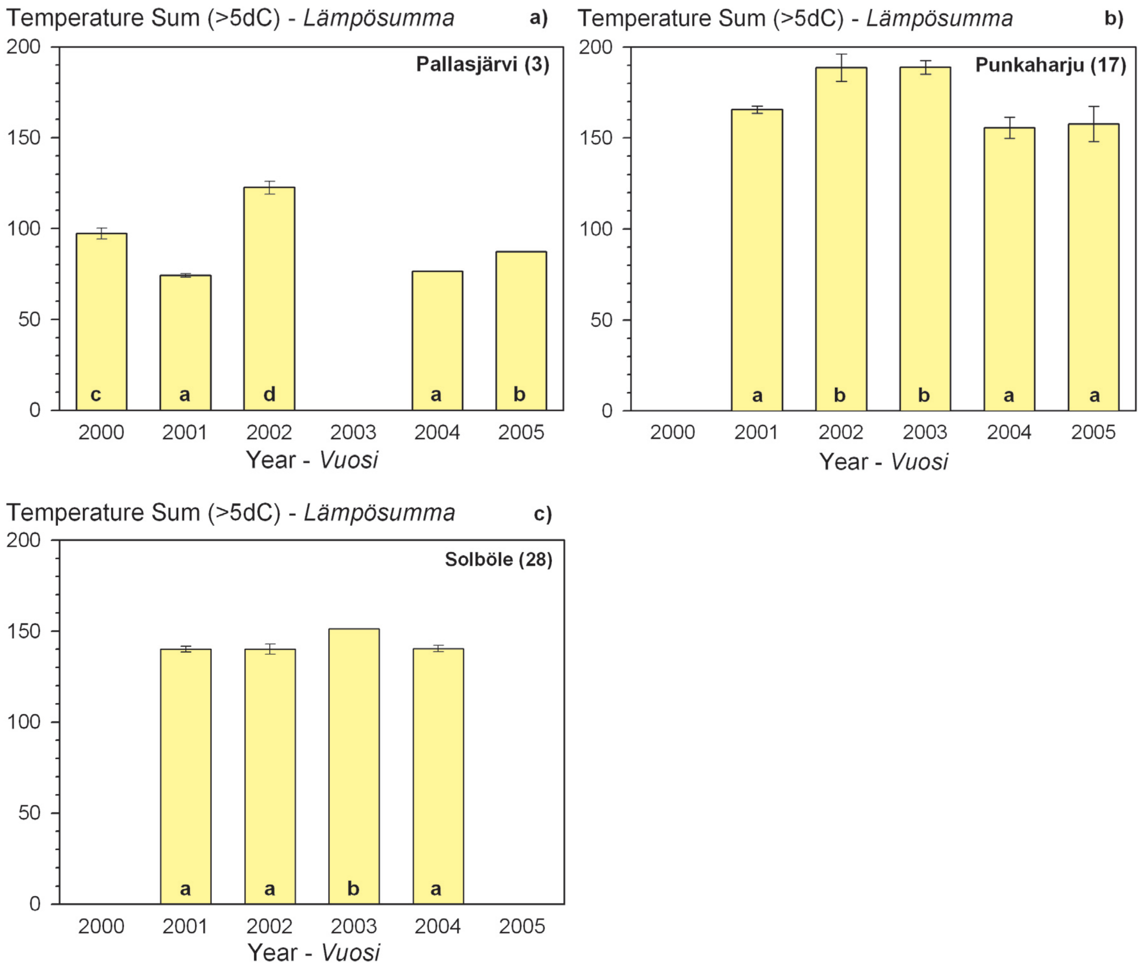

Figure 2. Temperature sum at bud burst over the years for Norway spruce in Pallasjärvi (a), Punkaharju (b) and Solböle (c). Bars show means. Error bars show SEM. Small letters represent significantly different groups.
Kuva 2. Lämpösumman keskiarvo (± keskiarvon keskivirhe) silmujen puhjetessa Pallasjärven (a), Punkaharjun (b) ja Solbölen (c) kuusihavaintoaloilla. Tilastollisesti merkitsevästi toisistaan eroavat vuodet on merkitty eri kirjaimin.

The standard error of the mean (SEM) seemed to be larger on a temperature sum basis compared to that on a Julian day basis for both plots and years (Table 3). SEM was significantly smaller for Julian day compared to the temperature sum ($p < 0.001$).

There was significant correlation between environmental parameters and the pooled plots, indicating differences between the northern and southern plots. Correlations within plots or years are necessary in order to find correlations between environmental parameters and the start of growth onset. The correlations within the plots for temperature sum were variable. For Pallasjärvi a negative relationship was found between growth onset and temperature sum ($r = –0.398$, $p = 0.007$), while for Solböle there was a positive relationship ($r = 0.706$, $p < 0.001$). No relationship was found for Punkaharju. Due to the interdependent nature of Julian day and day length, it was not possible to determine correlations for the environmental variables, photoperiod and accumulated photoperiod. The number of observations of night frost were too few to perform correlation analysis. The results of correlation analysis on soil temperature were variable. On a Julian day scale, there was a significant positive relationship for the plots at Pallasjärvi and Punkaharju ($r = 0.861$ and $r = 0.946$, respectively with $p < 0.001$ for both). This indicates that growth onset

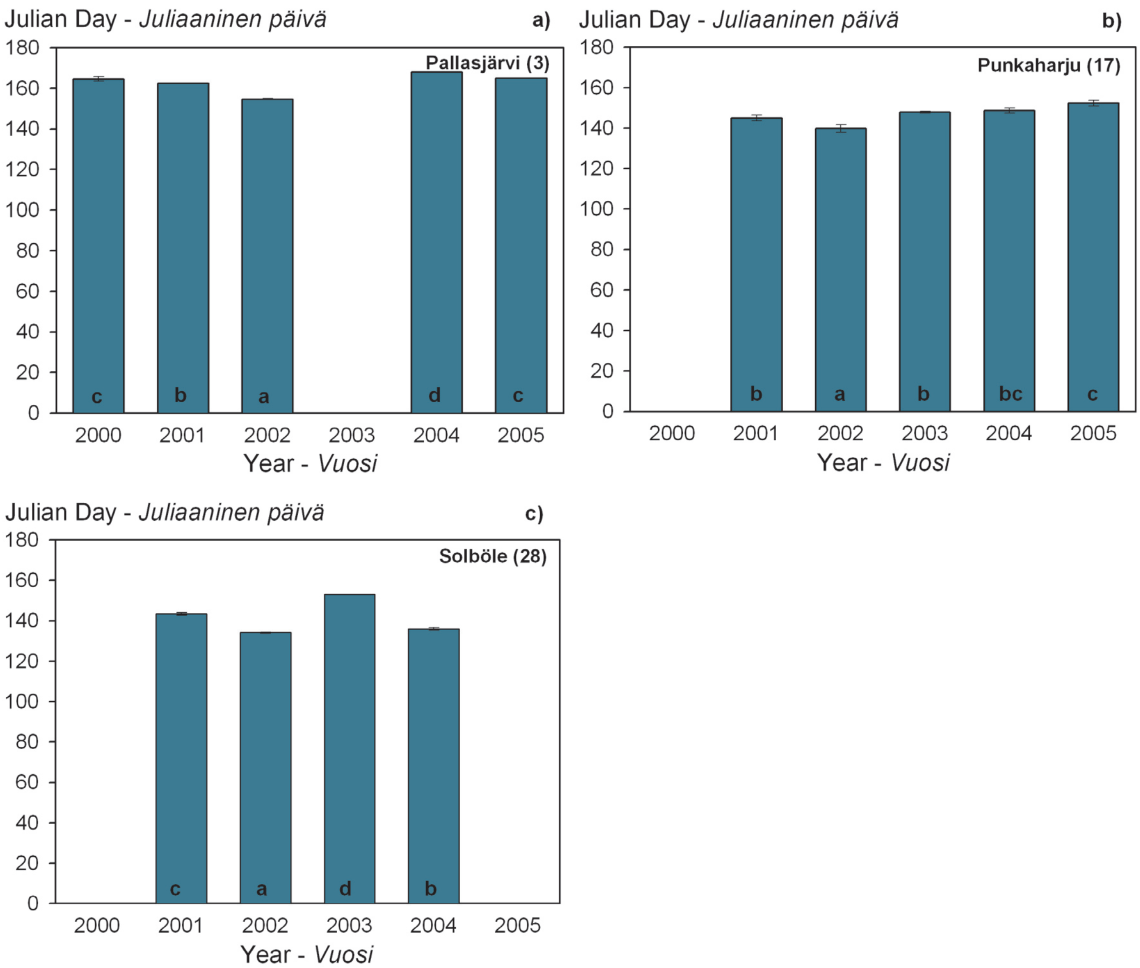

Figure 3. Julian day at bud burst over years for Norway spruce in Pallasjärvi (a), Punkaharju (b) and Solböle (c). Bars show means. Error bars show SEM. Small letters represent significantly different groups.
Kuva 3. Juliaaninen päivä (keskiarvo ± keskiarvon keskivirhe) silmujen puhjetessa Pallasjärven (a), Punkaharjun (b) ja Solbölen (c) kuusihavaintoaloilla. Tilastollisesti merkitsevästi eroavat vuodet on merkitty eri kirjaimin.

starts later when the exponential increase in soil temperature starts later. No significant relationship was found for the plot at Solböle. On a temperature sum scale, none of the correlations with soil temperature over the plots were significant.

Comparison between northern and southern plots

It was evident that, on the average, on the northern plot flushing occurred 19 days later than on the southern plots ($p < 0.001$; Table 4), but this occurred at a 69 units lower temperature sum ($p < 0.001$). Furthermore, there was a significant year * orientation interaction for Julian day ($p < 0.001$). This interaction was not present for temperature sum ($p = 0.100$). The years 2000 and 2003 were excluded from these analyses because of incomplete data sets.

Scots pine

For pine, bud burst on the basis of Julian day and the temperature sum differed significantly over the years ($p < 0.001$; Fig. 4). The magnitude of the variation over the years was 133 temperature units and 15 days. The year 2004 clearly stood out as a particularly early year.

Table 3. The means and their standard errors for Julian day and temperature sum at bud burst for Norway spruce in Pallasjärvi, Punkaharju and Solböle in 2000–2005.
Taulukko 3. Juliaanisen päivän ja lämpösumman keskiarvo keskivirheineen silmujen puhjetessa Pallasjärven, Punkaharjun ja Solbölen kuusialoilla jaksolla 2000–2005.

Site *Havaintoala*	Year *Vuosi*	Temperature sum *Lämpösumma*		Julian day *Juliaaninen päivä*	
		Average *Keskiarvo*	SEM	Average *Keskiarvo*	SEM
Pallasjärvi	2000	97	3.03	165	1.12
	2001	74	0.85	162	0.16
	2002	123	0.62	155	0.33
	2004	77		168	0.00
	2005	87		165	0.00
Punkaharju	2001	166	2.00	145	1.39
	2002	189	7.60	140	1.85
	2003	189	3.80	148	0.47
	2004	156	5.83	149	1.26
	2005	158	9.70	152	1.51
Solböle	2000	185		145	
	2001	140	1.62	143	0.58
	2002	140	2.72	134	0.35
	2003	151	0.00	153	0.00
	2004	140	1.63	136	0.65

Table 4. Julian day at bud burst in the northern and southern plots and their difference.
Taulukko 4. Silmujen puhkeamisen juliaaninen päivä pohjoisilla ja eteläisillä havaintoalolla keskimäärin sekä niiden erotus.

Year *Vuosi*	North *Pohjoinen*	South *Eteläinen*	Difference *Erotus*
2001	162	144	18
2002	156	137	19
2004	168	143	25
2005	165	152	13

A significant, but weak, positive trend over the years was found for Julian day at bud burst ($r = 0.253$; $p = 0.001$). For the temperature sum at bud burst there was a significant, but weak, negative trend over the years ($r = –0.514$; $p < 0.001$).

No differences between trees were found with respect to temperature sum at bud burst or Julian day at bud burst. Although the differences between trees were not significant, ranking of the individual trees over the years showed that the same trees were always among the first or last to flush.

The number of observations was too small to determine correlation for night frost within the plots. Neither was it possible to determine correlations for the environmental variables, photoperiod and accumulated photoperiod, due to their interdependent nature. Too few observations were available for night frost to justify carrying out correlation analysis. A significant positive correlation was found between soil temperature and Julian day ($r = 0.493$; $p = 0.006$). This indicates that growth onset starts later when the exponential increase in soil temperature starts later. No significant correlation was found on a temperature sum basis, but a significant positive relationship with growth onset was found for temperature sum ($r = 0.672$; $p < 0.001$).

Species comparison

In Punkaharju spruce flushed, on the average, 6 days earlier than pine at a 36 units lower temperature sum ($p < 0.001$ in both cases) (Fig. 5), but the difference varied significantly over the years ($p < 0.001$). When individual years were analysed, spruce always flushed earlier than pine on both a Julian day and a temperature sum basis, except for the year 2004 when pine flushed 4.1 days earlier and at a 21.9 units lower temperature sum than spruce (Table 5).

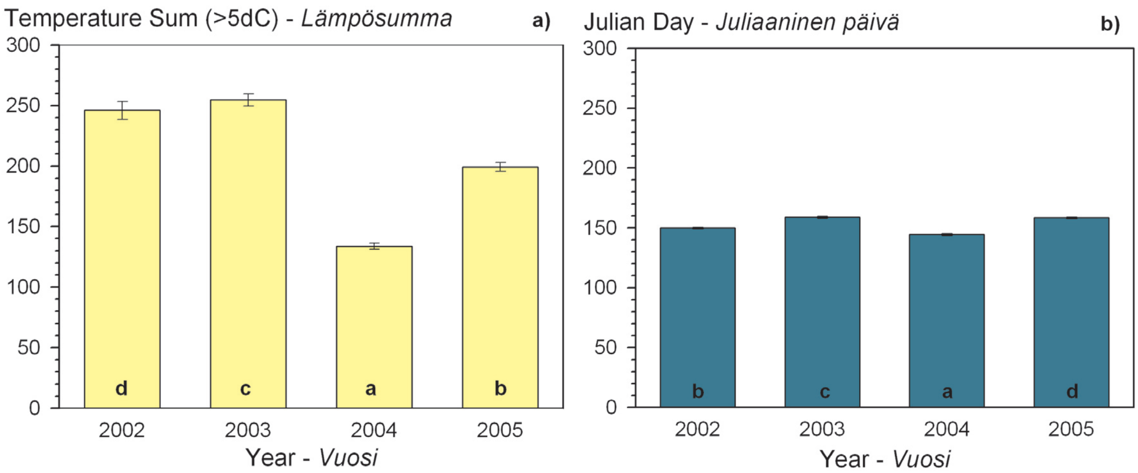

Figure 4. Temperature sum (a) and Julian day (b) at bud burst over years for Scots pine in Punkaharju. Bars show means. Error bars show SEM. Letters represent significantly different groups.
Kuva 4. Lämpösumma (a) ja juliaaninen päivä (b) silmujen puhjetessa Punkaharjun männikössä (keskiarvo ± keskiarvon keskivirhe). Tilastollisesti merkitsevästi eroavat vuodet on merkitty eri kirjaimin.

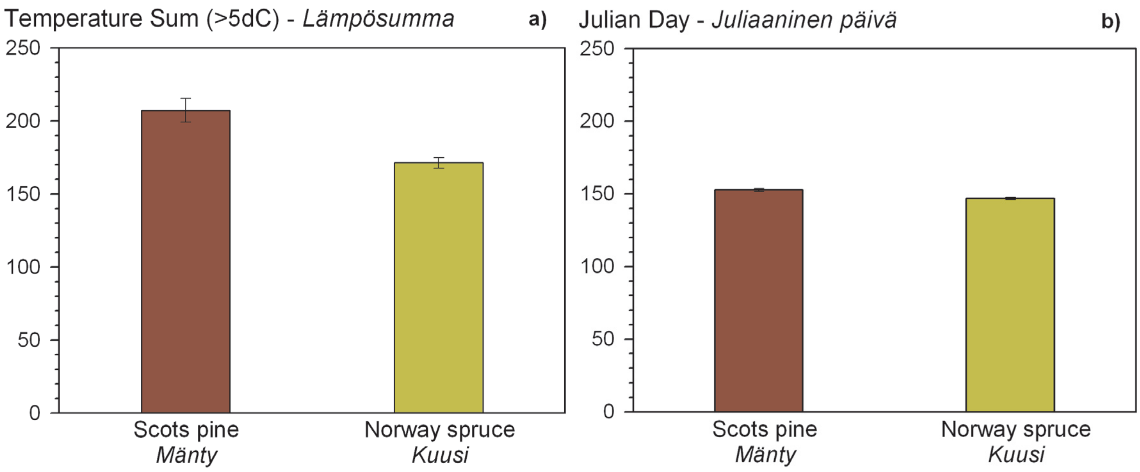

Figure 5. Growth onset of the two species in Punkaharju compared on a temperature sum (a) and a Julian day (b) basis. Bars show mean. Error bars show SEM.
Kuva 5. Kasvuunlähdön lämpösumma (a) ja juliaaninen päivä (b) männyllä ja kuusella Punkaharjulla (keskiarvo ± keskiarvon keskivirhe).

Table 5. Julian day and temperature sum at bud burst for Scots pine and Norway spruce in Punkaharju.
Taulukko 5. Juliaaninen päivä ja lämpösumma silmujen puhjetessa kuusella ja männyllä Punkaharjulla.

Year *Vuosi*	Julian day *Juliaaninen päivä*		Temperature sum *Lämpösumma*	
	Scots pine *Mänty*	Norway spruce *Kuusi*	Scots pine *Mänty*	Norway spruce *Kuusi*
2002	150	140	246	189
2003	259	148	255	189
2004	145	149	134	156
2005	158	152	199	158

Discussion

Differences between the plots

Weather is variable in both a spatial and a temporal sense, and causes large variation in the growth onset of trees. These variations in the prevailing weather conditions underlie the differences found between the northern and southern plots. The result that, under natural conditions, trees growing on the more northern plots flushed later than trees growing on more southern plots, and do so at lower temperature sums, is in agreement with earlier reports (e.g. Beuker 1994), and shows that the trees growing on the different plots are genetically adapted to the prevailing climatic conditions (Sarvas 1967).

Trends in growth onset

Following the generally accepted hypothesis that temperature is the forcing factor in breaking bud quiescence, it has been predicted that global warming will cause growth onset to start earlier in the year (Cannell and Smith 1986, Murray et al. 1989). In their meta-analysis, Root et al. (2003) found that the spring phenology of trees currently begins three days (sem ± 0.1) earlier as a result of global warming. Chmielewski and Rötzer (2001) found that the beginning of the growing season advanced 8 days over the period 1969–1998, due to an almost European-wide warming. There are, however, large fluctuations between years (Häkkinen 1999, Rousi and Pusenius 2005). In contrast, Murray et al. (1989) concluded in their modeling study that the date of growth onset would not show a marked shift towards earlier dates. For some scenarios Cannell and Smith (1986) found similar results.

Both Murray et al. (1989) and Cannell and Smith (1986) state that an increase in temperature also leads to an increased autumn temperature that, through chilling requirements, could delay the onset of growth. Among others, Partanen et al. (1998) found evidence that the length of the photoperiod has an influence on growth onset in Norway spruce, and that it is possible that premature growth onset may be prevented through the influence of the photoperiod. Because of the unpredictability of the weather conditions, the likelihood of a light signal being involved seems plausible. It has to be stressed however, that global warming does not only force its effects through temperature, but also through interaction with other factors (Root et al. 2003), for example, precipitation (Caldwell et al. 2003).

The significant trends found so far in our study were weak and showed contradicting patterns, indicating that the few significant correlations are most likely due to chance. These results are similar to the results of Chmielewski and Rötzer (2001), who found weak and contradicting trends for *Betula pubescens, Prunus avium, Sorbus aucuparia* and *Ribes alpinum* over a 30-year study period in Scandinavia and Eastern Europe. However, care must be taken when interpreting the results of the current study because the time series used are short (max. 5 years) and variation between years is high. Rousi and Pusenius (2005) concluded that their six-year study period was not long enough to reveal any significant advance in the date of growth onset for European white birch (*Betula pendula*). No clear trends were found in the data, which seems to indicate that global warming does not cause a shift in the timing of growth onset, and that temperature alone is not enough to explain the variance. The fact that the SEM on a Julian day basis seemed to be smaller than the SEM on a temperature sum basis may support the hypothesis that temperature is not the only forcing variable for growth onset. If temperature sum is used as the basis for the analysis then only the influence of temperature is analysed, but Julian day includes the whole complex of relevant factors, which apparently decreases variation. This indicates the influence of other factors on growth onset. It must be stressed, however, that the variation in temperature sum accumulation between years is considerable and that temperature sum and Julian day are interacting variables. Nevertheless, based on these results it seems credible that growth onset consists of a complex of several regulatory factors that are still poorly understood.

Patterns between species

This study indicates that growth onset occurs earlier (on both a Julian day and a temperature sum basis) in spruce than in pine. On the average, growth onset started 6 days (and 36 temperature units) earlier in spruce. This result is in line with the generally observed pattern. Rötzer et al. (2004) found that the average date of height growth onset was May 12th (S.D. ± 7.8) in Norway spruce compared to May 15th (S.D. ± 8.9) in Scots pine in southern Germany. Kramer (1996) found that the average date of height growth onset was May 10th (SD ± 8.1) for Norway spruce, compared to May 13th (S.D. ± 7.0) for Scots pine during the period 1951–1990 in Germany and the Netherlands.

In 2004, however, pine started growth onset 4 days (and 22 temperature units) earlier than spruce. This indicates that both species react differently to the environmental signals relevant for growth onset. Temperature sum accumulation in 2004 was characterized by exponential accumulation during a short period, followed by low temperatures (the last night frost occurred on the 24th of April), which are likely to have influenced bud development. In addition, the year 2003 was characterized by relatively high temperatures in autumn and early winter. Warm autumns and winters can delay growth onset because a larger temperature sum accumulation is needed to compensate for the unfulfilled chilling requirements (Cannell and Smith 1986, Murray et al. 1989). Hänninen and Pelkonen (1989) found that warm periods during chilling decreased the dormancy release ratio if they occurred in a later part of the chilling period (4 to 7 weeks). In an early part of the chilling period (1 to 3 weeks) the response of the dormancy release ratio was variable. Chilling requirements vary between species (Smith and Kefford 1964), and therefore it is possible that both species were affected in a different way by the warmer conditions in 2003. These factors together seem to indicate that, in pine, light is a more important forcing factor for growth onset than temperature accumulation.

Patterns between trees

Variation between genotypes has been observed for many species and traits. Beuker (1994) found differences with respect to growth onset for Scots pine. Differences in growth onset between genotypes have also been reported for Norway spruce (e.g. Beuker 1994). In this study, significant but relatively small differences between trees were only observed for spruce on the plot in Punkaharju. The differences for the other plots were not significant, but ranking of the trees for each year revealed that individual trees showed similar patterns over the years, indicating that there are differences between the trees. It is likely that variable weather conditions and the small number of observations obscured the differences in growth onset between the trees. It must be kept in mind, however, that the trees used in this study are over 60 years old and therefore may show less variation compared to the younger trees (Hannerz 1999, Partanen et al. 2004) which are usually used in short-term experiments under controlled conditions (Hänninen et al. 2001). In addition, the stands on the plots in this study have been subjected to normal forestry practices such as thinning. Depending on the practice applied when thinning a stand, the trees with the best potential (e.g. the trees best adapted to local conditions) are usually released from competition. It is possible that this has resulted in decreased variation between the trees (Beuker 1994).

Correlation with environmental variables

Although the mechanisms underlying growth onset and cessation have been intensively studied they, as well as their interactions, are still not fully understood. In this study, the polarity of the correlation between growth onset and temperature sum were different, indicating that these correlations are most likely due to chance, even though model studies have shown that trees with different temperature sum requirements are affected by global warming in a different way (Murray et al. 1989). Correlations could not be determined for the environmental parameters, photoperiod and accumulated photoperiod, due to the strong relationship between Julian day and the respective parameters. Under controlled conditions, the influence of time on these parameters can be omitted by standardizing the length of the photoperiod. Under natural conditions, however, this is not possible. Correlations could not be determined for night frost parameters due to the small number of observations. The positive relationship between the exponential increase in soil temperature and the growth onset for spruce and pine is most likely the result of increasing root activity with increasing soil temperature. In the temperate zone, the optimum temperature range for root growth is approximately 10 to 30 °C (but growth may continue to around 0 °C; Lambers et al. 1998), while the optimum for shoot growth is higher (Deans and Ford 1986). This allows the roots to become active before the shoots.

The short time series does not yet allow any conclusions to be drawn.

References

Beuker, E. 1994. Adaptation to climatic changes of the timing of bud burst in populations of Pinus sylvestris L. and Picea abies (L.) Karst. Tree Physiology 14: 961–970.

Beuker, E. 2002. Phenological observations on Level II plots in 2001. In: Rautjärvi, H., Ukonmaanaho, L. & Raitio, H. (eds.). Forest Condition Monitoring in Finland. National report 2001. The Finnish Forest Research Institute, Research Papers 897: 89–94.

Caldwell, M.M., Ballare, C.L., Bornman, J.F., Flint, S.D., Björn, L.O., Teramura, A.H., Kulandaivelu, G. & Tevini, M. 2003. Terrestrial ecosystems, increased solar ultraviolet radiation and interactions with other climatic change factors. Photochemical & Photobiological Sciences 2: 29–38.

Cannell, M.G.R. & Smith, R.I. 1986. Climatic warming, spring bud burst and frost damage on trees. Journal of Applied Ecology 23: 177–193.

Chmielewski, F.-M. & Rötzer, T. 2001. Response of tree phenology to climate change across Europe. Agricultural and Forest Meteorology 108: 101–112.

Cronan, C.S. 2003. Below ground biomass, production and carbon cycling in mature Norway spruce Maine, USA. Canadian Journal of Forest Research 33: 339–350.

Deans, J.D. & Ford, E.D. 1986. Seasonal patterns of radial root growth and starch dynamics in plantation-grown Sitka spruce trees of different ages. Tree Physiology 1: 241–251.

Häkkinen, R. 1999. Analysis of bud development theories based on long-term phenological and air temperature time series: application to Betula sp. leaves. Thesis University of Helsinki, Helsinki. 59 p.

Hannerz, M. 1999. Evaluation of temperature models for predicting bud burst in Norway spruce. Canadian Journal of Forest Research 29: 9–19.

Hänninen, H. & Pelkonen, P. 1989. Dormancy release in Pinus sylvestris L. and Picea abies (L.) Karst. seedlings: effects of intermittent warm periods during chilling. Trees 3: 179–184.

Hänninen, H., Beuker, E., Johnson, Ø., Leinonen, I., Murray, M. & Skrøppa, T. 2001. Impacts of climate change on cold hardiness of conifers. In: Bigras, F.J. & Colombo, S.J. (eds.). Conifer cold hardiness. p. 305–333.

Kramer, K. 1996. Phenology and growth of European trees in relation to climate change. Thesis. Landbouw Universiteit Wageningen. 210 p.

Lambers, H., Chapin, F.S. & Pons, T.L. 1998. Plant Physiological Ecology. Springer-Verlag, New York.

Makkonen, K. & Helmisaari, H.-S. 1999. Assessing fine-root biomass and production in a Scots pine stand – comparison of soil core and root ingrowth core methods. Plant and Soil 210: 43–50.

Mundall, E. 2002. Sunste calculator. [Online publication] Available at: http://www.mundall.com/cgi/sunsets.pl?countries 11–12–2005.

Murray, M.B., Cannell, M.G.R. & Smith, R.I. 1989. Date of bud burst of fifteen species in Britain following climatic warming. Journal of Applied Ecology 26: 693–700.

Partanen, J., Koski, V. & Hänninen, H. 1998. Effects of photoperiod and temperature on the timing of bud burst in Norway spruce (Picea abies). Tree Physiology 18: 811–816.

Partanen, J., Hänninen, H. & Häkkinen, R. 2004. Bud burst in Norway spruce (Picea abies): Preliminary evidence for age-specific rest patterns. Trees 19: 66–72.

Root, T.L., Price, J.T., Hall, K.R., Schneiders, S.H., Rosenzweig, C. & Pounds, J. A. 2003. Fingerprints of global warming on wild animals and plants. Nature 421: 57–60.

Rötzer, T., Grote, R. & Pretzsch, H. 2004. The timing of bud burst and its effect on tree growth. International Journal of Biometeorology 48: 109–118.

Rousi, M. & Pusenius, J. 2005. Variation in phenology and growth of European white birch (Betula pendula) clones. Tree Physiology 25: 201–210.

Sarvas, R. 1967. The annual period of development of forest trees. Proceedings of the Finnish Academy of Science and Letters 1965: 211–231.

Sarvas, R. 1972. Investigations on the annual cycle of development of forest trees. Active period. Communicationes Instituti Forestalis Fenniae 76(3): 1–110.

Smith, H. & Kefford, N.P. 1964. The chemical regulation of the dormancy phases of bud development. American Journal of Botany 51: 1002–1012.

3.8 Assessment of air quality on Level II plots
Ilman laadun seuranta tason II havaintoaloilla

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The air quality at a number of Level II plots was monitored using passive samplers during 2000–2001 and in 2004. The air quality parameters were ozone (O_3), sulphur dioxide (SO_2), nitrous oxide (NO_2) and ammonia (NH_3). During the first phase (2000–2001) air quality was monitored in open areas close to the plots at Pallasjärvi (Nr. 3), Uusikaarlepyy (Nr. 23) and Miehikkälä (Nr. 18), and in 2004 at Pallasjärvi, Juupajoki (Nr. 10) and Miehikkälä. Comparative measurements were performed close to the continuous air-quality monitoring stations of the Finnish Meteorological Institute in Virolahti (near Miehikkälä) and Matorova (near Pallasjärvi), and of the University of Helsinki in Hyytiälä (near Juupajoki). The first monitoring phase in 2000–2001 clearly showed that the SO_2 and NO_2 concentrations are higher in wintertime, and that the O_3 concentration reached a maximum in early spring. The seasonal patterns for all three gases were similar all over the country, but the NO_2 concentrations were very low at the northernmost monitoring site. In 2004 there was no clear difference between the monitoring sites for O_3, but the SO_2 and NO_2 concentrations were higher at the sites in south-eastern Finland near to the Russian border, and lower at the remote sites in Lapland. The NH_3 concentrations appeared to be relatively contradictory during both monitoring periods.

Tässä raportissa kuvataan ilman laatua muutamilla intensiivikoealoilla esittämällä avoimille paikoille sijoitetuilla passiivikeräimillä saatuja tuloksia vuosilta 2000–2001 ja 2004. Mitatut parametrit ovat otsoni (O_3), rikkidioksidi (SO_2), typpidioksidi (NO_2) ja ammoniakki (NH_3). Ensimmäisessä jaksossa 2000–2001 koealat olivat Pallasjärvi (no. 3), Uusikaarlepyy (no. 23) ja Miehikkälä (no. 18) ja vuonna 2004 Pallasjärvi, Juupajoki (no. 10) ja Miehikkälä. Vertailumittaukset tehtiin Ilmatieteen laitoksen mittausasemilla Matorovassa (lähellä Pallasjärveä) ja Virolahdella (lähellä Miehikkälää) sekä Helsingin yliopiston metsäasemalla Hyytiälässä (lähellä Juupajokea). Ensimmäisen mittausjakson (2000–2001) tuloksissa SO_2- ja NO_2-pitoisuudet olivat korkeimmat talviaikana, kun taas O_3-pitoisuudet olivat korkeimmillaan aikaisin keväällä. Vuodenaikaisvaihtelu oli samansuuntaista kaikilla mittauspaikoilla, mutta NO_2-pitoisuudet olivat hyvin matalia pohjoisimmalla mittauspaikalla. Vuoden 2004 O_3-pitoisuuksissa ei havaittu selviä eroja eri mittauspaikkojen välillä, sen sijaan SO_2- ja NO_2-pitoisuudet olivat korkeimpia Kaakkois-Suomessa, lähellä Venäjän rajaa olevilla mittauspaikoilla, ja matalimpia Lapissa sijaitsevilla mittauspaikoilla. Molemmilla mittausjaksoilla saadut NH_3-pitoisuudet ovat jonkin verran ristiriitaisia.

Introduction

The lack of ozone data has been a serious limitation for the ICP Forests Intensive Monitoring (Level II) database. In addition to the obvious connections with the potential effects of ozone on forests, ozone data are also relevant in relation to other topics related to important international agreements, such as changes in tropospheric chemistry and regional ozone formation. These agreements include the Multi-Pollutant, Multi-effect Protocol of the Convention on Long-range Transboundary Air Pollution (CLRTAP), the UN Convention on Biological Diversity (CBD) the EU Habitat Directive, the EU Acidification Strategy, and the EU Air Quality directive.

Since 1999, the Working group on Air Quality within the Expert Panel on Deposition has been working to improve our knowledge of the concentrations of various pollutants in the air, and the effects of these pollutants across forested areas in Europe. The intention was to carry out air quality measurements using passive sampling in connection with visible injury assessment. The main gaseous pollutant being monitored is ozone, although other pollutants such as sulphur dioxide (SO_2), nitrogen oxide (NO_2) and ammonia (NH_3) are also included in order to complement the deposition surveys being carried out by ICP-Forests on many of the Level II plots. The results of a test phase with different types of passive samplers, carried out in 2000 and 2001 in some European countries, were presented in the Level II Technical report 2003 (De Vries et al. 2003).

The use of passive samplers is considered to be a reliable and comparatively inexpensive method of obtaining information on ambient air quality, especially in remote forest areas where it is not technically or economically feasible to operate continuous monitoring stations. As a result, this method was chosen for assessing ambient air quality at Level II sites. However, it is also necessary to determine the comparability of these data with data from continuous monitoring sites. This information is particularly important for quality assurance and quality control purposes, as well as for extending the database used for modelling ozone concentrations over Europe (e.g. EMEP). Passive sampling monitoring within the Working Group is being carried out in accordance with a sub-manual based on document nr. 264 of the European Committee of Standardization (CEN 2001).

As a considerable amount of the ozone data collected at the European level are derived from monitoring devices situated in urban/sub-urban areas (e.g. De Leeuw et al. 2001), often at low altitudes, the collection of a comprehensive ozone dataset for forested sites will greatly increase our knowledge of ozone levels in remote areas, including a broad range of altitudes.

Material and methods

Ambient air quality was monitored as a part of the ICP Forests programme using passive samplers during 2000–2001, and again in 2004. During the first phase the monitoring was carried out at three Level II plots in different parts of Finland and, for comparison purposes, in the immediate vicinity of two air-quality monitoring stations of the Finnish Meteorological Institute (FMI) (Table 1). In 2004, passive sampler monitoring at one of the plots was changed to another Level II plot, and a comparison set of passive samplers installed near to the air-quality monitoring station of Helsinki University (HU). The measured parameters were ozone (O_3), sulphur dioxide (SO_2), nitrogen oxide (NO_2) and ammonia (NH_3).

The passive samplers were supplied by IVL (Gothenburg, Sweden; Ferm 2001). The temperature data required in calculating the results were obtained from the weather station on the Level II plot or from a nearby FMI meteorological station. The samplers were located at a height of 3 m in the open area used for monitoring bulk deposition on the three Level II plots and at a suitable open location in the immediate vicinity of the air-quality monitoring stations.

Monitoring started in July 2000 and continued until June 2001. The next stage was carried out from mid-April 2004 to the beginning of November 2004 (seven 4-week periods). During 2000–2001 there were a couple of 2- and 3-week periods at one Level II plot, and in 2004 two 2-week periods at one Level II plot and the nearby FMI station. All the measurements were performed in duplicates.

The samplers were sent by IVL to Metla’s laboratory at Rovaniemi, and then to the field personnel

Table 1. The latitude, altitude and distance between the Level II plots and air-quality monitoring stations of the Finnish Meteorological Institute (FMI) and Helsinki University (HU).
Taulukko 1. Ilmalaadun seurannassa mukana olleiden tason II havaintoalojen sekä Ilmatieteen laitoksen (FMI) ja Helsingin yliopiston (HU) mittausasemien leveysaste, korkeus (mpy) ja jatkuvatoimisten mittaus-asemien etäisyys tason II havaintoaloilta.

Sample plot *Havaintoala*	Nr. *No.*	Latitude *Leveys-aste* °N	Altitude a.s.l. *Korkeus mpy* m	Distance to Level II plot *Etäisyys tason II hav.alalta* km	Sampling period *Mittausjakso* 2000–2001	 2004
Pallasjärvi	3	67	301		x	x
Uusikaarlepyy	23	63	3		x	
Juupajoki	10	61	147			x
Miehikkälä	18	60	48		x	x
Matorova, FMI (near plot nr. 3) *(lähellä alaa no. 3)*		67	344	0.5		x
Hyytiälä, HU (near plot nr. 10) *(lähellä alaa no. 10)*		61	164	4		x
Virolahti, FMI (near plot nr. 18) *(lähellä alaa no. 18)*		60	4	21	x	x

prior to the start of each monitoring period. At the end of the four-week sampling period the samplers were sent first to Rovaniemi, and then to IVL in Gothenburg for analysis. IVL's accredited laboratory performed the analyses and calculated the results as micrograms/m^3 STP (standard air temperature and pressure, 20°C, 1013 hPa), with corrections for air temperature and altitude. The passive samplers manufactured by IVL are widely used, and the accuracy of the ozone measurements is within 5% over the range 30–90 µg m^{-3}.

The concentrations of gases can be expressed using a number of different units, but µg m^{-3} or ppb, are the most widely used units. The relationship between these two units is: ppb = µg m^{-3} * 2.14.

Results and discussion

The first monitoring stage in 2000–2001 clearly showed that the concentrations of SO_2 and NO_2 were higher in wintertime (Figs. 1 b–c), and that the concentration of O_3 reached a maximum in early spring (Fig. 1a). This is in agreement with FMI measurements in Virolahti and Sammaltunturi (Leinonen 2001). In 2004 monitoring started in week 17, and therefore only the latter part of the typical episode of elevated O_3 concentrations in early spring was observed (Fig. 2a). There were no clear differences between the monitoring sites for O_3 during this period, but the concentrations of SO_2 and NO_2 were higher at the sites in south-eastern Finland near the Russian border, and lower at the remote sites in Lapland (Figs. 2b–c). The 12-month means, minimum and maximum values, for O_3, SO_2, NO_2 and NH_3 during the period July 2000–June 2001, as well as the detection limits for the individual gas samplers are presented in Table 2.

The monitoring of NH_3 proved to be relatively problematic: many of the values were below the detection limit or uncertain for technical reasons, and the variations between duplicate measurements were relatively large. The NH_3 measurements at the comparison stations in some cases also varied considerably (Table 3). However, NH_3 is mainly derived from local emission point sources, and the concentrations can vary considerably due e.g. to the wind direction. The NH_4^+ concentrations measured in deposition on the Level II plots were the highest in Uusikaarlepyy and Miehikkälä (See Chapter 3.5 in this volume). However, the same trend was not as clear in the passive sampler measurements (Figs. 1d, 2d).

Table 2. The 12-month mean O_3, SO_2, NO_2 and NH_3 concentrations and minimum and maximum values for the period July 2000 – June 2001. The detection limits for the different passive gas samplers are given. The plots are arranged in the table to correspond to the latitude of the plots (N–S).
Taulukko 2. O_3-, SO_2-, NO_2- ja NH_3-pitoisuuksien 12 kk:n keskiarvot sekä minimi- ja maksimiarvot mittausjaksolla heinäkuusta 2000 – kesäkuuhun 2001. Eri parametrien määritysrajat on esitetty taulukossa. Havaintoalat on järjestetty pohjoisesta etelään.

Sample plot *Havaintoala*		O_3 , µg m^{-3}		SO_2 , µg m^{-3}		NO_2 , µg m^{-3}		NH_3 , µg m^{-3}	
Detection limit *Määritysraja*		2	n	0.20	n	0.10	n	0.30	n
Pallasjärvi	Mean – *Ka.*	53	12	0.80	11	0.31	11	0.89	10
	min–max	13–93		<DL–2.20		<DL–0.71		<DL–2.74	
Uusikaarlepyy	Mean – *Ka.*	49	12	0.79	12	2.10	13	1.55	11
	min–max	21–78		<DL–0.84		1.15–3.68		<DL–5.79	
Miehikkälä	Mean – *Ka.*	42	13	1.52	13	2.56	13	0.44	8
	min–max	18–70		0.46–2.88		0.91–5.50		<DL–1.77	
Virolahti	Mean – *Ka.*	49	13	1.87	13	3.64	13	1.36	13
	min–max	31–73		0.66–3.53		2.10–5.50		0.50–3.22	

Table 3. Mean O_3, SO_2, NO_2 and NH_3 concentrations and minimum and maximum values for the period April–October 2004. The detection limits for the different passive gas samplers are given. The plots are arranged in the table to correspond to the latitude of the plots (N–S).
Taulukko 3. O_3-, SO_2-, NO_2- ja NH_3-pitoisuuksien keskiarvot sekä minimi- ja maksimiarvot mittausjaksolla huhtikuusta lokakuuhun 2004. Eri parametrien määritysrajat on esitetty taulukossa. Havaintoalat on järjestetty taulukossa vastaamaan pohjois–etelä gradienttia Suomen läpi.

Sample plot *Havaintoala*		O_3 , µg m^{-3}		SO_2 , µg m^{-3}		NO_2 , µg m^{-3}		NH_3 , µg m^{-3}	
Detection limit *Määritysraja*		2	n	0.20	n	0.10	n	0.30	n
Pallasjärvi	Mean – *Ka.*	55	7	0.53	7	0.28	6	1.76	3
	min–max	40–80		0.23–1.01		<DL –0.79		<DL –2.81	
Matorova	Mean – *Ka.*	58	7	0.58	7	0.44	6	1.16	4
	min–max	44–83		0.27–0.83		<DL–1.24		<DL–2.49	
Juupajoki	Mean – *Ka.*	53	7	0.69	7	1.48	7	0.92	6
	min–max	38–84		0.48–0.93		0.94–2.48		<DL–4.28	
Hyytiälä	Mean – *Ka.*	53	7	0.70	7	1.26	7	0.79	6
	min–max	34–90		0.40–1.01		0.70–2.23		<DL–1.90	
Miehikkälä	Mean – *Ka.*	52	8	1.02	8	1.68	8	1.68	7
	min–max	34–79		0.78–1.48		1.19–2.59		<DL –5.15	
Virolahti	Mean – *Ka.*	55	8	1.20	8	2.86	8	1.80	7
	min–max	39–78		0.91–1.56		1.97–5.20		<DL–10.5	

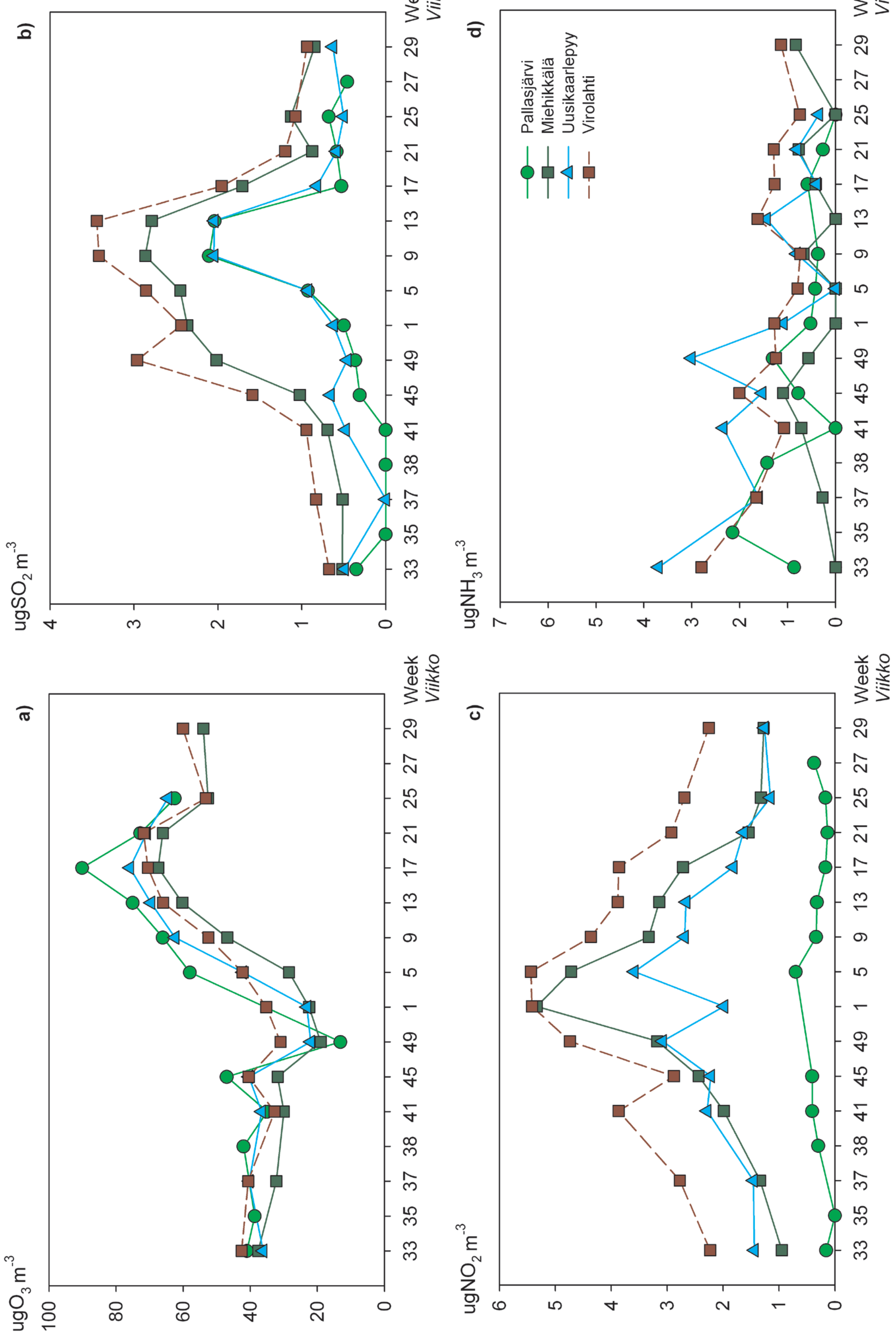

Fig. 1a – d. The 4-week O_3, SO_2, NO_2 and NH_3 concentrations for the period July 2000–June 2001 on the Level II plots and comparison air-quality monitoring stations.
Kuva 1a – d. O_3-, SO_2-, NO_2- ja NH_3-pitoisuudet neljän viikon mittausjaksoissa heinäkuusta 2000 – kesäkuuhun 2001 tason II havaintoaloilla ja vertailevilla mittausasemilla.

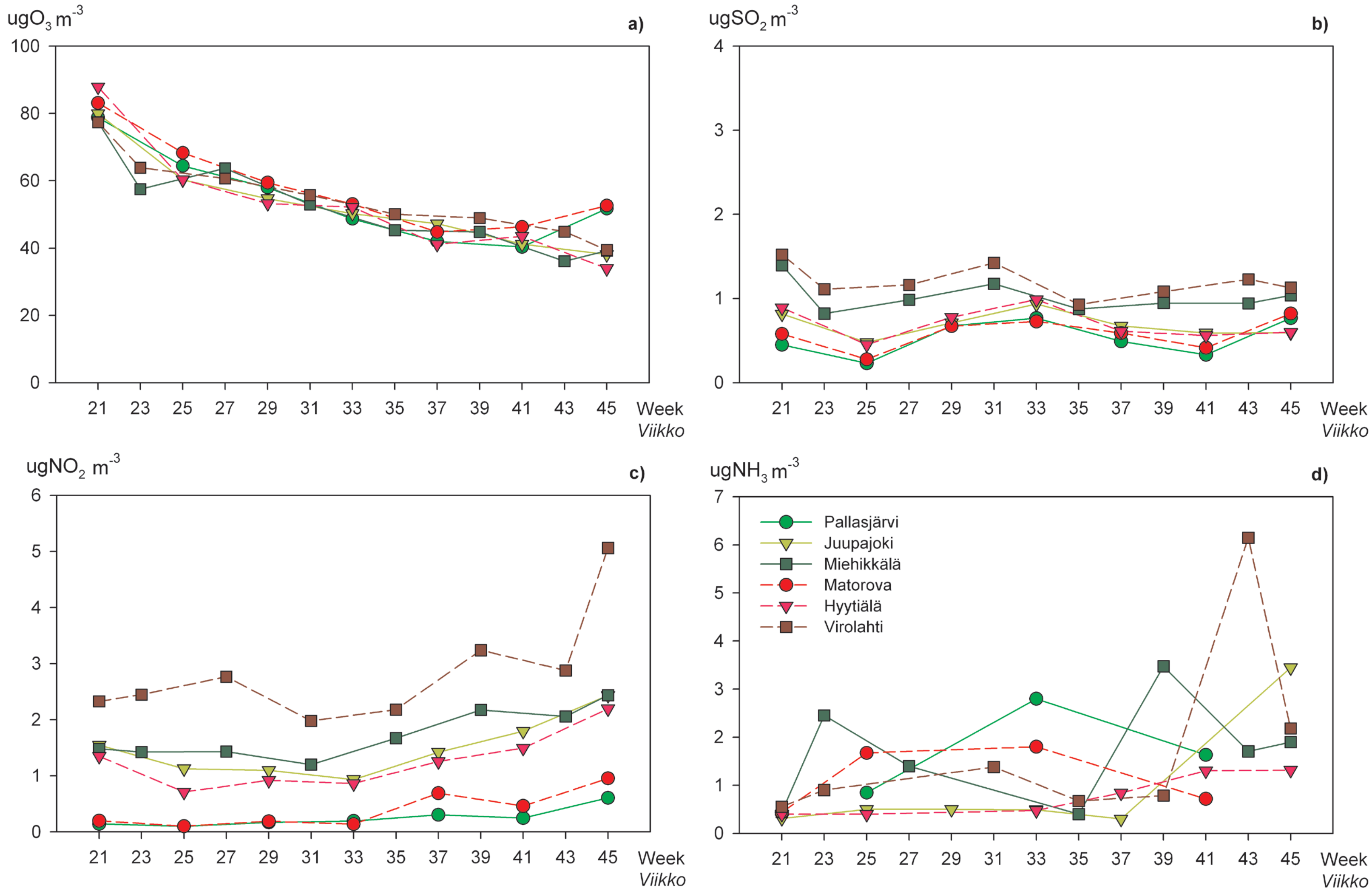

Fig. 2a – d. O_3, SO_2, NO_2 and NH_3 four-week concentrations for the period April–October 2004 on the Level II plots and comparing monitoring stations.
Kuva 2a – d. O_3-, SO_2-, NO_2- ja NH_3-pitoisuudet neljän viikon mittausjaksoissa huhtikuusta lokakuuhun 2004 tason II havaintoaloilla ja vertailevilla mittausasemilla.

The measurements of the other gases were more regular (Table 3). Only a very few measurements were below the detection limits for SO_2 and NO_2, and none for O_3. The measurements of these gases at the comparison stations in most cases closely followed each other, although the differences between Miehikkälä (Level II site) and Virolahti (FMI) were larger due to the longer distance between the two sites (Figs. 2a–d, Table 3). There also are main roads with a considerable amount of traffic in the area. In contrast, the other monitoring sites are located in forested areas.

Some problems were encountered at one of the sites during the first monitoring phase. FMI's northernmost air-quality monitoring station is located on the top (altitude 560 m) of Sammaltunturi Fell (5 km from the Pallasjärvi Level II plot). The site is very exposed, and there were considerable icing problems during the winter. During the next monitoring period the site of the passive samplers was moved to the new EMEP station on the slope of a fell (Matorova), which is much closer (about 0.5 km) to the Level II plot at Pallasjärvi. The monitoring was carried out during the Mid-European growing season (from April to October), as stated in the sub-manual for monitoring air quality.

Results from European Level II network

In France, the O_3 concentrations were measured during 2000–2002 using the same kind of IVL passive samplers. The mean O_3 concentrations for the 26 sites over the 3-year period varied between 43 and 89 $\mu g\ m^{-3}$, measured in two weeks periods. Most of the concentrations varied between 32 and 100 $\mu g\ m^{-3}$ (Ulrich et al. 2006).

In order to obtain an overall view of O_3 concentrations at the European level, sampling periods per site and country were aggregated to give 6-month means representing the vegetation period from April to September. Results were obtained for eight countries in 2002, and six in 2003. In 2002 over 60%, and in 2003 about 50% of the concentrations ranged between 30–45 ppb. In 2002 15% of the concentrations and in 2003 30% ranged between 45–60 ppb. The highest ozone concentrations were measured in northern Italy, with time-weighted average seasonal concentrations of 60–75 ppb. Four different types of passive samplers were used for these measurements (Lorenz et al. 2005).

In Germany, NH_3 was measured on six Level II plots in 2002–2003. Most of the one-month mean values were below 5 $\mu g\ m^{-3}$, but at one of the plots the concentrations were between 5 to 20 $\mu g\ m^{-3}$ (Lorenz at al. 2005). In Switzerland, the mean seasonal (from April to September) NH_3 concentrations at sites comparable to the Level II plot open areas (forest clearings, no agricultural activities nearby) were 0.9–4.1 $\mu g\ m^{-3}$ (Thöni et al. 2004).

The most applicable monitoring period still needs to be determined from the point of view of comparison with other European monitoring on Level II plots, as well as the different climatic and geographical conditions throughout Europe.

References

CEN 2001. Ambient Air Quality – Diffusive samplers for the determination of concentrations of gases and vapours – Part 3: Guide to selection, use and maintenance. TC. No: 264. European Rwef. Nr. 13528–3.

De Leeuw, F., Sluyter, R., Van Breugel, P. & Bogman, F. 2001. Air pollution by ozone in Europe in 1999 and the summer of 2000. European Environment Agency, Topic Report 1/2001. 55 p.

De Vries, W., Reinds, G. J., Posch, M., Sanz, M. J., Krause, G. H. M., Calatayud, V., Renaud, J. P., Dupouey, J. L., Sterba, H., Vel, E. M., Dobbertin, M., Gundersen, P. & Voogd, J. C. H. 2003. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report. UNECE/EC: Geneva, Brussels. 161 p.

Ferm, M. 2001. Validation of a diffusive sampler for ozone in workplace atmospheres according to EN838. Proc. From International Conference Measuring Air Pollutants by Diffusive Sampling, Montpellier, France 26–28 September 2001. p. 298–303.

Leinonen, L. (ed.) 2001. Ilman laadun mittauksia – Air quality measurements 2000. Finnish Meteorological Institute. ISBN 951-697-542-9. 224 p.

Lorenz, M., Becher, G., Mues, V., Fischer, R., Becker, R., Calatayud, V., Dise, N., Krause, G.H.M., Sanz, M. & Ulrich, E. 2005. Intensive Monitoring of Forest Ecosystems in Europe. Technical report. UNECE/EC Geneva. 96 p.

Ulrich, E., Dalstein, L., Günthardt-Goerg, M.S., Vollenweider, P., Cecchini, S., Vas, N., Sjöberg, K., Skarman, T. & Pihl Karlson, G. 2006. RENECOFOR – Effets de l'ozone sur la végétation, concentrations d'ozone (2000–2002) et symptômes d'ozone sur la vegetation forestière (2001–2003). Editeur: Office National des Forêts, Direction Technique, Département Recherce. ISBN 2-84207-300-2. 126 p.

Thöni, L., Brang, P., Braun, S., Seitler, E. & Rihm, B. 2004. Ammonia monitoring in Switzerland with passive samplers: patterns, determinants and comparison with modelled concentrations. Environmental Monitoring and Assessment 98: 93–107.

4 Results of other studies related to forest damages and long-term monitoring

Muiden ympäristö- ja metsätuhoseurantojen ja -tutkimusten tuloksia

4.1 The use of light microscopy to assess the impact of ozone stress on Norway spruce needles in the field

Otsonivaurioiden havainnointi kuusen neulasista valomikroskooppisesti

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Light microscopy was used to study previously specified ozone-induced symptoms in the foliage of Norway spruce. The three youngest green needle generations from twenty mature trees in two stands growing on sites of different soil fertility at Asa, southern Sweden, were sampled in 1999. The critical dose of ozone, expressed as AOT40, was 6362 ppb.h. Light microscopy showed ozone-specific symptoms: decreased chloroplast size with electron dense stroma advancing gradually from the outer to inner cell layers, being most severe in the needle side facing the sky. The symptoms were expressed as ozone syndrome index at the needle generation, tree and stand levels. The index had higher values on the site of low fertility. The study shows that light microscopy can be used for quantitative diagnosis of the impact of ozone stress on conifers in the field.

Työssä tutkittiin otsonin aiheuttamiksi tunnettuja oireita valomikroskooppisesti kuusen neulasista. Neulasnäytteet kerättiin vuonna 1999 kahdesta ravinnetasoltaan erilaisesta metsiköstä, kuusten (n = 20) kolmesta nuorimmasta neulasvuosikerrasta. Metsiköt sijaitsevat Asassa, Etelä-Ruotsissa. Kertynyt otsoniannos, joka ilmaistaan AOT40:nä, oli 6362 ppb.h. Valomikroskooppisesti voitiin todeta otsonille tyypilliset oireet: kloroplastin koon pieneneminen ja samanaikainen strooman tummuminen sekä oireiston eteneminen asteittain uloimmista solukerroksista sisempiin kerroksiin. Oireet esitettiin otsonioireindeksinä neulasvuosikerta-, puu- ja metsikkötasoille. Indeksi oli korkein ravinteisuudeltaan alhaisemmalla kasvupaikalla. Tutkimus osoitti, että valomikroskopia soveltuu kvantitatiiviseen otsonioireiden havainnointiin havupuilla kenttäolosuhteissa.

Introduction

As ozone is a potential risk for European forests (Kivimäenpää 2003, Ashmore 2005), diagnostic methods are needed for the assessment of the impact of ozone stress on trees in the field. Scoring of visible injury in leaves and needles is the most widely used method to assess the impact of ozone stress on mature trees in Europe and North America (e.g. Chappelka et al. 1999, Sanz et al. 2000). Visible symptoms typical to ozone are now well recognized and documented, especially in broad-leaved plants (e.g. Innes et al. 2001). Therefore the Working Group on Air Quality (Expert Panel on Deposition), within the framework of the ICP Forests programme, selected the scoring of visible symptoms as the tool for assessing ozone injuries at the European level on the Level II intensive monitoring Plots (Submanual for the assessment... 2006). Visible injuries on the needles of many conifer species, like Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), cannot yet be reliably associated with ozone levels in the field. In addition, macroscopically visible injuries are difficult to detect, because any cell death is hidden by the compact rhomboid form of spruce needles (Submanual for the assessment... 2006, Pictorial atlas of... 2006). Therefore, it is important to find diagnostic methods that can be used to replace the scoring of visible injuries, or to be applied together with the scoring method. This is especially important in those vegetation zones where conifers are the main woody species.

Microscopy is a highly potential tool for diagnosis, because ozone induces microscopic changes in the structure of the foliage (e.g. Sutinen et al. 1990, Holopainen et al. 1992, Fink 1999, Günthardt-Goerg et al. 2000). Ozone-affected chloroplasts are characterized by (1) a decrease in their size, together with (2) simultaneous darkening and often granulation of the stroma (e.g. Sutinen 1987a, Sutinen et al. 1990, Anttonen et al. 1996, Anttonen and Kärenlampi 1996, Holopainen et al. 1996) and (3) a gradual advance of these chloroplast changes from the outer cell layers under the stomata towards the deeper cell layers (Sutinen 1987b, Sutinen et al. 1990). The specificity of the method is based on the fact that the substructure and ultrastructure of conifer needles, especially those of Norway spruce and Scots pine, have been intensively studied over the past 30 years. The effects of natural (e.g. season, needle age) and stress-related (e.g. drought, sulphur dioxide, ozone, nutrient imbalances) factors are well described (Holopainen et al. 1992, Anttonen et al. 1995, Sutinen and Koivisto 1995, Anttonen and Kärenlampi 1996, Anttonen et al. 1996, Palomäki 1996, Wulff 1996, Jokela 1998, Fink 1999, Utriainen et al. 2000, Utriainen and Holopainen 2001). No other presently known stress factor is known to induce similar, simultaneously occurring changes as those listed above for ozone. Other characteristics of the microscopic changes are that they are first detected in the sun-exposed side of a needle and that, with increasing concentrations or dose of ozone, the severity of the symptoms also increases (Sutinen et al. 1990, Holopainen et al. 1996). This means that they are more advanced in older needles under chronic ozone exposure (Sutinen et al. 1990). Furthermore, microscopic methods have earlier been successfully used to evaluate forest health in the field (Meyberg et al. 1988, Sutinen 1990, Palomäki and Raitio 1995, Alvarez et al. 1998, Sutinen et al. 1998).

We studied whether ozone-specific symptoms (i.e. small chloroplast, electron dense stroma and gradual advance of these chloroplast changes in the tissue) can be seen in mature spruces at ambient ozone levels growing on two forest sites in southern Sweden. An additional aim was to express the symptoms at the needle generation, tree and stand level as a quantitative syndrome index that could be used for comparisons between forest sites and for determining correlations with foliar nutrient concentrations.

Material and methods

Study area, sampling and preparation for microscopy

The study site is located in the Asa Forest Research Park, Swedish University of Agricultural Sciences, in the interior of southern Sweden (57°10’N, 14°47’E). Two stands, numbers 574 1450 and 574 1590, located approx. 3 km from the ozone monitoring mast and within 1.5 km of each other, with planted Norway spruce (*Picea abies*) trees of the Asa provenance, were selected for the study. Based on the soil geochemistry and soil fertility (Holmqvist et al. 2002), site 574 1450 was designated as the site with higher fertility (HF), and site 574 1590 as the site with lower fertility

(LF). The average ozone concentration measured at 5 m height was 34.8 nl L^{-1} (daylight hours, 1 April – 30 September) and the AOT40 value was 6362 nl L^{-1} h in the study year (1999). In the preceding years the concentrations and doses, were 28.4 nl L^{-1}, 3143 nl L^{-1} h (1998), 33.3 nl L^{-1}, 6392 nl L^{-1} h (1997) and 34.4 nl L^{-1}, 9020 nl L^{-1} h (1996) respectively. Other stand characteristics, as well as the weather data, are given in Kivimäenpää et al. (2004).

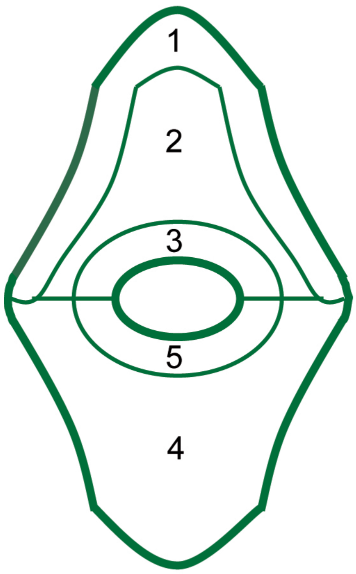
The trees were selected by first drawing a sampling line through each stand at random on a map. In the field ten spruce trees, located 10 m apart from each other along the lines, were systematically sampled for microscopy in both stands on 16 November 1999. The samples for foliar nutrient analysis were simultaneously taken from the same branch on the same trees. The foliar nutrient concentrations have been reported by Jönsson et al. (2001). The samples were collected following the guidelines of the Manual on methods and criteria... (2000). Similar light condition of the sampled needles is important for the nutrient analyses (e.g. Walker 1991), as well as for evaluation of the symptoms of ozone stress, because light affects the stomatal conductance of the needles, which is the main factor determining ozone uptake (Wieser et al. 2000). One branch facing SW from the seventh whorl from the top of the trees was sampled. All the branches were exposed to full light and there were no visually detectable differences between shoots from the different sites.

Five green current (C), second (C+1) and third (C+2) year needles were detached from the upper side, in the middle of the lateral shoots of the branch and were immediately put into tubes containing a fixative solution (1.5% glutaraldehyde, 1.5% paraformaldehyde, 0.15 M sucrose, 2 mM $CaCl_2$ in 0.08 M cacodylate buffer, pH 7.0) at a temperature of +4°C. Further sample preparation is described in Jönsson et al. (2001). Sections (2 μm thick) for light microscopy (LM) were cut on an LKB Ultratome III (Bromma, Sweden). The sections were fixed on a glass slide on the surface of an electric warm plate, stained with freshly prepared 1% toluidine blue (in distilled water) for 8 minutes at +30°C, rinsed with distilled water, stained with 1% p-phenylene diamine (in 1:1 methanol:isopropanol, v:v) for 4 minutes at room temperature, rinsed twice with 1:1 methanol:isopropanol and left to dry at room temperature.

Estimation of ozone impact

Three needle cross-sections from each generation per tree were examined under the light microscope (Zeiss Axioplan, Jena, West Germany) at 1250x magnification (100x objective). Pre-experiments showed that double-staining with freshly prepared stains gave an adequate staining result for the evaluation of ozone-induced changes under the light microscope. The few cells showing disrupted cell organelles or very dense (dark) cytoplasm in otherwise well-preserved samples were omitted from the analysis, because the estimation of chloroplast size and darkening would have been unreliable. Therefore, n was 9 (C and C+1) or 10 (C+2) at the HF site and 7 (C) or 8 (C+1, C+2) at the LF site.

Based on the gradual advance of ozone injury from the cell layer under the hypodermis on the sky-facing side (the first ozone affected cells) to the cell layer under the endodermis on the ground-facing side (the last ozone affected cells) (Sutinen et al. 1990), the mesophyll tissue in the cross-section of spruce needle was divided into five regions (Fig. 1). Region 1 consisted of the mesophyll cell layer under the epi- and hypodermis on the sky-facing side of the needle; region 2 of the second to fourth cell layers from the hypodermis on the sky-facing side. Region 3 was the cell layer above the sky-facing endodermis. Region 4 was the ground-facing side of the mesophyll



Regions *Alueet*	Dark chloroplast *Tummat viherhiukkaset*	Chloroplast length *Viherhiukkasen pituus*	Ozone syndrome *Otsonioire*
1	1	S1	1
2	1	S2	1
3	0	S3	0
5	0	S3	0
4	1	S2	1

Ozone syndrome index = 3
Otsonioireindeksi = 3

Figure 1. Schematic illustration of the cross-section of a Norway spruce needle showing mesophyll tissue divided into five regions (1–5) based on the order and magnitude of the development of ozone-related changes, and small and electron-dense chloroplasts. Epidermis and hypodermis, the outermost cell layers and endodermis, and the cell layer around the conducting tissue (circle inside the cross-section), are not shown. Region 1: the mesophyll cell layer under the sky-facing hypodermis; region 2: second to fourth cell layers under the sky-facing hypodermis; region 3: the cell layer above the sky-facing endodermis; region 4: cells under the ground-facing side of the needle, excluding the cell layer under the endodermis; region 5: the cell layer under the ground-facing endodermis.
The figure also shows an example of the calculated ozone syndrome for one C+2 needle: The median values for dark chloroplasts and median length class S1 = <5 µm, S2 = 5–6 µm, S3 = 6–7 µm and S4 = >7 µm) are shown for five corresponding regions of the needle. Based on the advance of ozone symptoms, the cell layer under the ground-facing endodermis, i.e. region 5 of the C needles of a given tree, was taken as the control region. If the region under analysis had dark chloroplasts (regions 1, 2 and 4) and smaller chloroplasts (regions 1, 2 and 3) than the control region (in this case S3 in the C needles in the region 5), then the region under analysis was given a value of 1, indicating an ozone effect. If both requirements were not fulfilled, the region was given a value of 0, indicating no ozone effect. The sum of these values per needle generation is the ozone syndrome index for that needle generation (i.e. the ozone syndrome index here is 3).
Kuva 1. Kuusen neulasen poikkileikkaus kaavamaisena kuvana, jossa on erotettu viisi tutkimusaluetta. Alueiden jako perustuu otsonioireiden, viherhiukkasten pienenemisen ja tummumisen, asteittaiseen etenemiseen neulasten taivaanpuoleiselta yläpinnalta (kuusella) kohti maanpuoleista alapintaa. Alue 1: uloin mesofyllin solukerros neulasen taivaanpuoleisella sivulla; Alue 2: kaksi-neljä solukerrosta taivaanpuoleiselta sivulta; Alue 3: neulasen taivaanpuoleisen sivun endodermin viereinen mesofyllisolukerros; Alue 4: neulasen maanpuoleiset mesofyllisolukerrokset lukuunottamatta endodermin viereistä solukerrosta, joka on alue 5. Kuvassa on myös esimerkki kolmivuotiaan neulasen valomikroskooppitutkimuksiin perustuvasta otsonioireindeksin laskemisesta: tummentuneiden ja samanaikaisesti pienten viherhiukkasten esiintyminen eri solukkoalueilla. Vihehiukkasten kokoluokat jaoteltiin seuraavasti: S1 = <5 µm, S2 = 5–6 µm, S3 = 6–7 µm, S4 = >7 µm. Koska kenttä- ja laboratoriokokeissa otsonioireiden esiintymistä ei ole todettu nuorimman vuosikerran neulasten alueella 5, tämä alue on valittu indeksiä laskettaessa kontrollialueeksi. Jokaista kunkin neulasvuosikerran aluetta siis verrataan tuoreimman neulasvuosikerran alueeseen. Jos tutkittavalla neulasalueella viherhiukkaset ovat tummia ja pienempiä kuin C neulasen alueella 5 (tässä tauksessa pienempiä kuin S3) saa tutkittava alue arvon 1, mikä osoittaa otsoninoiretta ko. aluella. Kun kaikkien viiden alueen otsoniarvot lasketaan yhteen saadaan ko. neulasvuosikerran otsonioireindeksi, joka tässä tapauksessa on 3.

tissue, excluding the cell layer under the endodermis. Region 5 was the layer under the ground-facing endodermis.

The length of the chloroplasts in the cells of each five regions of the needle cross-section was determined under the microscope with the help of a scale in the ocular. The length was divided into four size classes: S1 = under 5 µm, S2 = 5–6 µm, S3 = 6–7 µm and S4 = over 7 µm. Darkening of the chloroplasts in the same needle regions was also assessed. If half or more of the cells in a given region had dark chloroplasts, then the region was given a value of 1, otherwise 0. Medians for chloroplasts length and darkening were calculated from three needle cross-sections for each needle region of each needle generation per tree.

Calculating the ozone syndrome index

Light microscopic data were used to calculate an index for the ozone syndrome, which includes three components: 1) size of chloroplasts is decreased, 2) the diminished chloroplasts are electron dense, and 3) these small, electron dense chloroplasts show gradual advance from the outer to the inner cell layers. As there is no control treatment in the field against which to compare the ozone symptoms, the tree was used as its own control. Region 5 (Fig. 1) of the C needles was used as the control because microscopic ozone alteration occurs last in this region (Sutinen et al. 1990), i.e. this region represents the chloroplasts in intact needles, in which the chloroplasts are about the same size in both sky- and ground-facing sides, even in older needle generations (Sutinen et al. 1990, Wulff et al. 1996). Thus, in a given tree, the median size classes of the chloroplasts from all cross-sectional regions separately, in C, C+1 and C+2 needles separately, were compared to the median size class in region 5 of the C needles. If the median chloroplast size class in the selected region in the given needle generation was smaller than the median chloroplast size class in region 5 of the C needles, and if also the median value for darkening of the chloroplasts was 1 in the same region, then that region was given a value of 1, indicative of ozone effect (Fig. 1 regions 1, 2 and 4). If one or both of these two requirements in the region were not met, the region was given a value of 0, indicative of no ozone effect (Fig. 1 regions 3 and 5). Thus each needle generation on each tree was given five values of 0 or 1 and the sums of the values (0–5) represent the ozone syndrome index for the needle generations. The sum of index from needle generations (in our case three generations) represents an ozone syndrome index for the tree, which could then be given values between 0 and 14 (not 15 as the region 5 of the C needles is always 0).

Statistical treatment

Differences in ozone syndrome indexes between the sites were studied by the Mann-Whitney test. Correlation between ozone syndrome indexes and foliar nutrient concentrations were studied by the Spearman's rank correlation test. Statistical analyses were performed using SPSS 10.0.

Results

Dark chloroplasts were readily discernable against the light cytoplasm (Fig. 2a, b), whereas the stroma of the intact chloroplasts was as light as the cytoplasm (Fig. 2c). The smallest chloroplasts were always detected in region 1 (see Fig. 1). Occasionally, chloroplasts as small as 4 µm occurred in this region in the C+2 needles from the LF site. Needle region 1 also had the highest proportion of trees showing dark chloroplasts. Region 2 was the next worst affected. Region 5 was the least affected having the largest chloroplasts, even 8 µm long, and with no dark chloroplasts. The gradual change in chloroplast length between regions 1 and 2 can be seen by comparing Fig. 2a and 2b. At the needle level, the gradual advance of the change was consistent. The differences in chloroplast length and darkening were small between the needles from the same tree (data not shown). The differences between the trees were larger: the chloroplast length in a given needle region of a given needle generation varied within two to four size classes. Small, dark chloroplasts were more frequent at the LF site than at the HF site, and the C+2 needles were more seriously affected than the younger needle generations. The ozone syndrome index at the HF site was 1 and at the LF site 4.3. The larger the ozone index per needle generation, the more advanced was the syndrome. The index values per tree had significantly ($p = 0.023$) higher values at the LF site compared to the HF site. Five of the nine trees at the HF site, but only one of the seven trees at the LF site, had an ozone syndrome index of 0 indicating no ozone effect. The ozone syndrome index and the concentrations of magnesium (Mg; $p = 0.007$), phosphorus (P; $p<0.0005$), nitrogen (N; $p = 0.023$), sulphur (S; $p = 0.018$) and the Mg/N ($p = 0.016$) and P/N ($p = 0.016$) ratios were negatively and significantly correlated in the C needles. In the C+1 needles, the negative correlation between the ozone syndrome index and the concentration of P ($p = 0.056$) approached statistical significance.

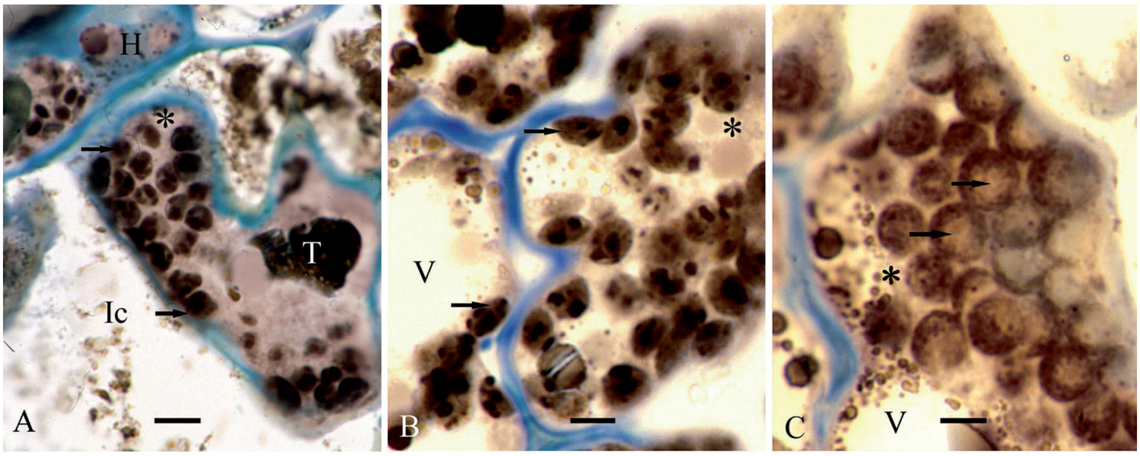


Figure 2. Mesophyll cells of a third-year needle from region 1 (A) and region 2 (B) (for the regions, see Fig. 1) showing ozone-related changes and of a current year needle from region 5 (C) showing intact structures, collected from a mature Norway spruce growing on a site of low fertility at Asa, Sweden, on 16 November 1999. Typical for the effect of ozone stress, the chloroplasts are small and dark (black arrows in A and B) and are most affected in the cells next to the hypodermis, i.e. in region 1. The chloroplasts in region 1 in Fig. A belong to size class S1, i.e. the lengths of the chloroplasts are under 5 µm, and those in Fig. B to size class S2, i.e. the lengths of the chloroplasts are 5–6 µm. In Fig. C the chloroplasts have light stroma (black arrows) and belong to size class S3, i.e. the lengths of the chloroplasts are 6–7 µm. Cytoplasm is marked with asterisks. Cell walls are stained blue. Abbreviations: Ic, intercellular space; V, vacuole; T, tannin; H, hypodermis. Bars 5 µm.

Kuva 2. Kolmivuotiaan neulasen mesofyllisoluja alueelta 1 (kuva A) ja alueelta 2 (kuva B) (Alueista katso kuva 1). Kuvassa 2C on mesofyllisolu tuoreimman neulasen alueelta 5. Näytteet on neulasista, jotka on kerätty Ruotsista Asan koealueelta ravinteisuudeltaan huonommalta kasvupaikalta marraskuussa 1999. Viherhiukkaset ovat otsonioireelle tyypillisesti pieniä – kuvassa A alle 5 µm ja kuvassa B 5–6 µm – ja tummia (mustat nuolet kuvissa A ja B) verrattuna tuoreimman neulasvuosikerran kontrollialeen (alue 5) viherhiukkasiin (kuva C), jotka ovat vaaleita (musta nuoli) ja kooltaan 6–7 µm. Soluseinät erottuvat sinisinä. Solulima on merkittu tähdellä, soluvälitila = Ic, vakuoli = V, tanniini = T, hypodermi = H. Mittajana = 5 µm.

Discussion

Light microscopy showed that the typical effects of ozone stress on chloroplasts (decreased size accompanied by electron dense stroma), similar to that reported in several ozone exposure studies with young conifer seedlings (e.g. Sutinen 1987a, Sutinen et al. 1990, Anttonen and Kärenlampi 1996, Holopainen et al. 1996), were present in mature Norway spruces at ambient ozone concentration in the field. Furthermore, the gradual advance of the chloroplast changes in the tissue was similar to that reported in exposure studies (Sutinen et al. 1990). The results mean that ambient ozone concentrations, with an AOT40 dose considerably lower (6362 ppb.h in 1999) than the present critical dose of 10000 ppb.h, do have an effect on mature spruce trees growing in southern Sweden. Other methods and tree species, e.g. *Betula pendula* (Pääkkönen et al. 1996) and *Pinus radiata* (Calzada et al. 2001), have also shown the effects of ozone on tree foliage far below the current critical dose for AOT40.

The ozone syndrome index had higher values at the low fertility site than at the high fertility site, suggesting a greater ozone impact at the low fertility site. Needle concentrations of most nutrients were lower at the LF site compared to HF site, and the P/N and Mg/N ratios were at the limit of deficiency at the LF site (Jönsson et al. 2001). Low nutrient status can enhance the ozone response of trees (Holopainen et al. 1993, Landolt et al. 1997, Utriainen and Holopainen 2001). The possible effect of nutrient status is supported by the negative correlations between the index for ozone syndrome and the needle concentrations of N, Mg, P, and S, the Mg/N and P/N ratios. The chloroplast alterations similar to those described here have earlier been shown to be more enhanced in ozone-exposed Scots pine needles with low and deficient N concentrations compared to those with a good nutrient status (Kainulainen et al. 2000, Utriainen and Holopainen 2001). Furthermore, the ozone symptoms have also earlier been reported to correlate negatively with the nitrogen status of Scots pine in the field (Sutinen et al. 1998).

With respect to diagnosing the ozone impact in the field, this study shows that light microscopy can be used to identify and monitor the impact of ozone stress on mature Norway spruces. The ozone syndrome index offers a quantitative and statistically sound tool for assessing the ozone impact at the needle generation, tree and stand levels. The syndrome (including small and dark chloroplasts with a gradual advance from the outer to the inner cell layers) used here as a basis for the ozone syndrome index calculation is rigorous enough to identify the impact of ozone in the field, i.e. the syndrome cannot be confused with the effects of any natural or stress factors. Thus the less severe symptom of ozone observable at the electron microscopic level, such as darkening and granulation of chloroplast stroma without any size decrease, as reported by Utriainen et al. (2000), are ignored in the bioindication of ozone in the field.

As the appearance of the microscopic syndrome is in agreement with that of visible symptoms with respect to needle age and needle side (Sutinen et al. 1990, Sanz et al. 2000, Submanual for the assessment... 2006), the method can also be used together with the scoring of visible symptoms on conifer needles, for example in cases where the origin of visible injury is uncertain. The results of this study highlight the importance of collecting samples for nutrient analysis, together with microscopy samples, to assess ozone injury. According to the "Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests" (2000), needle samples for nutrient analyses must be collected during the dormant period. This time is also suitable for collecting samples for microscopy because of the low metabolic activity of the needles and thus good preservation of the samples (Kivimäenpää et al. 2001). More recommendations for collecting needles for reliable diagnosis are given in Kivimäenpää et al. (2005).

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References

Alvarez, D., Laguna, G. & Rosas, I. 1998. Macroscopic and microscopic symptoms in Abies religiosa exposed to ozone in a forest near Mexico City. Environmental Pollution 103: 251–259.

Anttonen, S. & Kärenlampi, L. 1996. Slightly elevated ozone exposure causes cell structural changes in needles and roots of Scots pine. Trees – Structure and Function 10: 207–217.

Anttonen, S., Herranen, J., Peura, P. & Kärenlampi L. 1995. Fatty acids and ultrastructure of ozone-exposed Aleppo pine (Pinus halepensis Mill.) needles. Environmental Pollution 87: 235–242.

Anttonen, S., Sutinen, M.-L. & Heagle, A.S. 1996. Ultrastructure and some plasma membrane characteristics of ozone-exposed loblolly pine needles. Physiologia Plantarum 98: 309–319.

Ashmore, M.R. 2005. Assessing the future global impacts of ozone on vegetation. Plant, Cell and Environment 28: 949–964.

Calzada, I., Mesanza, J., Casado, H. & Castillo, F.J. 2001. Biochemical changes in needles of Pinus radiata D. Don trees in relationship to long-term ozone exposure indices. Environmental Pollution 114: 325–335.

Chappelka, A., Skelly, J., Somers, G., Renfro, J. & Hildebrand, E. 1999. Mature black cherry used as a bioindicator of ozone injury. Water, Air, and Soil Pollution 116: 261–266.

Fink, S. 1999. Pathological and regenerative plant anatomy. Borntraeger, Berlin.

Günthardt-Goerg, M.S., McQuattie, C.J., Maurer, S. & Frey, B. 2000. Visible and microscopic injury in leaves of five deciduous tree species related to current critical ozone levels. Environmental Pollution 109: 489–500.

Holmqvist, J., Thelin, G., Rosengren, U. & Sverdrup, H. 2002. Assessment of sustainability in the Asa Forest Park. In: Sverdrup, H. & Stjernquist, I. (eds.). Developing principles and models for sustainable forestry in Sweden. Kluwer Academic Publishers, Dordrecht. p. 381–426.

Holopainen, T., Anttonen, S., Wulff, A., Palomäki, V. & Kärenlampi, L. 1992. Comparative evaluation of the effects of gaseous pollutants, acidic deposition and mineral deficiencies: structural changes in the cells of forest plants. Agriculture, Ecosystems and Environment 42: 365–398.

Holopainen, T., Palomäki, V. & Rantanen, L. 1993. Responses of conifer seedlings to slightly elevated ozone level in Kuopio open-field fumigation experiment. In: Tuomisto, J. & Ruuskanen, J. (eds.). Proceedings First Finnish Conference of Environmental Sciences. Kuopio University Publications C. Natural and Environmental Sciences 14. p. 117–120.

Holopainen, T., Anttonen, S., Palomäki, V., Kainulainen, P. & Holopainen, J.K. 1996. Needle ultrastructure and starch content in Scots pine and Norway spruce after ozone fumigation. Canadian Journal of Botany 74: 67–76.

Innes, J.L., Skelly, J.M. & Schaub, M. 2001. Ozone and broadleaved species. Ozon, Laubholz- und Krautpflanzen. Haupt, Bern.

Jokela, A. 1998. Structural and functional responses of Scots pine needles to nutrient stress. Acta Universitatis Ouluensis A 308.

Jönsson, A.M., Kivimäenpää, M., Stjernquist, I. & Sutinen, S. 2001. Frost hardiness in bark and needles of Norway spruce in southern Sweden. Trees – Structure and Function 15: 171–176.

Kainulainen, P., Utriainen, J., Holopainen, J.K., Oksanen, J. & Holopainen, T. 2000. Influence of elevated ozone and limited nitrogen availability on conifer seedlings in open-air fumigation system: effects on growth, nutrient content, mycorrhiza, needle ultrastructure, starch and secondary compounds. Global Change Biology 6: 345–355.

Kivimäenpää, M. 2003. The cell and tissue structures of Norway spruce and Scots pine needles as tools for the diagnosis of ozone impact. Kuopio University publications C. Natural and environmental sciences 157. ISBN 951-781-255-8. ISSN 1235-0486.

Kivimäenpää, M., Sutinen, S., Medin, E.L., Karlsson, P.E. &Selldén, G. 2001. Diurnal changes in microscopic structures of mesophyll cells of Norway spruce, Picea abies (L.) Karst., and the effects of ozone and drought. Annals of Botany 88: 119–130.

Kivimäenpää, M., Jönsson, A.M., Stjernquist, I., Selldén, G. & Sutinen, S. 2004. The use of light and electron microscopy to assess the impact of ozone on Norway spruce needles. Environmental Pollution 127: 441–453.

Kivimäenpää, M., Selldén, G. & Sutinen, S. 2005. Ozone-induced changes in the chloroplast structure of conifer needles, and their use in ozone diagnostics. Environmental Pollution 137: 466–475.

Landolt, W., Günthardt-Goerg, M.S., Pfenninger, I., Einig, W., Hampp, R., Maurer, S. & Matyssek, R. 1997. Effect of fertilization on ozone-induced changes in the metabolism of birch (Betula pendula) leaves. New Phytologist 137: 389–397.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests, Part IV. Sampling and analysis of needles and leaves. 2000. [Internet site]. Available at: http://www.icp-forests.org/Manual.htm.

Meyberg, M., Lockhausen, J. & Kristen, U. 1988. Ultrastructural changes in the mesophyll cells of spruce needles from a declining forest in northern Germany. European Journal of Forest Pathology 18: 169–175.

Pääkkönen, E., Vahala, J., Holopainen, T., Karjalainen R. & Kärenlampi L. 1996. Growth responses and related biochemical and ultrastructural changes of the photosynthetic apparatus in birch (Betula pendula) saplings exposed to low concentrations of ozone. Tree Physiology 16: 597–605.

Palomäki, V. 1996. Conifer needle ultrastructure as an indicator of environmental stress factors with special reference to unbalanced nutrition. Kuopio University Publications C. Natural and Environmental Sciences 54.

Palomäki, V. & Raitio, H. 1995. Chemical composition and ultrastructural changes in Scots pine needles in a forest decline area in southwestern Finland. Trees – Structure and Function 9: 311–317.

Pictorial atlas of sensitive species. 2006. [Internet site]. Available at: http://www.gva.es/ceam/ICP-forests.

Sanz, M.J., Calatayud, V. & Calvo, E. 2000. Spatial pattern of ozone injury in Aleppo pine related to air pollution dynamics in a coastal-mountain region of eastern Spain. Environmental Pollution 108: 239–247.

Submanual for the assessment of ozone injury on European Forest Ecosystems. 2006. [Internet site]. Available at: http://www.gva.es/ceam/ICP-forests.

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

Sutinen, S. 1987b. Cytology of Norway spruce needles. II. Changes in yellowing spruces from the Taunus Mountains, West Germany. European Journal of Forest Pathology 17: 74–85.

Sutinen, S. 1990. Structural changes in needle tissue of spruce trees from a damaged stand in southern Finland. Scandinavian Journal of Forest Reseach 5: 403–412.

Sutinen, S. & Koivisto, L. 1995. Microscopic structure of conifer needles as a diagnostic tool in the field. In: Munawar, M., Hänninen, O., Roy, S., Munawar, L., Kärenlampi, L. & Brown, D. (eds.). Bioindicators of Environmental Health. SPB Academic Publishing, Amsterdam. p. 73–81.

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

Sutinen, S., Lumme, I., Mäenpää, M. & Arkhipov, V. 1998. Light microscopic structure of needles of Scots pine (Pinus sylvestris L.) in relation to air pollution and needle element concentrations in S.E. Finland and the Karelian Isthmus, N.W. Russia. Trees – Structure and Function 12: 281–288.

Utriainen, J. & Holopainen, T. 2001. Nitrogen availability modifies the ozone responses of Scots pine seedlings in an open-field system. Tree Physiology 21: 1205–1213.

Utriainen, J., Janhunen, S., Helmisaari, H.-S. & Holopainen, T. 2000. Biomass allocation, needle structural characteristics and nutrient composition in Scots pine seedlings exposed to elevated CO_2 and O_3 concentrations. Trees – Structure and Function 14: 475–484.

Walker, R.B. 1991. Measuring mineral nutrient utilization. In: Lassoie, J.P. & Hinckley, T.M. (eds.). Techniques and approaches in forest tree ecophysiology. CRS Press, Boston. p. 184–206.

Wieser, G., Häsler, R., Götz, B., Koch, W. & Havranek, W.M. 2000. Role of climate, crown position, tree age and altitude in calculated ozone flux into needles of Picea abies and Pinus cembra: a synthesis. Environmental Pollution 109: 415–422.

Wulff, A. 1996. Ultrastructural, visible and chemical indications of dry and wet deposited air pollutants in conifer needles. Kuopio University Publications C. Natural and Environmental Sciences 41.

Wulff, A., Ahonen, J. & Kärenlampi L. 1996. Cell ultrastructural evidence of accelerated ageing of Norway spruce needles in industrial areas. New Phytologist 133: 553–556.

4.2 Pest and disease situation during 2002–2005 according to the Forest Damage Advisory Service

Metsätuhot vuosina 2002–2005 metsätuhotietopalvelun saamien tietojen perusteella

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This summary of biotic and abiotic forest damage is based on the annual forest damage reports compiled for the Ministry of Agriculture and Forestry. The reports are available in Finnish on the Internet. Information is gathered from the local Forest Owners Associations, Forestry Centres and damage records supplied by individual forest owners or nurseries, as well as researchers. Due to the heterogeneity of the data, caution is needed when making comparisons. For the pine sawflies (*Neodiprion sertifer* and *Diprion pini)*, annual prognoses are made using permanent sample plots.

Tämä metsien abioottisia ja bioottisia tuhoja koskeva katsaus perustuu maa- ja metsätalousministeriölle toimitettuihin metsätuhoraportteihin. Raportit ovat saatavilla verkkoversiona suomeksi (http://www.metla.fi/metinfo/metsienterveys). Tiedot raportteja varten kootaan metsänhoitoyhdistyksiltä, metsäkeskuksilta, metsänomistajilta, taimitarhanhoitajilta ja tutkijoilta saaduista tuhohavainnoista. Aineiston epäyhtenäisyys on syytä huomioida tietojen tulkinnassa. Mäntypistiäisennusteet (*Neodiprion sertifer* ja *Diprion pini)* perustuvat pysyviltä havaintoaloilta kerättävään aineistoon.

Storms caused the main damage in most years

In the year 2001, storm felled more than 7 million m³ of forest. The harvesting of damaged trees was successful, especially in the heaviest damaged areas, and 70% of the damaged trees were removed from the forests before summer 2002 (Ihalainen and Ahola 2003). Windthrows were again reported all over Finland in 2002, and the most severe thunderstorms occurred in South Finland. The amount of wind damage decreased during 2003–2005, but damage was reported throughout Finland. Snow damage had been decreasing from 2002 to 2004, but increased sharply in 2005, when damage was reported over 2000 ha.

Sudden frost damaged pine seedlings in autumn in the Suomenselkä watershed area after the long warm period in 2003. In 2004, the early spring was warm and the trees started to grow early. The warm period was followed by a cold spell with frosty nights, which damaged pines and especially aspen. The summer and autumn 2004 were warm and rainy and the trees continued to grow late and not all the shoots had time to become lignified. As a result, a large number of trees were damaged during the markedly fluctuating winter weather. The spreading of salt on the roads to prevent icing damaged conifers along the roadsides. This was very prominent along the south coast, where salt spray from the open sea may have also had some effect.

Drought affected the forests from 2002 and 2003 onwards

In 2002 the dry period started already in April, lasted for two months, and then continued in August after a rainy period. The warm autumn suddenly turned into a cold autumn, and many broadleaved trees still bore green leaves when the first snow fell. Ground water levels were exceptionally low almost everywhere. The drought continued in spring 2003, and along the south coast many pine forests on rocky soils suffered considerably. On slightly deeper soils, the pines had shorter shoots and needles. Dry birch tops were frequently observed. Most of the dead pines were not harvested, and bark beetles and longhorn beetles had abundant breeding material. As a result, trees damaged or killed by beetles were reported increasingly in and around stands damaged by drought. In autumn 2003, and especially in summer 2004, precipitation was exceptionally high and summer floods ended the drought.

Fungal damage was relatively insignificant due to the drought

Fungal diseases were, in general of little importance because of the drought. The heavy rains after the dry period did not induce epidemics. The expansion of an epidemic of *Gremmeniella abietina* ceased in 2002, and damage was reported mainly from Southwest Finland. The decrease continued

Figure 1. After the storms in 2001, experiment plots were established to study the damage done by *Ips typographus*. (Photo: Antti Pouttu).
Kuva 1. Vuoden 2001 myrskyjen jälkeen perustettiin erikokoisia koealoja kirjanpainajien aiheuttamien seuraustuhojen tutkimiseksi. (Kuva: Antti Pouttu).

in 2003, with few damage reports from Southeast Finland and Lapland. In 2004 *G. abietina* was slightly more frequent, but far from an epidemic state. Damage was reported from Southwest and Southeast Finland and Ostrobothnia. The increase continued in 2005, and *G. abietina* occurred more frequently than on the average, but there was no economically significant damage.

The control of *Heterobasidion* root rots is subsided by the state in the official risk zone. Control is also recommended in all over areas where *Heterobasidion* occurs. There were increasing numbers of reports of *Heterobasidion annosum*, the pine root rot, from the western part of Finland. The control of root rot should be encouraged especially in Western Finland, which is not officially part of the risk zone.

Needle casts were negligible in the forests during the period. Only in 2002 were there reports of *Lophodermella sulcigena* in Northern Lapland. On the other hand, the juniper needle cast, *Stigmina juniperina,* defoliated junipers throughout south and central Finland. The damage drew wider attention in 2003, and has become more serious every year. Eventually it turned ornamental junipers into an unfortunate state. The needles, starting from the lower parts of crown, turn brownish and later greyish before they fall. Junipers may lose all their foliage in a couple of years, and many have lost most of their needles, only a small tuft of green remaining at the top. Affected junipers may remain alive with only a small number of living needles, but the recovery of aesthetic value is unlikely.

Figure 2. Pine forests on rocky soils suffered from drought, and as secondary damage, from *Tomicus* bark beetles. (Photo: Antti Pouttu).
Kuva 2. Kalliomänniköt kärsivät kuivuudesta ja seuraustuhoina ytimennävertäjistä. (Kuva: Antti Pouttu).

During the dry period rusts were not very common. In 2002 there was increasing occurrence of *Melampsora pinitorqua* on pines in Ostrobothnia. The host change to aspen was successful in the autumn, but pine seedlings were mainly saved from damage by the dry spring in 2003. The birch leaf rust, *Melampsoridium betulinum*, was reduced by the drought, but was revived by the rainy conditions in 2004. The alder leaf rust, *Melampsoridium hiratsukanum*, was common on grey alder (*Alnus incana*). The most abundant needle rust was *Chrysomyxa ledi* throughout the period in question, and it has increased since the drought years.

The only diseases that were possibly favoured by the drought were leaf spot diseases, like *Pyrenopeziza betulicola*. Leaf spot diseases, together with drought, caused birch leaves to yellow and fall prematurely throughout most parts of Finland every year during 2002 to 2005.

In nurseries, spring 2003 revealed a slightly increased proportion of seedlings damaged by *Gremmeniella* and winter frosts. A lot of *Botrytis cinerea* was found when packing the seedlings in the late autumn in 2003 and 2005 because of the wet, warm autumn.

A new pathogen, *Phytophthora ramorum*, causing sudden oak death, was reported in Finland in a nursery producing ornamentals in 2004 (Lilja and Kokkola 2005). It has caused alarming damage to oaks in America and is being controlled in England and the Netherlands, where it infects mainly Rhododendrons and *Viburnus*. The host selection of *P. ramorum* is very wide, but it has so far not been found in nature in Finland.

Insect damage was locally significant

The windthrows and trees stressed by drought offered Scolytidae and Cerambycidae abundant breeding material. Fortunately, the initial population levels of the main pests were comparatively low. There were only scattered reports of *Ips typographus* attacks on living trees after the storms in 2001 and 2002. *Tomicus piniperda* was reported to damage pine tops near windthrow and snow damage areas in 2002, and to attack the drought-stressed pines on shallow soils in 2004 and 2005.

Defoliating insects were apparently favoured by the dry, warm summers in 2002 and 2003. In 2002 the population levels of Diprionidae species were low. Two small-scale outbreaks of Diprionids were reported: one in Saariselkä, Lapland, where *Neodiprion sertifer* defoliated timberline pines, and the other in Kustavi, in the SW archipelago, where there was a small-scale outbreak of *Gilpinia pallida*. The former mass-outbreak areas of *Diprion pini* in eastern Finland were recovering well from defoliation, but a new outbreak occurred in 2004, and continued in 2005. Some stands had to be salvage cut in autumn 2005. An increase in the population levels of *Neodiprion sertifer* has also been noted.

The spectacular outbreak of *Rheumaptera hastata* in 2001 faded in 2002 according to the number of flying individuals, but more damage was reported on birch than in previous years. This might be because awareness of the species has increased. Some damage was reported still in 2003.

Vast areas of mountain birch (*Betula pubescens* ssp. *czerepanowii*) were defoliated by *Epirrita autumnata* in NW Lapland in 2003. The outbreak continued in 2004 and 2005, but the main areas attacked shifted to the east. Single trees died and dry branches were widely visible, but most of the birches survived the defoliation because the summers were warm and the birches had enough

Figure 3. Defoliators were abundant in North and East of Finland. *Diprion pini* (left) outbreak recured in East and *Epirrita autumnata* (right) defoliated over 800 km² mountain birch forests in the north. (Photos: Antti Pouttu).
Kuva 3. Lehti- ja neulastuholaiset olivat runsaslukuisa. Pilkkumäntypistiäiset (vasemmalla) tuhosivat neulastoa Pohjois-Karjalassa ja tunturimittarin toukat (oikealla) söivät Käsivarren koivikot lehdettömiksi. (Kuvat: Antti Pouttu).

resources to produce another set of leaves later in the summer. The total damaged area comprised over 800 km² in Finland (Virtanen et al. 2006), and it stretched well over into Sweden and Norway as well.

The Chrysomelids, *Melasoma aenea* and *Agelastica alni*, defoliated alders widely in south and east Finland in 2003, and to lesser extent during the following years, too. The Curculionids of the genus *Phyllobius* have been damaging birch seedling stands planted on previous arable land. *Hylobius abietis* pine weevils are common pests of pine seedlings in planted stands, but the population and damage trends are difficult to quantify from the scattered information. It is considered to be a commonplace pest and not readily reported.

Slightly more damage by *Acanhtolyda hieroglyphica* than usually was reported from western Finland. The nun moth, *Lymantria monacha*, has been widely recorded in Southern Finland, and relatively many imagos were found on Seili Island on the SW coast. Earlier the nun moth was considered to be a rare species in Finland, but it might also become a new pest species here as climate warming proceeds. During the drought period, some Aphididae species caused yellow or brown flagging especially on aspen and also on birches and elms.

Moose is the major threat to young stands

The moose, *Alces alces*, has repeatedly been the most serious pest in young stands. The population has been reduced by increasing hunting culls, but the damage levels have not yet been reported to decrease. This might be due to fact that moose damage is reported only when it reaches the level making it eligible for state compensation. Damage is thus a cumulative process over several years that eventually reaches a certain limit, and therefore does not accurately reflect the real-time annual damage. Moose damage compensation in forestry reached a peak in 2001, when they totalled almost 4.5 million euros. Since then they have gradually fallen to slightly less than 3 million euros in 2004 owing to a change in the principles applied in granting moose damage compensation (Maa- ja metsätalousministeriö 2006).

It is difficult to distinguish between the damage caused by the white-tailed deer, *Odocoileus virginianus*, roe deer, *Capreolus capreolus*, or even moose. Probably most of the damage caused by deer species has earlier been attributed to moose. The population of roe deer has been rapidly increasing, and the first damage report was received in 2004. The number of reports increased in 2005.

Voles are periodically significant pests in seedling stands. In summer 2002 the vole populations were increasing or abundant and, in winter 2002/03, severe damage was reported throughout Finland. By summer 2003 the populations had collapsed as expected in most of southern and central Finland, resulting in very little vole damage in winter 2003/04. In summer 2004 there was a pronounced increase in the vole populations, which continued and caused heavy damage in 2005. The population levels in autumn 2005 were the highest since the peak year of 1991.

References

Ihalainen, A. & Ahola, A. 2003. Pyry- ja Janika-myrskyjen aiheuttamat puuston tuhot. Metsätieteen aikakauskirja 3/2003: 385–401.

Lilja, A. & Kokkola, M. 2005. Phytophthora-lajien aiheuttamat uudet uhkat metsätaloudessa. Metsätieteen aikakauskirja 3/2005: 335–345.

Maa- ja metsätalousministeriö. 2006. [Internet site]. Tilastoja hirvieläinvahingoista. Available at: http://www.mmm.fi/attachments/5fOMUxDO1/5g4fI3Llv/Files/CurrentFile/tilastoja_hirvielainvahingot.pdf [Cited 10.8.2006].

Metsätuhoraportit 2002–2005. [Internet site]. Finnish Forest Research Institute. Available at: http://www.metla.fi/metinfo/metsienterveys/metsientila/index.htm [Cited 1 Aug 2006].

Virtanen, T., Pekkanen, K., Mikkola, K. & Kauhanen, H. 2006. Käsivarren tunturimittarituhot vuosina 2004 ja 2005. In: Nikula, A. & Varmola, M. (eds.). Ilmastonmuutos Lapissa – näkyvätkö muutokset – sopeutuuko luonto? Working Papers of the Finnish Forest Research Institute 25: 33–41.

4.3 Forest damage observed in the 10th National Forest Inventory of Finland during 2004–2005

Valtakunnan metsien 10. inventoinnissa vuosina 2004–2005 havaitut tuhot

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The results of stand level damage assessments made on the 23 611 sample plots in the 10th National Forest Inventory (NFI) during 2004–2005 are presented in this study. Slight damage, i.e. damage that does not affect the silvicultural quality of the stand, is not included in the results (except in the maps). The total area of all types of damage was 5.314 mill. ha, or 26.3% of the total forest land area. Abiotic factors and fungi were the most common groups of causal agents in the10th NFI data. The most frequently identified causes of damage in all stands were snow and moose. Resin-top disease and Scleroderris canker caused by *Gremmeniella abietina* are other commonly identified causal agents in pine-dominated forests. Rot fungi are the most frequent causes of damage in spruce-dominated forests. Annosum root rot (*Heterobasidion* sp.) was found in almost 100 000 ha of spruce forests. Other decay fungi were the most frequent causes of damage in deciduous stands. The geographical distribution of the most common causes of damage are also shown in the maps. Compared to the previous inventory (9th NFI), the area of forest showing damage symptoms appears to have increased by 1.8%-units. The damage caused by moose has increased the most, especially in pine stands.

Raportissa esitellään valtakunnan metsien 10. inventoinnin (10. VMI) kuviokohtaisia tuhotuloksia 23 611 havaintoalalta vuosilta 2004–2005. Lievät tuhot, eli tuhot jotka eivät alennna metsikön metsänhoidollista laatua, eivät ole tuloksissa mukana (karttoja lukuunottamatta). Sellaisten metsien pinta-ala, joissa tuhoja esiintyy, on kaikkiaan 5,314 milj. ha tai 26,3 % metsämaan pinta-alasta. Abioottiset tekijät ja sienet ovat tärkeimpiä tuhonaiheuttajaryhmiä 10. VMI:ssa. Lumi- ja hirvituhot ovat yleisimpiä tuhonaiheuttajia koko aineistossa. Tervasroso ja versosurma ovat mäntyvaltaisten metsien yleisimmät tunnistetut tuhonaiheuttajat. Lahottajasienet ovat puolestaan yleisimpiä kuusivaltaisissa metsissä. Juurikääpien aiheuttamaa lahoa tavattiin lähes 100 000 ha:lla kuusikoissa. Lahottajasienet ovat yleisimpiä tuhonaiheuttajia myös lehtipuuvaltaisissa metsissä. Yleisimpien tuhojen levinneisyyttä esitellään myös karttojen avulla. Edelliseen inventointiin (9. VMI) verrattuna sellaisten metsiköiden pinta-ala, joissa tuhoja esiintyy, näyttää lisääntyneen 1,8 %-yksiköllä. Erityisesti hirvituhot ovat lisääntyneet männiköissä.

Introduction

Since 1920's, the forests of Finland have been regularly monitored by National Forest Inventories (NFI) at intervals of about 10 years. The main aim of the first few NFIs of Finland was to estimate the volume and growth of the growing stock and the cutting potential. Other aims, like forest health, multiple use of forests and biodiversity, have become more and more important in the recent NFIs. The monitoring of forest damage was introduced in the 7th NFI in 1977–1984. However, only a few causes of damage were recorded in this NFI. The 8th NFI (1986–1994) was the first to include more detailed information on forest health, including diseases and pests. In the 9th NFI, started in 1996, these aspects were further developed.

From the very beginning the NFIs have been based on statistical sampling. The recent NFIs have been regional inventories, i.e. the field work has been carried out districtwise. The design of the 10th NFI, started in 2004, was changed into a continuous inventory, i.e. field plots are measured throughout the whole country each year. The new design makes it possible to estimate the results at the nation level annually or bi-annually. The field data collection of the 10th NFI will be completed by the end of 2008.

The sampling units of the NFI are sample plots located systematically in clusters. The spacing of the clusters varies from 6 km in southern Finland to 10 km in northern Finland. The number of sample plots per cluster varies from 12 to 14. A large number of variables describing the site, growing stock, damage, implemented and recommended silvicultural measures etc., are recorded for the stand on each plot. The description of damage includes description of symptoms, severity, and timing of the damage and identification of the causal agent. Details of the current NFI can be available at http://www.metla.fi/hanke/3401/index-en.htm.

The results in this article are based on 10th NFI field data collected in 2004 and 2005. The results of the standwise damage assessments are presented. The number of sample plots was 23,611, and 16,872 of these were located on forest land. The results are compared with data from the 9th NFI carried out in 1996–2003.

Results and discussion

Table 1 shows the area of abiotic and biotic damage by causal agent and dominant tree species. The total area of forest land (i.e. forest with a growing potential greater than 1 m^3/ha/year) in Finland is 20.164 mill. ha. The area of pine-dominated forest land is 13.308 mill. ha, spruce-dominated forest land 4.749 mill. ha, and deciduous dominated forest land 1.857 mill. ha.

The total area affected by damage is 5.314 mill. ha, or 26.3% of the total forest land area. This includes all stands, which showed symptoms of damage irrespective of the age of the damage (if the damage was still visible and affecting the quality of the stand at the time of the field observations). Slight damage, i.e. damage that does not affect the silvicultural quality of the stand, is not included in Table 1 (but is included in the maps (Figs. 1–6).

The area of damage with unidentified cause is 1.856 mill. ha (9.2% of the forest land area). Identification of the causal agent is not an easy task in NFI field data collection because most of the damage is already old at the time of observation, and the field work is performed throughout the field season. The proportion of unidentified damage has remained at about the same level since the 8th NFI (see Yli-Kojola and Nevalainen 2006).

Abiotic factors and fungi are the most common groups of causal agents in the 10th NFI data. The incidence of insect damage is very low. This is partly due to the fact that the results are presented standwise presented in this paper. However, it can be seen, e.g. that the very severe epidemics of the large pine sawfly (*Diprion pini* L.) (Lyytikäinen-Saarenmaa and Tomppo 2002) had already passed in 2004.

The most frequent identified cause of damage in all stands are snow and elk (moose). The area of snow damage is 739,000 ha and the area of moose damage 611,000 ha. Snow damage is more common in pine-dominated stands, while elk (moose) injuries are relatively more common in

Table 1. Damage on forest land in the 10th NFI (2004–2005) by causal agent and dominant species. Standwise assessments. Mild damage (not affecting the stand quality) excluded.
Taulukko 1. Tuhojen pinta-ala aiheuttajan ja vallitsevan puulajin mukaan 10. VMI:n aineistossa (2004–2005). Tulos perustuu kuviokohtaisiin arvioihin. Lievät tuhot, jotka eivät alenna metsikön metsänhoidollista laatua, eivät ole mukana.

Agent group	Causal agent	Dominant species – *Vallitseva puulaji*								Total – *Yhteensä*	
Tuhonaiheuttajaryhmä	*Tuhonaiheuttaja*	Treeless *Puuton*		Pine *Mänty*		Spruce *Kuusi*		Deciduous *Lehtipuut*			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Game and grazing	Total – *Yhteensä*	0	0.0	4861	3.7	536	1.1	1011	5.5	6408	3.2
Selkärankaiset	Voles – *Myyrät*	0	0.0	16	0.0	16	0.0	8	0.0	39	0.0
	Elk – *Hirvi*	0	0.0	4729	3.6	503	1.1	876	4.7	6107	3.0
	Other vertebrates – *Muut selkärankaiset*	0	0.0	116	0.1	18	0.0	128	0.7	262	0.1
Insects – *Hyönteiset*	Total – *Yhteensä*	0	0.0	751	0.6	24	0.1	25	0.1	801	0.4
	Tomicus sp. - *Ytimennävertäjät*	0	0.0	234	0.2	0	0.0	8	0.0	242	0.1
	Hylobius abietis – *Tukkimiehentäi*	0	0.0	1	0.0	9	0.0	0	0.0	10	0.0
	Pine sawflies, unspecified – *Mäntypistiäiset yht.*	0	0.0	322	0.2	0	0.0	0	0.0	322	0.2
	Diprion pini – *Pilkkumäntypistiäinen*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Neodiprion sertifer – *Ruskomäntypistäinen*	0	0.0	36	0.0	0	0.0	0	0.0	36	0.0
	Other defoliators – *Muut neulastuholaiset*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	Ips sp. – Kirjanpainajat	0	0.0	1	0.0	8	0.0	9	0.1	18	0.0
	Other identified insect – *Muu tunnistettu hyönteinen*	0	0.0	21	0.0	0	0.0	9	0.1	30	0.0
	Unknown insect – *Tunnistamaton hyönteinen*	0	0.0	135	0.1	8	0.0	0	0.0	143	0.1
Fungi – *Sienet*	Total – *Yhteensä*	0	0.0	5991	4.5	3196	6.7	1818	9.8	11005	5.5
	Heterobasidion – *Juurikäävät*	0	0.0	293	0.2	996	2.1	8	0.0	1297	0.6
	Other decay fungi – *Muut lahottajasienet*	0	0.0	292	0.2	1635	3.4	1592	8.6	3519	1.8
	Gremmeniella abietina – *Versosurma*	0	0.0	2051	1.5	87	0.2	16	0.1	2154	1.1
	Melampsora pinitorqua – *Versoruoste*	0	0.0	626	0.5	35	0.1	0	0.0	660	0.3
	Cronartium sp. – *Tervasrosot*	0	0.0	2096	1.6	51	0.1	0	0.0	2147	1.1
	Other rust fungi – *Muut ruostesienet*	0	0.0	0	0.0	59	0.1	0	0.0	59	0.0
	Needle cast fungi – *Neulaskaristeet*	0	0.0	259	0.2	8	0.0	0	0.0	267	0.1
	Other identified fungus – *Muu tunnistettu sieni*	0	0.0	224	0.2	35	0.1	9	0.1	268	0.1
	Unknown fungus – *Tunnistamaton sieni*	0	0.0	150	0.1	290	0.6	193	1.0	633	0.3

Table 1. Continues
Taulukko 1. Jatkuu

Agent group *Tuhonaiheuttajaryhmä*	Causal agent *Tuhonaiheuttaja*	Dominant species – *Vallitseva puulaji*								Total – *Yhteensä*	
		Treeless *Puuton*		Pine *Mänty*		Spruce *Kuusi*		Deciduous *Lehtipuut*			
		km²	%	km²	%	km²	%	km²	%	km²	%
Abiotic – *Abioottiset*	Total – *Yhteensä*	17	0.7	9069	6.8	2818	5.9	959	5.2	12864	6.4
	Wind – *Tuuli*	9	0.4	931	0.7	555	1.2	38	0.2	1533	0.8
	Snow – *Lumi*	0	0.0	5863	4.4	1092	2.3	437	2.4	7392	3.7
	Frost – *Halla, pakkanen*	0	0.0	16	0.0	308	0.7	9	0.1	333	0.2
	Soil factors – *Maaperätekijät*	0	0.0	1684	1.3	727	1.5	446	2.4	2857	1.4
	Other abiotic factors – *Muut abiottiset*	0	0.0	267	0.2	95	0.2	30	0.2	392	0.2
Fire – *Tuli*	Forest fire – *Metsäpalo*	9	0.4	308	0.2	42	0.1	0	0.0	358	0.2
Man – *Ihmisen toiminta*	Total – *Yhteensä*	0	0.0	1667	1.3	281	0.6	117	0.6	2065	1.0
	Harvesting – *Puunkorjuu*	0	0.0	92	0.1	188	0.4	43	0.2	324	0.2
	Other action of man – *Muu ihmisen toiminta*	0	0.0	1575	1.2	93	0.2	73	0.4	1741	0.9
Air pollution *Ilman epäpuhtaudet*	Total – *Yhteensä*	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Other – *Muut tekijät*	Total – *Yhteensä*	0	0.0	592	0.5	566	1.2	278	1.5	1436	0.7
Unknown – *Tuntematon*	Total – *Yhteensä*	0	0.0	12360	9.3	4013	8.5	2187	11.8	18560	9.2
Damage total – *Tuhoja yhteensä*		17	0.7	35291	26.5	11435	24.1	6396	34.5	53140	26.4
No/mild damages *Ei tuhoa/lievä tuho*		2490	99.3	97792	73.5	36050	75.9	12168	65.6	148500	73.7
Total forest land area – *Metsämaan pinta-ala*		2508	100.0	133083	100.0	47485	100.0	18565	100.0	201640	100.0

deciduous than in coniferous stands. Resin-top disease, caused by two closely related species, *Cronartium flaccidum* (Alb. et Schw.) Wint. and *Endocronartium pini* (Pers.) Hiratsuka (later referred to as *Cronartium* sp.), and Scleroderris canker caused by *Gremmeniella abietina* (Lagerb.) Morelet, are other common causal agents in pine-dominated forests.

Rot fungi are the most frequent causes of damage in spruce-dominated forests. Annosum root rot (*Heterobasidion* sp.) was found on almost 100,000 ha of spruce forests, and other decay fungi on 164,000 ha. Other decay fungi are the most frequent causes of damage in deciduous stands.

The geographical distribution of some biotic and abiotic forms of damage are presented in Figures 1–6. Elk (moose) damage, for instance, occurs all over country, although there are some clear clusters especially in young deciduous stands (Fig. 2). Snow damage in pine stands is more pronounced in northern Finland (Fig. 3). *Gremmeniella abietina* is surprisingly frequent in northern Finland, and is also concentrated in areas south of the city of Oulu, and in the south-eastern corner of the country (Fig. 4), compared to the 8th NFI (Nevalainen 1999, 2002, Yli-Kojola and Nevalainen 2006). *Cronartium* damage in pine stands is frequent in the north, as well as in central eastern Finland, for instance (Fig. 5). The distribution of *Heterobasidion* sp. is as expected, except that infected pine stands were found quite far in the north-east (Fig. 6). It should be emphasized that the group leader of the NFI team has recorded the cause as *Heterobasidion* after having found unequivocal evidence of the fungus (conks, for instance). This can be very difficult in spruce stands.

The area of damaged forests seems to have increased by 316,000 ha (1.8%-units) between the 9th (1996–2003) and 10th NFI (2004–2005) (Table 2). Elk (moose) damage has increased the most, especially in pine stands. Damage due to snow and *Gremmeniella* have also slightly increased, for instance. Moose damage increased also between the 8th and 9th NFI in young stands in southern Finland (Tomppo and Joensuu 2003). In the 8th NFI (1986–1994), the proportion of at least moderate damage was even less, 21.5% (Yli-Kojola and Nevalainen 2006). However, it is possible that a change in the classification of damage between the 9th and 10th NFI could have increased the accuracy of damage observations, and therefore more damage was found. The classification guidelines as such have not changed between the inventories, but it was possible to register the two most serious injuries per stand in the 10th NFI, whereas only one form of damage could be registered in the 9th and 8th NFIs.

Abiotic factors and fungal diseases seem to be the main threats to the health of Finland's forests also according to the standwise NFI assessments. NFIs produce accurate estimates of forest resources. The standard errors of forest damage estimates can be very large, however (Tomppo and Joensuu 2003). The error is even larger in the 10th NFI. The other weaknesses are related to i) the spatial representativeness of the field plots, ii) the reliability of the field survey, including the observers ability to identify the causes, and iii) the epidemic nature of some forms of damage. The faster rotation in the 10th NFI and the use of permanent plots improve the possibilities for nationwide comparisons. The field team leaders could reliably distinguish at least *Gremmeniella abietina* from other symptoms (Nevalainen 1999) but, on the other hand, in the routine inventory slight infections are easily overlooked. The most important stand damage (in the economic sense) can be recorded reliably in the routine NFI type of inventories. Despite some problems, the NFI's are the only large-scale, representative way to monitor the changes in forest health and disease conditions in the long run.

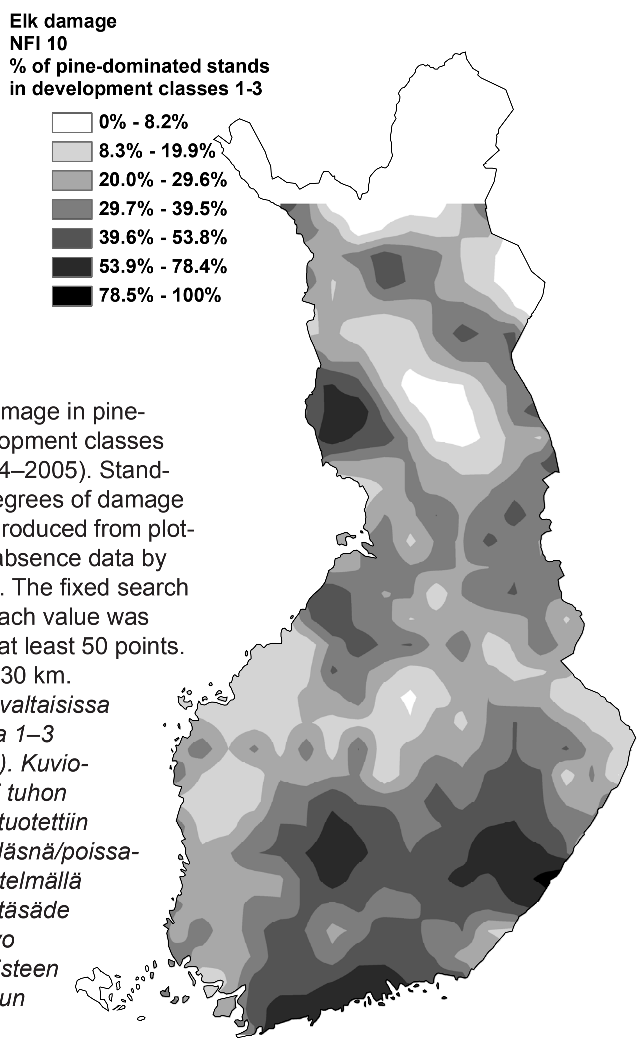

Figure 1. Elk (moose) damage in pine-dominated stands, development classes 1–3, in the 10th NFI (2004–2005). Standwise assessments. All degrees of damage included. The map was produced from plotwise damage presence/absence data by kriging (spherical model). The fixed search radius was 50 km, and each value was calculated as a mean of at least 50 points. The output cell size was 30 km.
Kuva 1. Hirvituhot mäntyvaltaisissa metsissä, kehitysluokissa 1–3 10. VMI:ssä (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Kartta tuotettiin koealakohtaisesta tuhon läsnä/poissaolotiedosta kriging-menetelmällä (pallomalli). Kiinteä etsintäsäde oli 50 km, ja jokainen arvo laskettiin vähintään 50 pisteen keskiarvona. Tulostussolun koko oli 30 km.

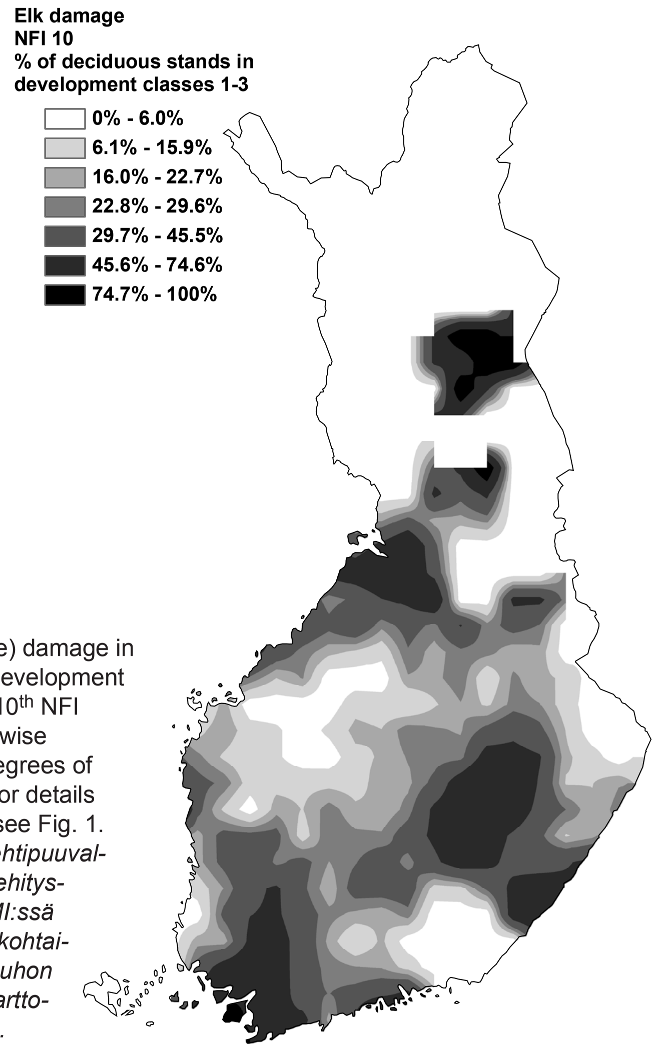

Figure 2. Elk (moose) damage in deciduous stands, development classes 1–3, in the 10th NFI (2004–2005). Standwise assessments. All degrees of damage included. For details of map production, see Fig. 1.
Kuva 2. Hirvituhot lehtipuuvaltaisissa metsissä, kehitysluokissa 1–3 10. VMI:ssä (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Karttojen teko, kts. kuva 1.

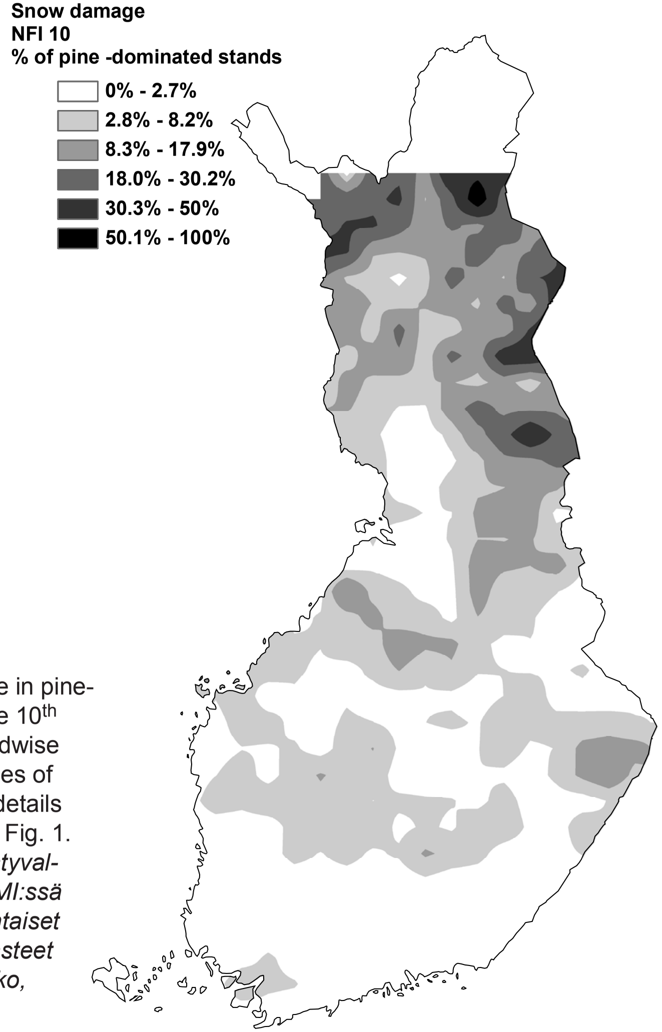

Figure 3. Snow damage in pine-dominated stands in the 10th NFI (2004–2005). Standwise assessments. All degrees of damage included. For details of map production, see Fig. 1.
Kuva 3. Lumituhot mäntyvaltaisissa metsissä 10.VMI:ssä (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Karttojen teko, kts. kuva 1.

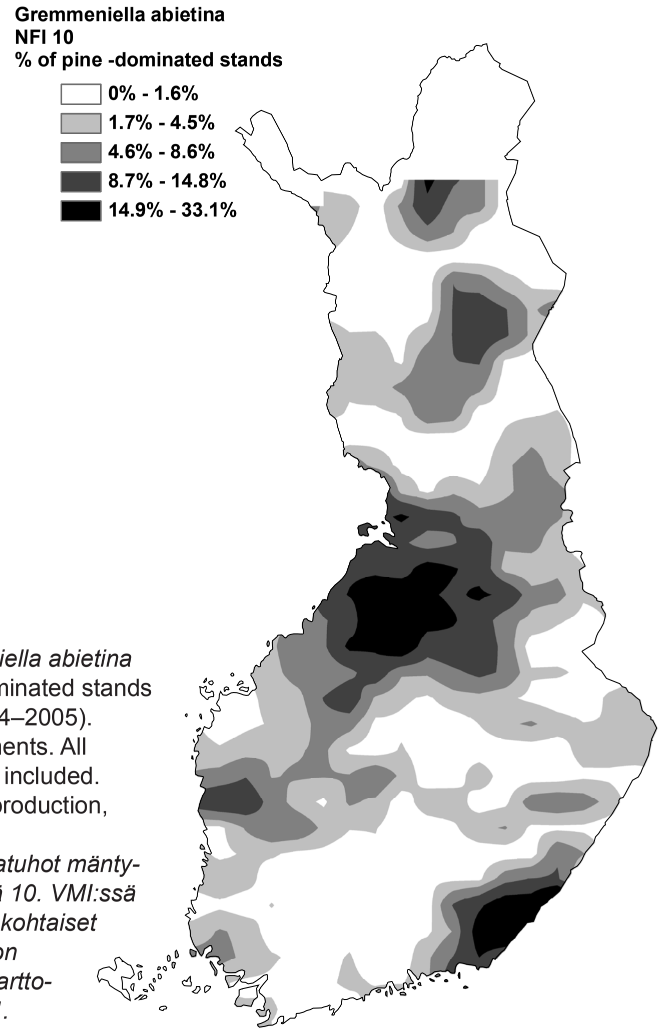

Figure 4. *Gremmeniella abietina* damage in pine-dominated stands in the 10th NFI (2004–2005). Standwise assessments. All degrees of damage included. For details of map production, see Fig. 1.
Kuva 4. Versosurmatuhot mäntyvaltaisissa metsissä 10. VMI:ssä (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Karttojen teko, kts. kuva 1.

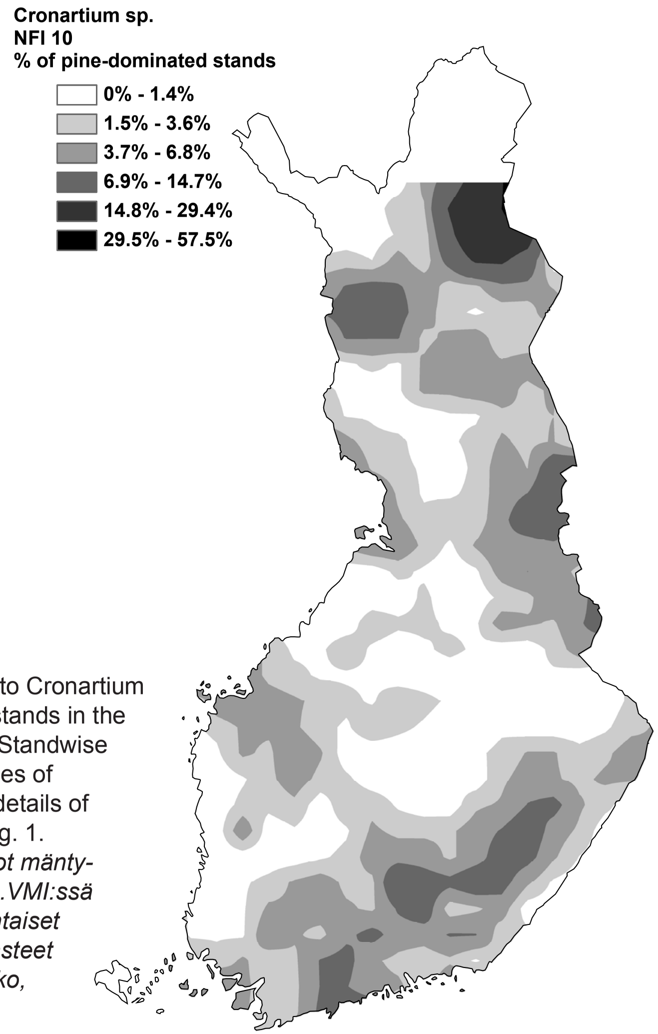

Figure 5. Damage due to Cronartium sp. in pine-dominated stands in the 10th NFI (2004–2005). Standwise assessments. All degrees of damage included. For details of map production, see Fig. 1.
Kuva 5. Tervasrosotuhot mäntyvaltaisissa metsissä 10.VMI:ssä (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Karttojen teko, kts. kuva 1.

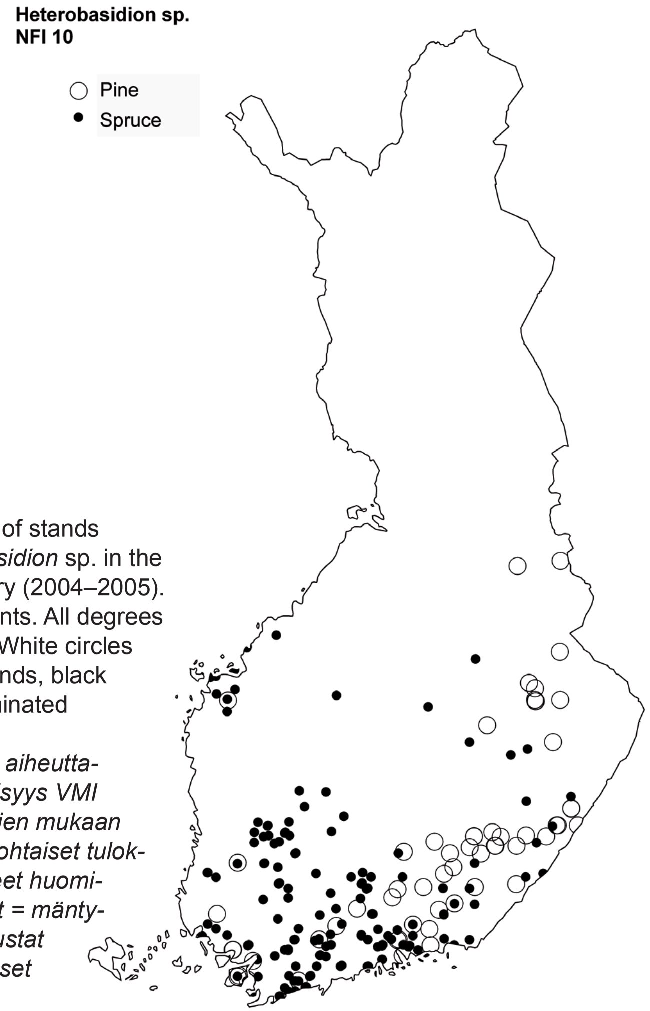

Figure 6. Distribution of stands infected by *Heterobasidion* sp. in the 10th NFI field inventory (2004–2005). Standwise assessments. All degrees of damage included. White circles = pine-dominated stands, black circles = spruce-dominated stands.
Kuva 6. Juurikääpien aiheuttamien tuhojen levinneisyys VMI 10:n maastohavaintojen mukaan (2004–2005). Kuviokohtaiset tulokset. Kaikki tuhon asteet huomioitu. Avoimet ympyrät = mäntyvaltaiset metsiköt, mustat ympyrät = kuusivaltaiset metsiköt.

Table 2. Change in the area (sq. km) and proportion (%) of damage on forest land between the 10th (2004–2005) and 9th NFI (1996–2003), by causal agent and dominant species. Standwise assessments. Mild damage (not affecting the stand quality) excluded.
Taulukko 2. Metsätuhojen pinta-alan ja osuuden muutokset 10. ja 9. VMI:n välillä tuhon aiheuttajan ja vallitsevan puulajin mukaan. Tulos perustuu kuviokohtaisiin arvioihin. Lievät tuhot, jotka eivät alenna metsikön metsänhoidollista laatua, eivät ole mukana.

Agent group *Tuhonaiheuttajaryhmä*	Causal agent *Tuhonaiheuttaja*	Dominant species – *Vallitseva puulaji*								Total – *Yhteensä*	
		Treeless *Puuton*		Pine *Mänty*		Spruce *Kuusi*		Deciduous *Lehtipuut*			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Game and grazing Selkärankaiset	Total – *Yhteensä*	-20	-0.8	2090	1.6	260	0.6	226	1.4	2556	1.3
	Voles – *Myyrät*	0	0.0	-6	0.0	16	0.0	-17	-0.1	-8	0.0
	Elk – Hirvi	-3	-0.1	2013	1.5	259	0.6	155	1.0	2424	1.2
	Other vertebrates – *Muut selkärankaiset*	-17	-0.6	83	0.1	-14	-0.0	88	0.5	140	0.1
Insects – *Hyönteiset*	Total – *Yhteensä*	0	0.0	351	0.3	-28	-0.1	20	0.1	342	0.2
	Tomicus sp. - *Ytimennävertäjät*	0	0.0	124	0.1	0	0.0	8	0.0	132	0.1
	Hylobius abietis – *Tukkimiehentäi*	0	0.0	-3	0.0	-2	0.0	0	0.0	-5	0.0
	Pine sawflies, unspecified – *Mäntypistiäiset yht.*	0	0.0	294	0.2	0	0.0	0	0.0	294	0.2
	Diprion pini – *Pilkkumäntypistiäinen*	0	0.0	-66	-0.1	0	0.0	0	0.0	-66	-0.0
	Neodiprion sertifer – *Ruskomäntypistäinen*	0	0.0	-18	-0.0	0	0.0	0	0.0	-18	-0.0
	Other defoliators – *Muut neulastuholaiset*	0	0.0	-3	0.0	0	0.0	-3	-0.0	-6	0.0
	Ips sp. – *Kirjanpainajat*	0	0.0	0	0.0	5	0.0	9	0.1	14	0.0
	Other identified insect – *Muu tunnistettu hyönteinen*	0	0.0	-36	-0.0	-13	-0.0	9	0.1	-41	-0.0
	Unknown insect – *Tunnistamaton hyönteinen*	0	0.0	59	0.0	-18	-0.0	-3	-0.0	39	0.0
Fungi – Sienet	Total – *Yhteensä*	0	0.0	915	0.7	133	0.4	-468	-2.1	581	0.3
	Heterobasidion – *Juurikäävät*	0	0.0	121	0.1	-119	-0.2	2	0.0	4	0.0
	Other decay fungi – *Muut lahottajasienet*	0	0.0	-292	-0.2	-60	-0.1	-547	-2.5	-899	-0.4
	Gremmeniella abietina – *Versosurma*	0	0.0	1108	0.8	77	0.2	-6	-0.0	1178	0.6
	Melampsora pinitorqua – *Versoruoste*	0	0.0	-339	-0.3	25	0.1	-23	-0.1	-337	-0.2
	Cronartium sp. – *Tervasrosot*	0	0.0	270	0.2	9	0.0	-3	-0.0	277	0.2
	Other rust fungi – *Muut ruostesienet*	0	0.0	-7	-0.0	51	0.1	0	0.0	44	0.0
	Needle cast fungi – *Neulaskaristeet*	0	0.0	-213	-0.2	-28	-0.1	0	0.0	-241	-0.1
	Other identified fungus – *Muu tunnistettu sieni*	0	0.0	167	0.1	27	0.1	6	0.0	200	0.1
	Unknown fungus – *Tunnistamaton sieni*	0	0.0	102	0.1	150	0.3	103	0.6	354	0.2

Table 2. Continues.
Taulukko 2. Jatkuu.

Agent group *Tuhonaiheuttajaryhmä*	Causal agent *Tuhonaiheuttaja*	Dominant species – *Vallitseva puulaji*								Total – *Yhteensä*	
		Treeless *Puuton*		Pine *Mänty*		Spruce *Kuusi*		Deciduous *Lehtipuut*			
		km²	%	km²	%	km²	%	km²	%	km²	%
Abiotic – *Abioottiset*	Total – *Yhteensä*	3	0.1	1230	0.9	619	1.4	27	0.3	1879	1.0
	Wind – *Tuuli*	3	0.1	307	0.2	317	0.7	2	0.0	629	0.3
	Snow – *Lumi*	0	0	1314	1.0	44	0.1	249	1.4	1608	0.8
	Frost – *Halla, pakkanen*	-3	-0.1	5	0.0	-37	-0.1	-18	-0.1	-52	-0.0
	Soil factors – *Maaperätekijät*	0	0	47	0.0	24	0.1	18	0.1	89	0.1
	Other abiotic factors – *Muut abiottiset*	-3	-0.1	-499	-0.4	232	0.5	-214	-1.0	-484	-0.2
Fire – *Tuli*	Forest fire – *Metsäpalo*	5	0.2	56	0.0	39	0.1	-11	-0.1	89	0.1
Man – *Ihmisen toiminta*	Total – *Yhteensä*	0	0.0	-156	-0.1	1	0.0	-34	-0.2	-189	-0.1
	Harvesting – *Puunkorjuu*	0	0.0	-18	-0.0	45	0.1	3	0.0	30	0.0
	Other action of man – *Muu ihmisen toiminta*	0	0.0	-135	-0.1	-38	-0.1	-37	-0.2	-210	-0.1
Air pollution *Ilman epäpuhtaudet*	Total – *Yhteensä*	0	0.0	-3	0	-6	-0.0	0	0.0	-9	0.0
Other *Muut tekijät (mm. kilpailu)*	Total – *Yhteensä*	-3	-0.1	126	0.1	30	0.1	-162	-0.8	-9	0.0
Unknown *Tunnistamaton*	Total – *Yhteensä*	-9	-0.3	-961	-0.7	-492	-0.9	-542	-2.4	-2004	-0.9
Damage total *Tuhot yhteensä*		-29	-1.1	3595	2.7	523	1.5	-933	-3.6	3156	1.8
No/mild damage *Ei tuhoja/lievä tuho*		-94	1.1	-3706	-2.7	-1328	-1.5	236	3.6	-4893	-1.8
Total – *Yhteensä*		-123		-111		-806		-697		-1737	

References

Lyytikäinen-Saarenmaa, P. & Tomppo, E. 2002. Impact of sawfly defoliation on growth of Scots pine Pinus sylvestris (Pinaceae) and associated economic losses. Bulletin of Entomological Research 92(2): 137–140.

Nevalainen, S. 1999. Gremmeniella abietina in Finnish Pinus sylvestris stands in 1986–1992: a study based on the National Forest Inventory. Scandinavian Journal of Forest Research 14(3): 111–120.

Nevalainen, S. 2002. The incidence of Gremmeniella abietina in relation to topography in southern Finland. Silva Fennica 36(2): 459–473.

Tomppo, E. & Joensuu, J. 2003. Hirvieläinten aiheuttamat metsätuhot Etelä-Suomessa Valtakunnan metsien 8. ja 9. inventoinnin mukaan. Metsätieteen aikakauskirja 4: 507–535.

Yli-Kojola, H. & Nevalainen, S. 2006. Metsätuhojen esiintyminen Suomessa 1986–94. Metsätieteen aikakauskirja 1/2006: 97–180.

4.4 Hietajärvi – long-term results from a Finnish ICP Integrated Monitoring (IM) catchment

Hietajärvi – pitkäaikaisen seurannan tuloksia ICP Yhdennetyn ympäristön seurannan (YYS) valuma-alueelta

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We describe and present some of the results gained from the Integrated Monitoring activities at the Hietajärvi catchment in eastern Finland. Besides the collection of long-term monitoring datasets used to validate the effectiveness of international agreements concerning emissions of sulphur, nitrogen and heavy metals on the environment, the data has been used in numerous dynamic modelling exercises to indicate impacts of air pollution abatement policy and ecosystem recovery into the future. The data is increasingly being used to assess the impacts of climate change on carbon cycling in catchments located in the boreal zone. Results concerning all these aspects are presented, demonstrating the value of long-term, multi-disciplinary, integrated monitoring programmes.

Artikkelissa esitämme tuloksia Itä-Suomessa sijaitsevalta Hietajärven valuma-alueelta, joka kuuluu Ympäristön yhdennetyn seurannan (YYS) havaintoaloihin. Alueelta on kerätty seuranta-aineistoa, jonka avulla voidaan arvioida kansainvälisten rikki-, typpi- ja raskasmetallipäästöjen rajoittamista koskevien sopimusten toteutumisen vaikutusta. Tämän lisäksi aineistoa on hyödynnetty lukuisissa mallinnustehtävissä, joiden tarkoituksena on ollut kuvata päästöjen vähentämistoimien vaikutuksia ja ekosysteemin toipumiskehitystä. Aineistoa käytetään yhä enemmän myös arvioitaessa ilmastomuutoksen vaikutuksia valuma-alueiden hiilen kiertoon boreaalisessa vyöhykkeessä. Tulokset osoittavat pitkäaikaisen ja monitieteisen yhdennetyn seurannan tärkeyden.

Introduction

The International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM, www.environment.fi/syke/im), like the ICP Forests programme, is part of the Effects Monitoring Strategy under the Convention on Long-range Transboundary Air Pollution (LRTAP, www.unece.org/env/lrtap). In Finland, the ICP IM programme was started in 1987 at four catchments: Valkea-Kotinen (southern Finland), Hietajärvi (eastern Finland), Pesosjärvi (north-eastern Finland) and Vuoskojärvi (Lapland). ICP IM activities at Pallas (Lapland) are currently being set up. Since 1999, the terrestrial ICP IM programme carried out on the intensive permanent monitoring plots in Hietajärvi and Valkea-Kotinen catchments has been integrated into the ICP Forests/EU Forest Focus Intensive Monitoring (Level II) programme, and monitoring activities at the two northernmost sites has been reduced.

In celebration of nearly twenty years of ICP IM activities, we present some of our results from the Hietajärvi catchment (see also Niinioja and Rämö 2006). Particular attention is given to the deposition of acidity (sulphate) and heavy metals, their impacts on soils and surface water (lake), and to our modelling activities concerning the impacts of climate change on the water and carbon balances.

The ICP IM Programme

Integrated monitoring of ecosystems means the physical, chemical and biological measurements over time of different ecosystem compartments simultaneously at the same location. In practice, monitoring is divided into a number of compartmental subprogrammes that are linked by the use of the same parameters (cross-media flux approach) and/or same or close stations (cause-effect approach).

The main objectives of the ICP IM are:
• To monitor the biological, chemical and physical state of ecosystems (catchments/plots) over time in order to provide an explanation of changes in terms of causative environmental factors, including natural changes, air pollution and climate change, with the aim to provide a scientific basis for emission control.
• To develop and validate models for the simulation of ecosystem responses.
• To carry out biomonitoring to detect natural changes, in particular to assess effects of air pollutants and climate change.

The ICP IM sites (mostly forested catchments) are located in undisturbed areas, such as natural parks or comparable areas. The ICP IM network presently covers about 50 sites in 19 countries. The international Programme Centre is located at the Finnish Environment Institute in Helsinki. A manual (available at: www.environment.fi/syke/im) detailing the protocols for monitoring each of the necessary physical, chemical and biological parameters are applied throughout the programme.

The Finnish ICP IM programme is coordinated by an expert group consisting of scientists from the key participating institutes (Finnish Meteorological Institute, Finnish Forest Research Institute, Finnish Environment Institute, and Finnish Geological Survey) and the University of Helsinki. The key Finnish research institutes, several regional authorities and universities involved in environmental research have participated in the ICP IM Programme and have made considerable contributions.

The Hietajärvi IM catchment

The Hietajärvi catchment is located in the Patvinsuo National Park in eastern Finland (63° 10’ N, 30° 43’ E). It can be considered remote and is unaffected by local sources of air pollution. The catchment covers an area of 464 ha and has a range in relief of 49 m (Fig. 1). Typical of Finnish headwater catchments, there are areas of upland (41% of catchment area), peatland (32%), and a number of lakes and small, isolated ponds (27%). Most of the terrestrial monitoring has been carried out at ten permanent plots, the intensive paired plots (1 and 9, and 4 and 10) in particular. Plots 4 and 10 constitute the ICP-Forests/EU Forest Focus intensive monitoring level II plot 20.

Surface (quaternary) deposits consist of till (permanent plots 2 and 6), varying in thickness up to 15 m (mean 5.6 m), overlying ancient (ca. 2.7 billion-years-old) magmatic, mainly porphyritic granodiorite, bedrock. In some areas, the till is covered by a thin layer of sorted fine sand (permanent plots 1, 4, 5, 9 and 10). The soils in the upland area are predominately shallow (ca. 0.5 m) podzols. These soils started to develop some 10,200 years ago, when the area became deglaciated and

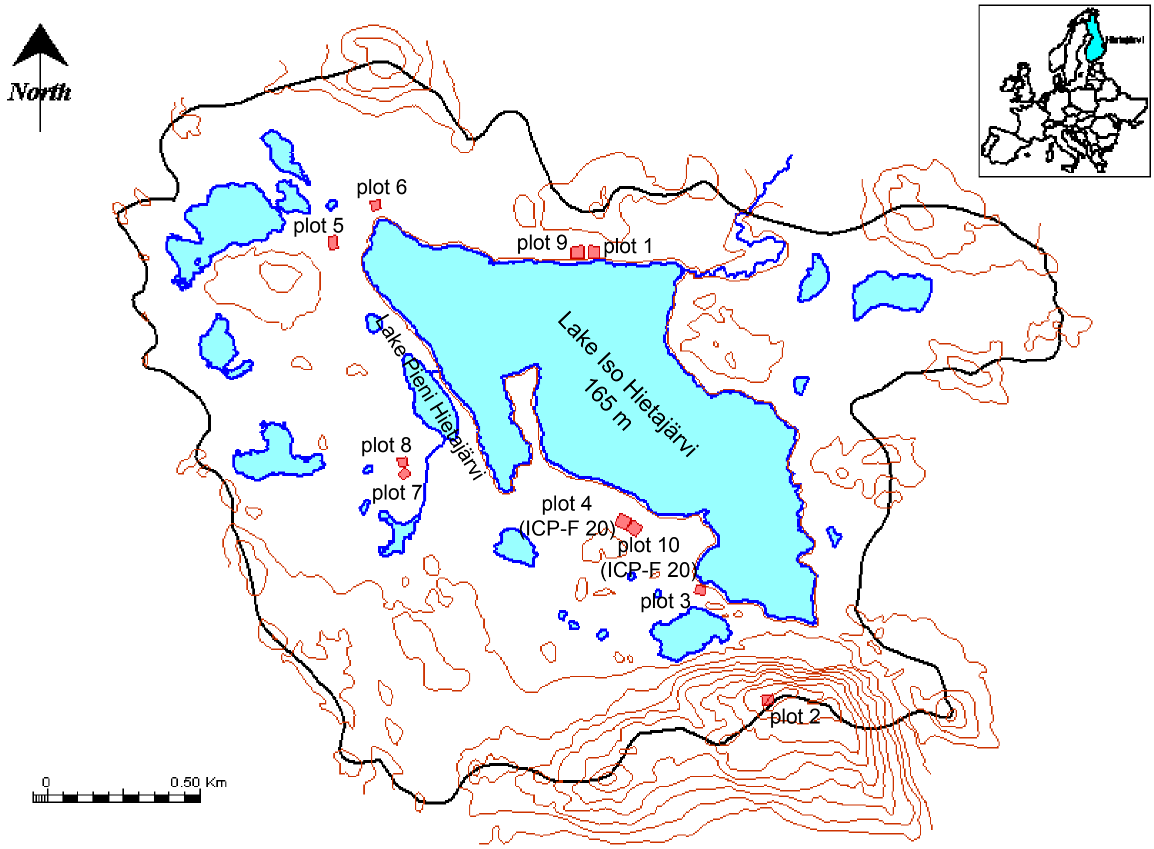

Figure 1. Map of the Hietajärvi catchment showing the location of the lakes, ponds and permanent monitoring plots.
Kuva 1. Järvien, lampien ja pysyvien seuranta-alojen sijainti Hietajärven valuma-alueella.

exposed to weathering processes and colonized by vegetation. In the lower lying areas, the soil is seasonally waterlogged, giving rise to gleyic properties. The riparian areas, surrounding the lakes and ponds, are peat covered (permanent plots 3, 7 and 8), mainly ombro-oligotrophic open bog. In the southeast corner of the catchment is a small area of exposed bedrock. The two main lakes, Iso Hietajärvi (83 ha) and Pieni Hietajärvi (2.4 ha), are shallow, the mean depth being 3.5 m. Runoff from the catchment is via Hietapuro, a small stream that flows northwards from lake Iso Hietajärvi.

The forest cover consists of a mosaic of 100–200-year-old fire regenerated Scots pine (*Pinus sylvestris* L.) stands, with Norway spruce, birch and aspen trees occurring, and submesic heath ground vegetation. The last major forest fires occurred some 150 years ago and the forests have been protected from management, slash and burn cultivation and tar production since the beginning of the last century. Pine also grows around the margins of the peatland areas.

The average annual effective (threshold +5°C) temperature sum is 1000–1028 °C, the annual mean air temperature +2.0°C, and precipitation averages 592 mm per year, of which about 30% falls as snow during the period November–March.

Deposition of acidity and heavy metals

Bulk deposition in open

The monitoring of air quality and deposition started in 1987. Hietajärvi is situated in a background area, without nearby sources of air pollution. Most of the deposition has been transported long distances and from beyond Finland. The air masses reaching Hietajärvi are mostly from the south-west, west, north-west and north directions. Climatological data from nearby meteorological stations have also been used in modelling exercises and in evaluating IM data.

The acidity and associated concentrations of sulphate in precipitation have strongly declined over the period of monitoring (Fig. 2), reflecting the reduction in SO_2 emissions that have occurred in Finland and throughout Europe. The reduction in sulphate concentrations has been the greatest in the south (Virolahti and Evo sites) and the least in the north (Oulanka and Kevo sites).

Ammonium concentrations in precipitation have declined similarly as those of sulphate (Ruoho-Airola et al. 1998, 2004, Waldén 2002). Concentrations of nitrate, however, have declined much more slowly, and changed little in recent years. The same trend in the concentrations of gaseous and particulate nitrate components is also evident at other monitoring stations in Finland.

Heavy metal deposition has been monitored at Hietajärvi since 1990, and forms one of the longest time series in Finland. The deposition load of heavy metals has decreased, particularly that of lead (Pb), which is clearly related to the replacement of leaded with unleaded petrol. Unfortunately, a favourable development cannot be seen for all heavy metals. For example, concentrations of cadmium (Cd) in precipitation have not declined significantly during the 15 years of monitoring; the annual load fluctuating between 15 and 30 mg m^{-2}.

Canopy interactions and throughfall

Because of the reactivity and large surface area of the canopy, forests are particularly effective receptors of airborne material arriving in both wet and dry forms. Thus, precipitation is intercepted and modified (substances withdrawn or added) by the canopy, and the loads of substances reaching

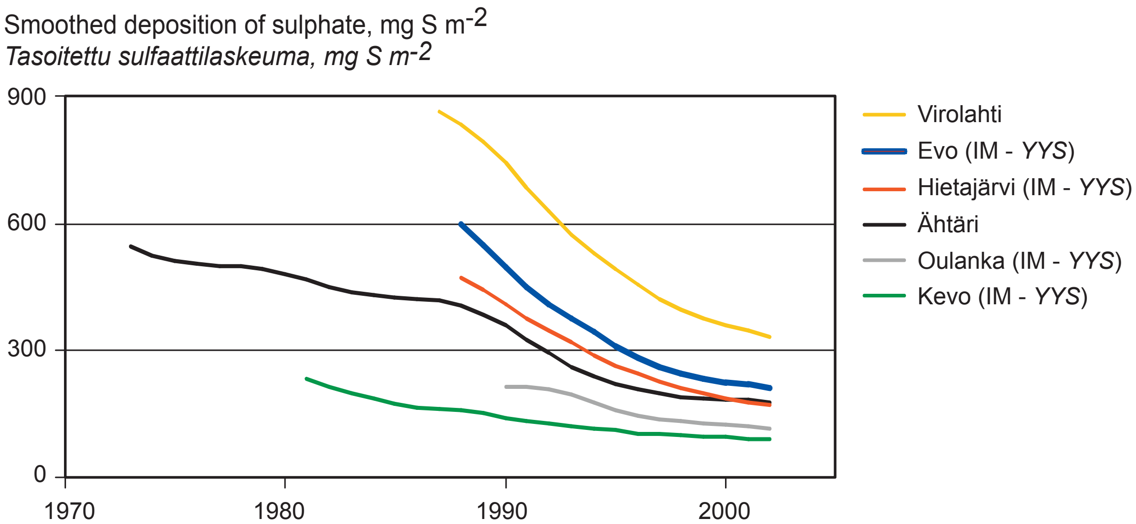

Figure 2. Trends in sulphate deposition at various monitoring stations in Finland.
Kuva 2. Sulfaattilaskeuman kehitys Hietajärvellä ja eräillä muilla Suomen tausta-asemilla.

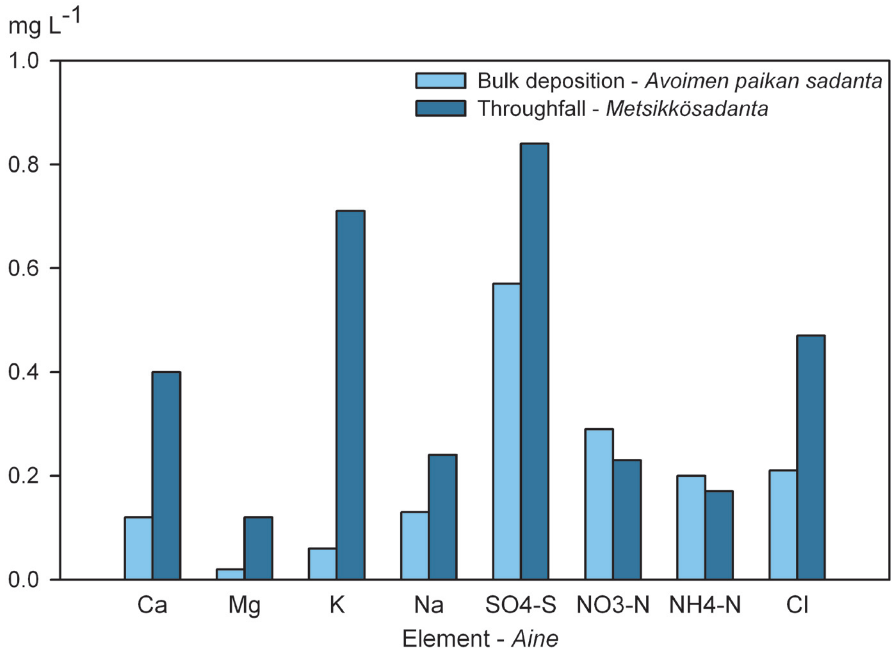

Figure 3. Solute concentrations in bulk precipitation and throughfall at Hietajärvi during 1989–1997 (Ukonmaanaho and Starr 2002).
Kuva 3. Avoimen paikan ja metsikkösadannan eri aineiden pitoisuudet 1989–1997 Hietajärvellä (Ukonmaanaho ja Starr 2002).

the forest floor, termed throughfall, differs from the bulk deposition recorded in the open (see previous section). We have monitored acidifying and eutrophicating compounds, base cations, chloride and dissolved organic carbon in throughfall at two permanent plots (plots 1 and 4) from 1989 (Ukonmaanaho et al. 1998a, Ukonmaanaho and Starr 2002, Starr and Ukonmaanaho 2004). From 2000, this monitoring has continued only at plot 4. Mean (1989–1997) concentrations for various solutes in throughfall compared to bulk deposition are presented in Fig. 3.

Concentrations of base cations (Ca, Mg, K and Na), SO_4 and Cl ions are higher in throughfall than in open area bulk deposition, while concentrations of inorganic nitrogen compounds, NO_3 and NH_4, in throughfall are less than in open area bulk deposition. Enrichment of throughfall is due to the washing-off of dry deposition intercepted by the canopy or by canopy (tissue) leaching, while depletion is due to canopy uptake, either by foliage or canopy dwelling epiphytes.

As with bulk deposition, throughfall has shown a marked decline in acidity over the monitoring period, with concentrations of sulphate declining by an average of 0.09 mg S L^{-1} yr^{-1} and acidity by 2.1 µmol H^+ L^{-1} yr (Ukonmaanaho and Starr 2002). The acidifying potential of deposition resulting from human activity is best described by its acid neutralizing capacity (ANC), the difference between the sum of base cations (Ca, Mg, K and Na) and strong mineral acid anions (Cl, SO_4 and NO_3) on an equivalent basis. The ANC of throughfall at Hietajärvi has increased over the monitoring period (Ukonmaanaho and Starr 2002). This indicates that the current anthropogenic acid deposition load is decreasing. However, there has only been a slight decline in total nitrogen concentrations (0.07 mg L^{-1} yr^{-1}) in throughfall at Hietajärvi.

Groundwater

Groundwater quality at Hietajärvi has been monitored since 1993. Water samples have been taken from five observation wells and from the Hietapuro stream. The groundwater is shallow and has a short retention time. Depending on the distance from lake Iso Hietajärvi and morphology, groundwater levels in the monitoring wells vary from 1 to 6 m depth.

The quality of groundwater has been rather stable over the monitoring period, but seasonal variation can clearly be seen. It is slightly acidic, with low titratable alkalinity and solute concentrations. This is due to the short retention time of water in the unsaturated zone. As with deposition, sulphate concentrations in the groundwater at Hietajärvi are decreasing (Fig. 4), but this trend, which is also seen in groundwater throughout southern Finland (Backman 2004), only started in 1998. The delay in the recovery of the groundwater presumably reflects the "memory" of acid deposition in the system. Trace metal concentrations are very low; usually below analytical detection limits.

Soil conditions

The soils in the Hietajärvi catchment have been surveyed, mapped, and sampled for chemical analysis. For monitoring purposes, the soil at seven of the permanent monitoring plots has been sampled and analysed according to the IM programme on three (some plots, 4) occasions (Starr and Ukonmaanaho 2001).

Acidification and weathering

Some chemical properties of the soil at four of the upland permanent monitoring plots that are particularly relevant to soil acidification are summarized in Table 1.

The cation exchange capacity (CEC) of the soil in the 5–20 cm and 20–40 cm layers is close to or below the critical value of 5 $mmol_{(+)}\ kg^{-1}$. This indicates that the soils are potentially sensitive to

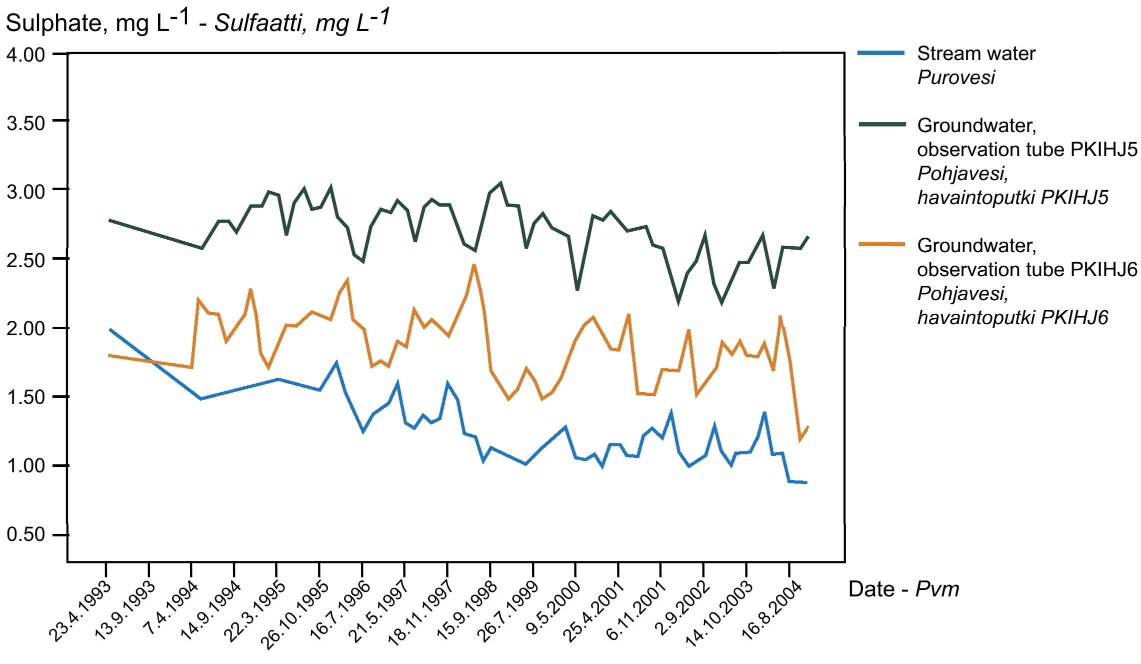

Figure 4. Sulphate concentrations in groundwater at Hietajärvi during 1993–2004. The ground water level in tube PKIHJ5 is at about 6 m depth and that at tube PKIHJ6 about 2 m depth.
Kuva 4. Pohjaveden sulfaattipitoisuus Hietajärvellä vuosina 1993–2004. Pohjavedenpinta on havainto-putkessa PKIHJ5 noin 6 m ja PKIHJ6 noin 2 m syvyydessä.

Table 1. Selected soil properties by depth at Hietajärvi (values are average of four permanent upland plots) (after Starr and Ukonmaanaho 2001).
Taulukko 1. Maaperän tunnuslukuja eri syvyyksistä Hietajärvellä (arvot ovat pysyvien metsämaa-alojen keskiarvoja) (Starr ja Ukonmaanaho 2001).

Layer *Kerros* cm	pH (in H_2O)	Cation exchange capacity *Kationin vaihtokapasiteetti* mmol(+) kg^{-1}	Base saturation *Emäskyllästysaste* %	Total carbon *Kokonaishiili* %	Clay *Savi* %
Humus	3.6	228	74	48.4	-
0–5	4.5	12	22	1.2	1
5–20	5.3	5	35	0.9	3
20–40	5.7	2	48	0.2	2

acidic deposition and have little buffering capacity against acid deposition. The low CEC values are due to the low clay and organic matter contents of the soils at Hietajärvi. However, soil pH values remain >5.0 and base saturation (BS, the fraction of CEC occupied by the sum of base cations) is >15%, indicating that soil acidification has not reached the level at which aluminium and heavy metals are released to soil solution in toxic concentrations.

Chemical weathering consumes (neutralizes) acidity (H^+ ions) and releases cations, including base cations (Ca, Mg and K), to the soil solution. Weathering is therefore an important acid neutralizing process, and central to the calculation of critical loads of acidity. We have determined the weathering release of Ca in the soils at Hietajärvi to be 0.4–1.6 g m^{-2} yr^{-1} and that of Mg to be 0.2–0.5 g m^{-2} yr^{-1} (Starr et al. 1998b). The combined release of Ca and Mg through weathering corresponds to an acid (H^+) consumption of 28 $mmol_{(+)}$ m^{-2} yr^{-1}. The bulk deposition load of sulphate-related acidity during the 1990s averaged some 21 mmol H^+ m^{-2} yr^{-1} (Ruoho-Airola 1995). Weathering was thus able to neutralize the acid rain load, preventing further acidification of the soil.

Modelled estimates of stand growth indicate that the forests at Hietajärvi are at, or near, steady-state (Starr et al. 1998a), as could be expected for old-growth forests. Nutrient cycling would, therefore, also tend to be in steady-state, with the uptake of base cations from the soil being balanced by inputs to the soil from foliar leaching and litterfall. Plot-scale mass balance budgets for major plant nutrients showed that leaching losses of base cations from the rooting zone were greater than total deposition inputs (Ukonmaanaho and Starr 2002). This could be expected to result in the depletion of exchangeable base cations stocks and decrease the base saturation of the soil. However, the production of base cations through weathering, as described earlier, would tend to compensate for such losses.

In conclusion, acid deposition inputs and biomass accumulation during the monitoring period have resulted in little further acidification of the soils at Hietajärvi. Since deposition loads of sulphate have declined, levels of soil acidification can be expected to decline and for base saturation to increase in the future, as dynamic acidification modelling has indicated (see section Modelling the future).

Carbon stocks and fluxes

Carbon densities in the upland soils to a depth of 30 cm vary from 3.3 to 4.9 kg m^{-2}, depending on the type of quaternary deposit, and that of the peat to the same depth averages 13.4 kg m^{-2} (Fig. 5).

Provisional estimates of C stocks (Gg) in the forest biomass, soil (upland plus peat to 30 cm depth), lake water, and lake-bottom sediment compartments for the entire catchment are: 17.3 (22%), 28.4 (36%), 0.014 (<0%), and 33.2 (42%), respectively (Starr et al. 2005, 2006). The corresponding stocks (Mg) of N were: 51 (1%), 652 (17%), 0.6 (<0%), and 3154 (82%). Therefore, and perhaps surprisingly, lake-bottom sediments are a major stock of both C and N in the landscape.

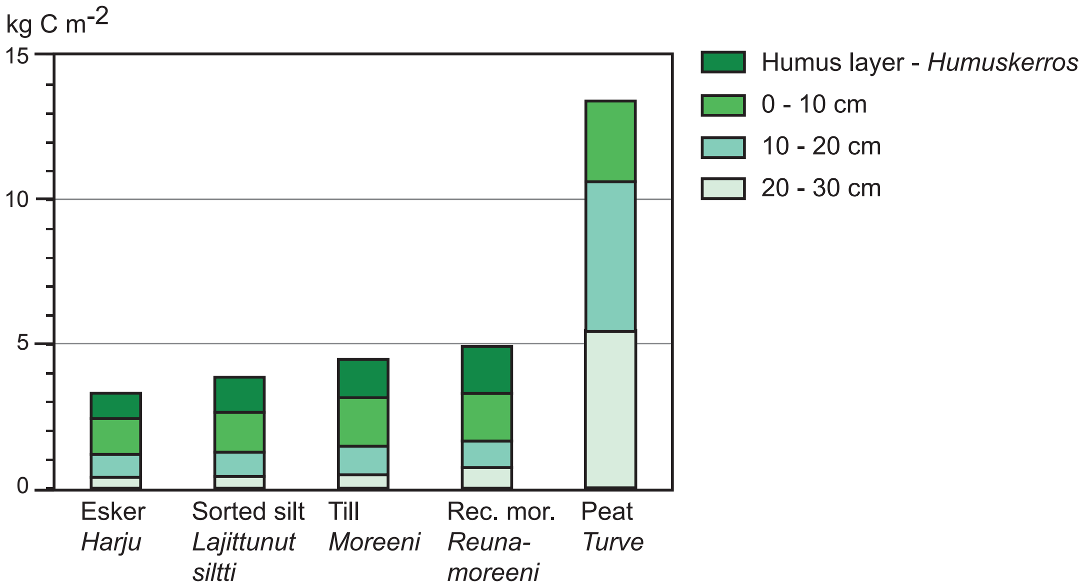

Figure 5. Carbon density of soil in the Hietajärvi catchment according to soil type and depth (Starr and Hartman 2003).
Kuva 5. Hiilen tiheys Hietajärven valuma-alueella eri maaperätyypeissä ja syvyyksissä (Starr ja Hartman 2003).

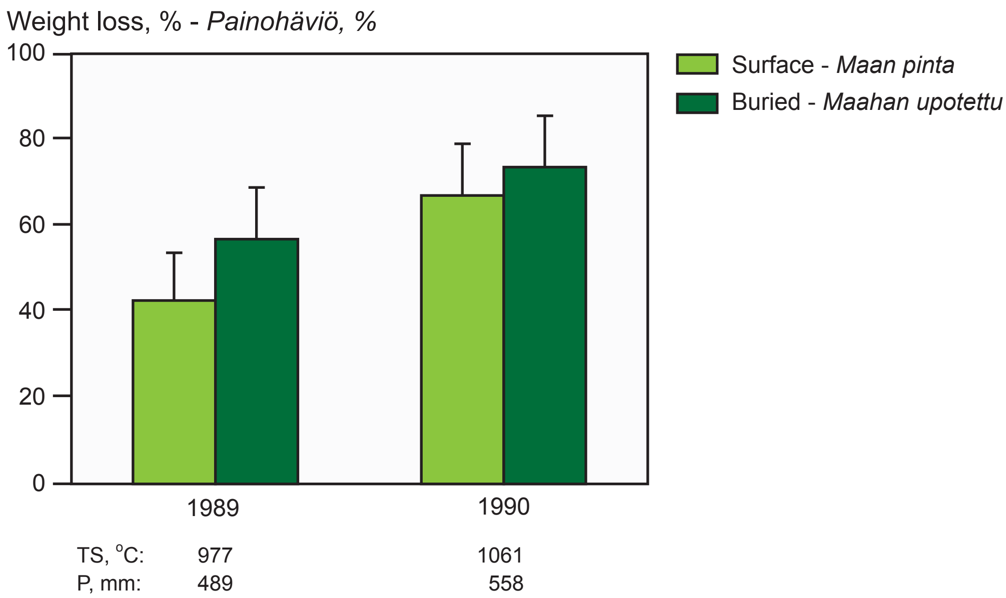

Figure 6. Decomposition (% weight loss after one year) of cellulose strips placed on the surface and buried in the humus layer for 1989 and 1990 (mean from 6 plots). The values below are the effective (threshold +5°C) temperature sum (TS) and amount of precipitation (P) for the two years (Kurka and Starr 1997).
Kuva 6. Vuosina 1989 ja 1990 pintaan ja humuskerrokseen asetettujen selluloosaliuskojen hajoaminen (painohäviö %:na yhden vuoden jälkeen) Hietajärvellä (kuuden koealan keskiarvo). Kuvan alareunassa efektiivinen lämpösumma (TS) (>5 °C) ja sademäärä (P) kahden vuoden aikana (Kurka ja Starr 1997).

Soil CO_2, efflux (respiration) measurements have not been made at Hietajärvi, but the rate of organic matter decomposition has been indicated using the litterbag method. Small strips of cellulose (coniferous wood pulp) and Scots pine or Norway spruce needles placed in netting bags have been laid out on, or buried in, the soil at the permanent monitoring plots and their loss in weight after 1, 2 or more years has been determined. Some results concerning the weight loss of cellulose are shown in Fig. 6.

The results show that buried organic matter decomposes faster than that on the surface and that decomposition varies considerably from year to year due to differing weather conditions. Variability within the catchment (between plots) has been shown to be related to differences in stand structure, which affects micro-climate, and the chemical properties of the humus layer (Kurka and Starr 1997, Kurka et al. 2000, 2001).

Annual leaching fluxes of dissolved organic carbon (DOC) have been calculated from concentrations measured in soil water and modelled estimates of the hydrologic flux (Starr and Ukonmaanaho 2004). The DOC fluxes at 40 cm depth at two of the permanent monitoring plots compared to throughfall fluxes are shown in Fig. 7. It is seen that leaching fluxes average 2 g C m^{-2}, and are about half that of the throughfall flux. The annual flux of carbon to the forest floor associated with litterfall is, however, much greater, being about 70 g C m^{-2}.

Surface water quality and biology

Surface water quality

Continuous measurement of runoff and regular monitoring of physicochemical properties of surface waters in the Hietajärvi catchment started in 1988. The intensive monitoring of key chemical parameters in the two study lakes (Iso Hietajärvi and Pieni Hietajärvi) and in the inlet and outlet streams (Kelopuro and Hietapuro, respectively) includes: pH, alkalinity, major cations

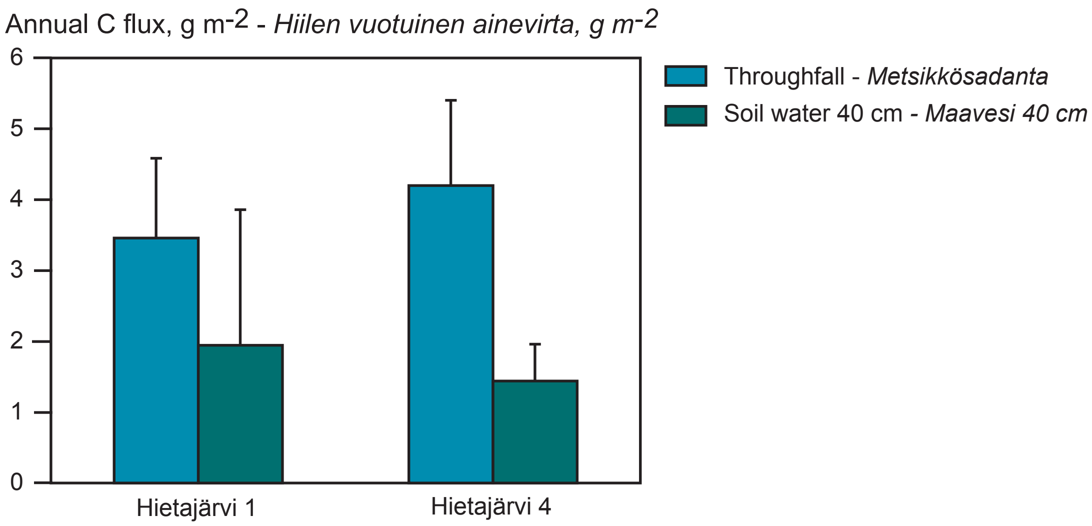

Figure 7. Annual mean (1991–1997) throughfall and soil leaching (at 40 cm) fluxes of DOC at Hietajärvi plots 1 and 4. (Starr and Ukonmaanaho 2004).
Kuva 7. Vuosittainen (1991–1997) liuenneen orgaanisen hiilen (DOC) metsikkösadanta- ja maavesivirrat Hietajärven havaintoaloilla 1 ja 4 (Starr ja Ukonmaanaho 2004).

and anions, phosphorus (P) and N, DOC (TOC) and TIC, and heavy metals. Measurements of temperature and oxygen conditions are also conducted.

Iso Hietajärvi is an oligotrophic lake (mean total P concentration is 6.1 mg L^{-1}, chlorophyll-a 2.4 µg L^{-1}) with clear water (mean water colour 20 mg Pt L^{-1}) (Niinioja et al. 2002, 2003). The median pH is 6.55 (range 5.9–7.3), indicating neutral or only weak acidic conditions. Although the lake can be considered sensitive to acidification because of its low buffering capacity (mean alkalinity 0.08 mmol L^{-1}), severe acidification due to acid deposition has not taken place.

Pieni Hietajärvi, which drains into Iso Hietajärvi, is a mesotrophic humic lake (mean total P 13 mg L^{-1}, chlorophyll-a 4.0 µg L^{-1} and mean water colour 120 mg Pt L^{-1}). Unlike Iso Hietajärvi, it is completely surrounded by peatland. The median pH is 5.85 (range 4.9–6.9), indicating moderate acid conditions. During the high flow periods in spring and autumn, the pH-value in Kelopuro (inlet stream of Pieni Hietajärvi) may drop episodically to below 5 due to inputs of acidic snowmelt waters and natural organic acids derived from the surrounding peat soils. However, there are no signs of chronic acidification in Pieni Hietajärvi.

Almost 20 years of monitoring records show improving water quality in the Hietajärvi catchment. Along with decreased acid deposition (see section Deposition of acidity and heavy metals), lake and stream water sulphate concentrations are decreasing and alkalinity and pH are increasing (Fig. 8).

The mean annual (1988–2003) runoff of Hietapuro is 11.7 l s^{-1} km-2 (370 mm) (Höytämö et al. 2004). The average leaching of phosphorus in the catchment is about 2 kg km^{-2} yr^{-1}, which is low compared to other undisturbed small forested catchments in Finland (Niinioja et al. 2004).

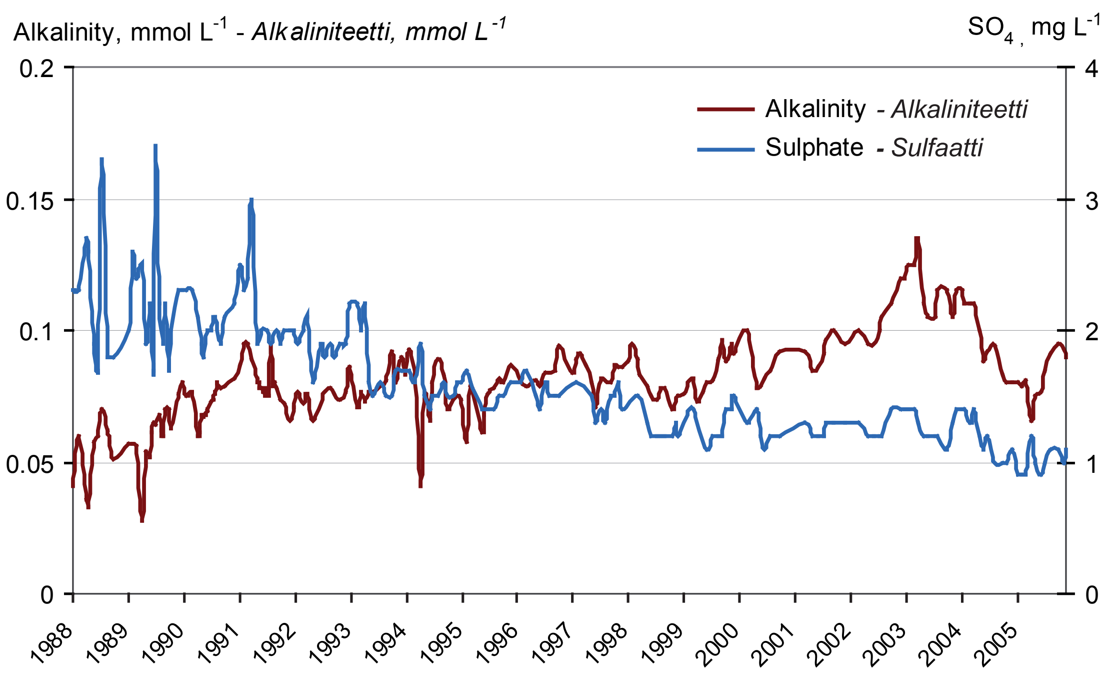

Figure 8. Alkalinity and sulphate concentrations in lake water from Iso Hietajärvi during 1988–2005.
Kuva 8. Ison Hietajärven alkaliniteetti ja sulfaattipitoisuus vuosina 1988–2005.

Biological Changes

Aquatic biota, such as algae, macroinvertebrates and fish, are sensitive indicators of environmental change, reflecting changes in the physical and chemical conditions of the aquatic ecosystem. Iso Hietajärvi is an important national reference lake in hydro-biological and chemical studies, since there are no direct human impacts on the biota and water quality.

Phytoplankton

The monitoring of phytoplankton in Iso Hietajärvi started in 1990. The algal community is dominated by Cryptophyceans, Chrysophyceans and Chlorophyceans, and flagellates of these groups are abundant (Holopainen et al. 2003). The abundance of diatoms and blue-green algae is low in Iso Hietajärvi, but the algal community is characteristic of Finnish oligotrophic, clear water lakes, as is the small inter-annual variation in phytoplankton biomass and species composition. Nevertheless, variation over the sixteen year monitoring period can be seen, and related to variations in precipitation (runoff), nutrient status, light condition (water colour) and acidity (pH) of the water.

Aquatic macroinvertebrates

There were no observable time-trends in numerical abundance or taxa richness of benthic invertebrates over the studied period 1990–2001 (Hämäläinen et al. 2003). Inter-annual density and richness variation in the two depth-zones studied showed different patterns, but no correlations were found between abundance or taxa richness and environmental variables. However, the community dissimilarity between consecutive years showed a positive correlation with the North Atlantic Oscillation (NAO) index of the intervening winter. This suggests that significant community changes between consecutive years are associated with mild winters with high precipitation (Hämäläinen et al. 2003).

Fish

Fish catches in Iso Hietajärvi has been carried out in 1988, 1994 and 2001 in order to monitor the fish community (Rask et al. 1998, Tammi et al. 2004). The species-poor fish community of Iso Hietajärvi is typical of small, oligotrophic, clear water lakes in south Finland. The most abundant species are perch and roach, but pike, ruffe and bleak are present. The high perch population, with numerous large individuals, is characteristic of forest lakes in the natural state. No appreciable changes in the fish community have occurred over the 13-year monitoring period. The successful stocks of acid-sensitive cyprinids in Iso Hietajärvi indicate that the fish community has not been affected by acidifying deposition. Based on EU Water Framework Directive criterion, the ecological status of Iso Hietajärvi can be considered excellent.

Mass balance budgets

The comparison of inputs and outputs (fluxes) of a substance (element, solute or water) for a defined compartment or compartments in the landscape (e.g. forest stand, soil, lake, catchment) is a particularly useful biogeochemical tool. Since the sum of inputs must balance the sum of outputs plus any changes in storage, fluxes that are not measured, or difficult to do so, can be estimated;

measured fluxes can be independently checked; compartments in which there is retention (or loss) can be identified or when they will reach capacity (or be depleted) can be determined; and the importance of various biogeochemical processes (e.g. deposition, soil leaching, uptake and accumulation in biomass, assimilation in soil microbes, adsorption/desorption by soil or sediment, organic matter decomposition, mineral weathering) operating can be assessed and evaluated. Mass balances are thus a simple and informative way of distilling and synthesizing a great deal of biogeochemical data.

Mass balance budgets for acidity (H^+ ions), heavy metals and major nutrients, both at the plot- and catchment-scales, have been calculated for Hietajärvi (Forsius et al. 1995, 2005, Ukonmaanaho et al. 2001, Ukonmaanaho and Starr 2002). We are currently working on catchment-scale budgets for carbon and nitrogen (Starr et al. 2005).

Budgets for some major nutrients

Simple input-output budgets for the forest-soil (ecosystem) system and for the soil-only system are summarized in Table 2. For the ecosystem budget, the input is total deposition (wet + dry deposition) while that for the soil, is the sum of throughfall and litterfall, i.e. external inputs (deposition) plus internal inputs (recycling nutrients). The output for both systems is the leaching flux at 40 cm depth.

Considering the deposition–soil (ecosystem) system first, deposition inputs are greater than leaching losses in the cases of nitrogen (N) and sulphur (S), indicating that the stores of these elements are increasing in the ecosystem (stand or soil). Inputs of N are actually greater, because

Table 2. Mean annual (1989–1997) element budgets for the Deposition–Soil system and for the Deposition–Litterfall–Soil system at Hietajärvi (mean of permanent plots 1 and 4) (Ukonmaanaho and Starr 2002).
Taulukko 2. Näytealakohtainen ravinnetase (1989–1997) Hietajärven valuma-alueella, pysyvien havainto-alojen 1 ja 4 keskiarvo (Ukonmaanaho ja Starr 2002).

	Ca	Mg	K	N	S
	mg m^{-2} yr^{-1}				
Deposition–Soil – *Laskeuma–maaperä*					
Inputs, TD = Total deposition[a] – *Kokonaislaskeuma*[a]	75	16	41	320[b]	376[c]
Outputs, SW = Leaching – *Maavesi*	152	51	103	12[b]	125[c]
Balance (= ∆storage = TD–SW)					
Tasapaino (= ∆varasto =TD–SW)	–77	–35	–62	308	251
Deposition–Litterfall–Soil – *Laskeuma–Karikesato–Maaperä*					
Inputs 1, TF = Throughfall – *Metsikkösadanta*	137	40	216	225[b]	376[c]
Inputs 2, LF = Litterfall – *Karikesato*	600	90	145	725	74
Inputs combined (= TF+LF) – *Yhdistetty input (= TF+LF)*	737	130	361	950	450
Outputs, SW = Leaching – *Maavesi*	152	51	103	12[b]	125[c]
Balance (= ∆storage = TF+LF–SW)					
– *Tasapaino (=∆varasto =TF+LF–SW)*	585	79	258	938	325

[a] Total deposition calculated from bulk deposition and throughfall measurements assuming SO_4 is conservative (Ukonmaanaho and Starr 2002). – *Kokonaislaskeuma laskettu olettaen, että metsikkösadannasta saatava sulfaatti edustaa ns. kuivalaskeumaa (Ukonmaanaho ja Starr 2002).*
[b] Inorganic N – *Epäorgaaninen N*
[c] Sulphate-S – *Sulfaatti-S*

N-fixation inputs are not included. Nitrogen is generally limiting in boreal forest ecosystems and, in undisturbed systems, is strongly retained. For base cations, however, deposition inputs are less than leaching outputs, suggesting that ecosystem stores of these elements are being depleted. But, as discussed earlier (section Acidification and weathering), weathering is an important internal source of base cations. Thus, even though the leaching outputs are greater than deposition inputs, stocks of exchangeable base cations may not necessarily be declining.

Inputs of N, S and base cations to the forest floor (throughfall plus litterfall) are considerably greater than leaching outputs, i.e. the soil is retaining these nutrients. Except for K and S, where throughfall is the main pathway, litterfall forms the greatest contribution to forest floor inputs. Potassium is relatively easily leached from the canopy, lowering the amount in litterfall. Sulphate in deposition does not interact with the canopy and the cycling of S is only via litterfall. Sulphur deposition at Hietajärvi, although low and declining (section Deposition of acidity and heavy metals), apparently is still accumulating in the soil.

If we assume that the forests at Hietajärvi are in steady-state (section Acidification and weathering), then nutrient recycling fluxes can be calculated as: throughfall + litterfall – total deposition – leaching. But if the forest ecosystem is not in steady-state, then nutrients are accumulating in the stand and/or soil. We are currently assessing the results from the successive stand biomass measurements and soil sampling of the permanent plots to determine if the stocks of nutrients in the stand and/or soil are changing or not.

Mass balance budgets of heavy metals

We have measured concentrations of cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) in deposition, throughfall, litterfall, soil, soil water, lake and stream water (Ukonmaanaho et al. 1998b, 2001, Starr et al. 2003). Cd and Pb are particularly toxic heavy metals while Cu and Zn are micro-nutrients and only toxic in high concentrations.

Plot-scale budgets (Fig. 9) indicate that the deposition loads of Cu and particularly Pb at Hietajärvi are accumulating in the soil, especially in the humus layer. On the other hand, it would appear that soil stores of Cd, Ni and Zn are apparently declining, as total deposition inputs of these metals are less than leaching losses. However, there is uncertainty about the Cd budget because of very low concentrations in the water samples, and for Ni, the difference between total deposition and leaching fluxes is small. The retention of Cu and Pb was expected because these metals are known to show a strong affinity for organic matter, even under acidic conditions. The retention of Zn in the humus layer was noticeably less, reflecting the lower adsorption strength of organic matter. The Zn and Cu budgets show a clear uptake and recycling component, with inputs to the forest floor (throughfall + litterfall) being considerably greater than either total deposition inputs and leaching outputs at 40 cm depth.

Catchment-scale input-output budgets indicate that much of the deposition inputs of all five heavy metals are retained within the catchment (Table 3). Copper and Pb again show the strongest, almost complete, retention. The total deposition inputs to the catchment are weighted values that take into account the contribution of additional dry deposition captured by the forested area. More detailed budgets (Ukonmaanaho et al. 2001) show that most of the retention was associated with the terrestrial part of the catchment, with the peatland areas probably playing a major role. Sedimentation of organo-metal complexes is the main process by which metals are retained within the lakes.

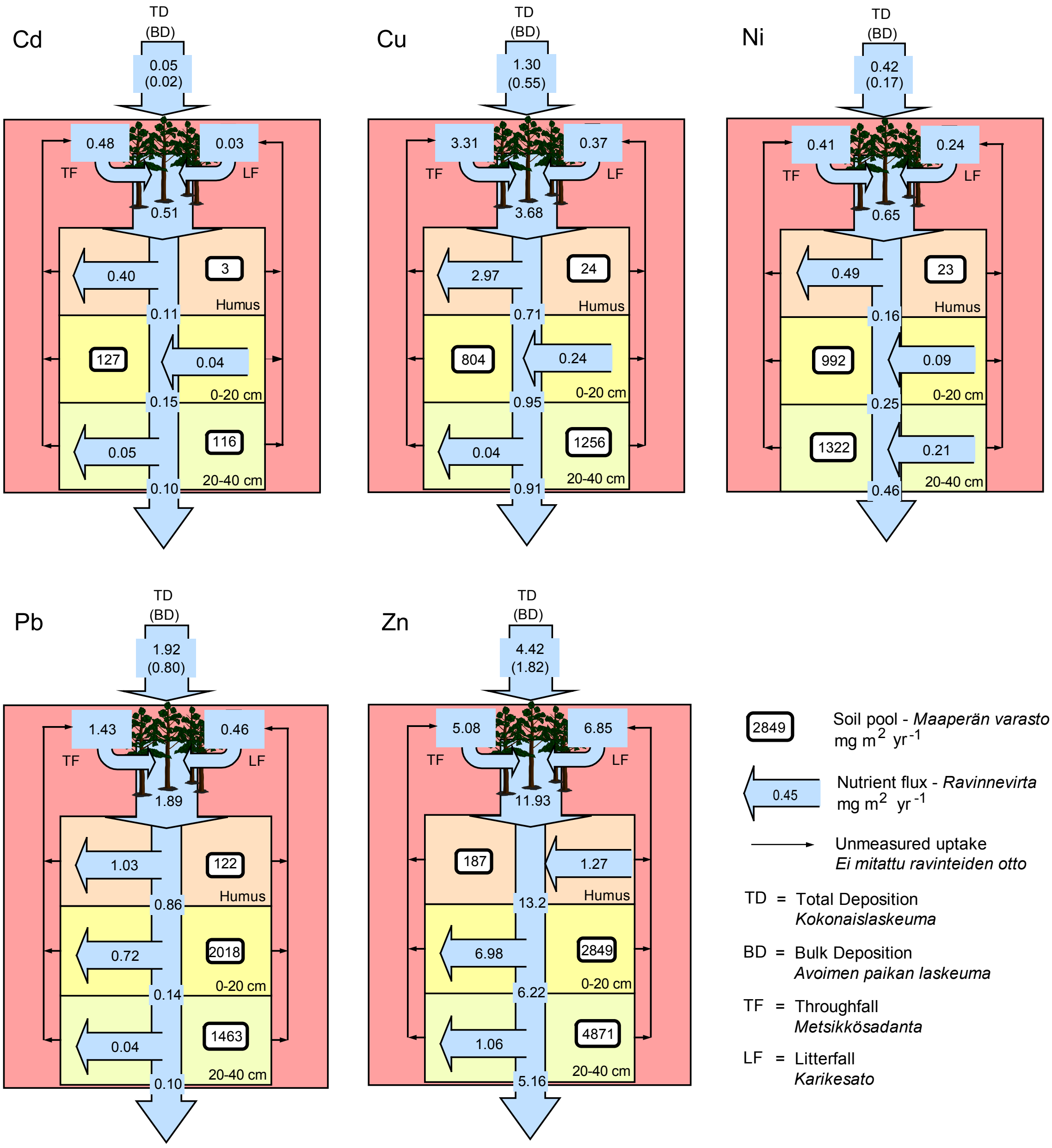

Figure 9. Average annual (1994–1996) heavy metal input-output budgets at the Hietajärvi plot 4. Results are in mg m^{-2} (Ukonmaanaho et al. 2001).
Kuva 9. Raskasmetallitase Hietajärven alalla 4 (1994–1996). Tulokset ilmoitettu mg m^{-2} (Ukonmaanaho ym. 2001).

Table 3. Mean annual (1994–1996) heavy metals input-output budgets for the Hietajärvi catchment.
Taulukko 3. Raskasmetallitase (1994–1996) Hietajärven valuma-alueella.

	Cd	Cu	Ni	Pb	Zn
	mg m^{-2} yr^{-1}				
Deposition – *Avoimen paikan laskeuma*	0.02	0.55	0.17	0.80	1.82
Total deposition (input) – *Kokonaislaskeuma*	0.04	1.04	0.33	1.50	3.45
Runoff water (output) – *Virtaama*	0.01	0.06	0.05	0.05	0.45
Output/Input, %	20	6	16	3	13
Retention (Input–Output) – *Pidättyminen* (Input–Output)	0.03	0.98	0.28	1.45	3.00
Relative retention (Input–Output/Input) – *Suhteellinen pidättyminen, %*	80	94	84	97	87

The strong retention of heavy metals, particularly that of Pb, will serve to maintain soil pools into the future, even though atmospheric inputs have declined (section Deposition of acidity and heavy metals). However, current concentrations of heavy metals in the humus layer are below lowest effective limits known to be detrimental to microbiological activity (Ukonmaanaho et al. 1998b).

Modelling the future

The comprehensive datasets collected at the ICP IM sites provide an excellent starting point for the development and application of mathematical models. In a policy-oriented framework, dynamic models are needed to explore the temporal aspect of ecosystem protection and recovery. The critical load concept, used for defining the environmental protection levels, does not reveal the time scales of recovery. Dynamic models have been used for sulphur and nitrogen emission/deposition scenario assessment at selected ICP IM sites (e.g. Forsius et al. 1998, Jenkins et al. 2003). Hietajärvi has been a key site in this modelling work.

Jenkins et al. (2003) applied the dynamic acidification model MAGIC to the Hietajärvi dataset and also ran several emission reduction scenarios with the calibrated model system. It was concluded that the ongoing recovery from acidification (section Surface water quality) is likely to continue also in the future, assuming presently agreed emission reductions up to the year 2030. Impacts of climate change processes on the acidification recovery at the Valkea-Kotinen IM site have also recently been assessed (Wright et al. 2006). The Hietajärvi dataset has also been used for modelling impacts of climate change on hydrological fluxes and element leaching at both the plot- and catchment-scale; these are reported on below.

Climate change and the soil water balance

Since soil moisture and drainage affects many processes operating in soils, it is important to consider how climate change will affect the water balance. To do this we generated meteorological data for Hietajärvi for the period 2041–2050 according to zero, low and high climate change scenarios. These data were then used as input to simulate the soil water balance of the permanent monitoring plots 4 and 10 (ICP Forest level II plot 20) using a water balance model. The same procedure has been applied to the Valkea-Kotinen IM site (Starr 2004).

The low and high climate change scenarios were based on the European Centre/Hamburg, ECHAM model #4 (Roeckner et al. 1996, Carter et al. 2000). Regionalised decadal changes in monthly air temperature and precipitation were entered into a climate simulator CLIGEN (Carter et al. 1995) to produce monthly values of temperature, precipitation and cloud cover from 1990 to 2050 for Hietajärvi. Zero change data were generated by setting the decadal change in temperature and precipitation to zero. The three sets of scenario-based climatic data were then input into WATBAL (Starr 1999), to simulate monthly values of the components of the water balance, including the water equivalent of the snow cover, soil moisture content, and drainage flux. The results for these particular components are shown in Fig. 10.

The snow cover during the winter months is less under the high change scenario and disappears a month earlier than under the low and zero change scenarios. Under the high change scenario, the peak in drainage associated with spring-time snowmelt is reduced, and occurs earlier, while the secondary peak in autumn is greater. The plant available moisture content of the humus layer plus upper 20 cm of soil, which would include most of the roots, is depleted after the snowmelt recharge in April to a minimum in July, and then recharged back to field capacity in autumn under all three climate change scenarios. However, the depletion during the growing season is clearly the greatest under the high change scenario, which would result in greater drought stress to the trees.

Climate change and carbon and nitrogen exports from the catchment

Holmberg et al. (2006) applied artificial neural networking to model daily total organic carbon (TOC), total nitrogen (Ntot) and total phosphorus (Ptot) concentrations in stream water and used the simulated concentrations to predict future fluxes under scenarios of climate change. Daily air temperature, precipitation and runoff observations were included in the input variables, as

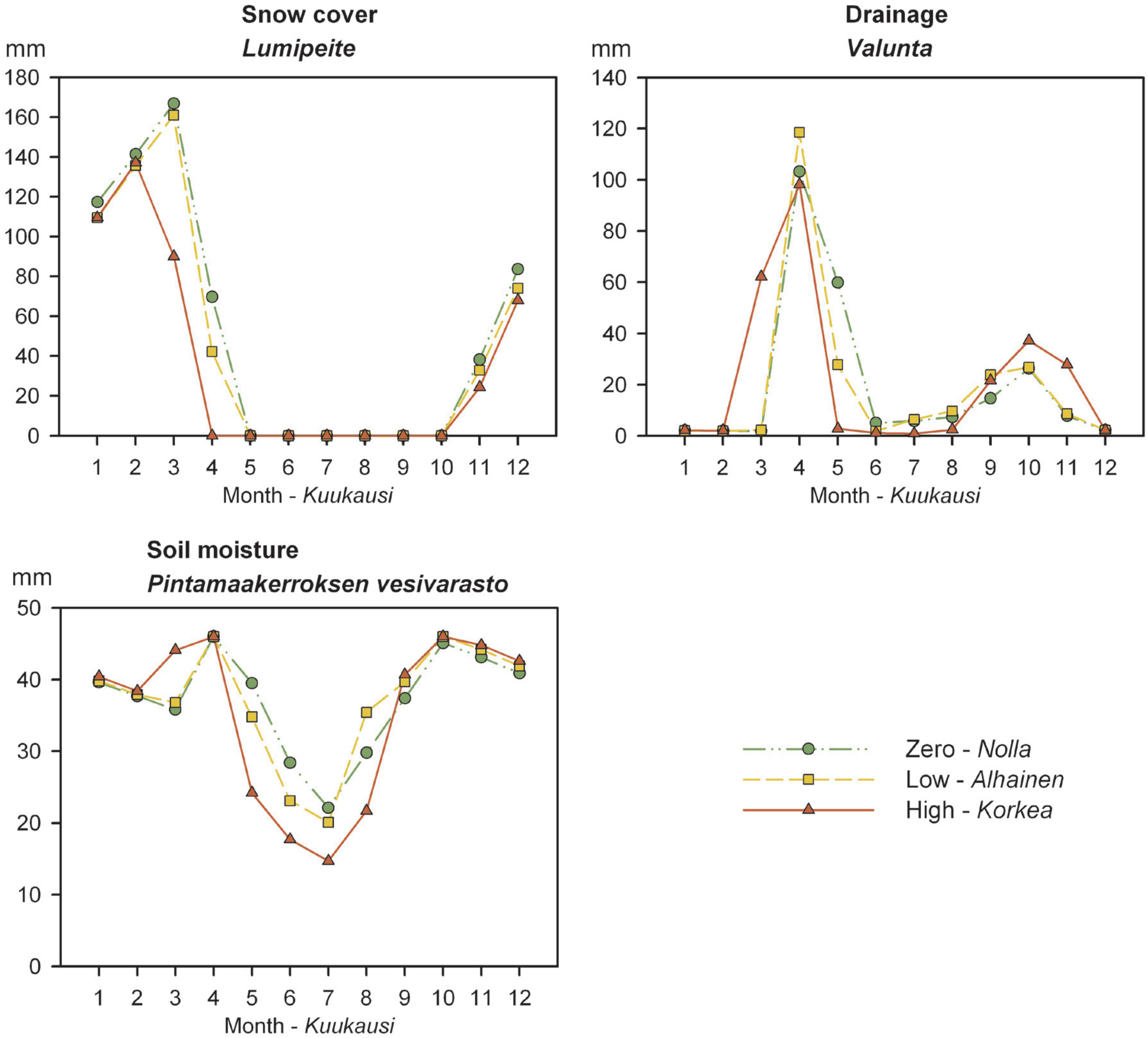

Figure 10. Simulated monthly mean (2041–2050) of snow pack (water equivalent), drainage flux at 20 cm depth in the mineral soil, and soil moisture content of the humus layer plus upper 20 cm layer of soil at the Hietajärvi permanent plots 4 and 10 according to the zero, low and high climate change scenarios. All values are in mm of water.
Kuva 10. Simuloitu kuukauden keskimääräinen lumipeite, valunta 20 cm:ssä ja humuskerroksen ja 20 cm pintamaakerroksen vesivarasto Hietajärven pysyvillä havaintoaloilla 4 ja 10 vuosina 2041–2050, "nolla", "alhainen" ja "korkea"-ilmastonmuutosskenaariolla. Kaikki tulokset on esitetty mm vettä.

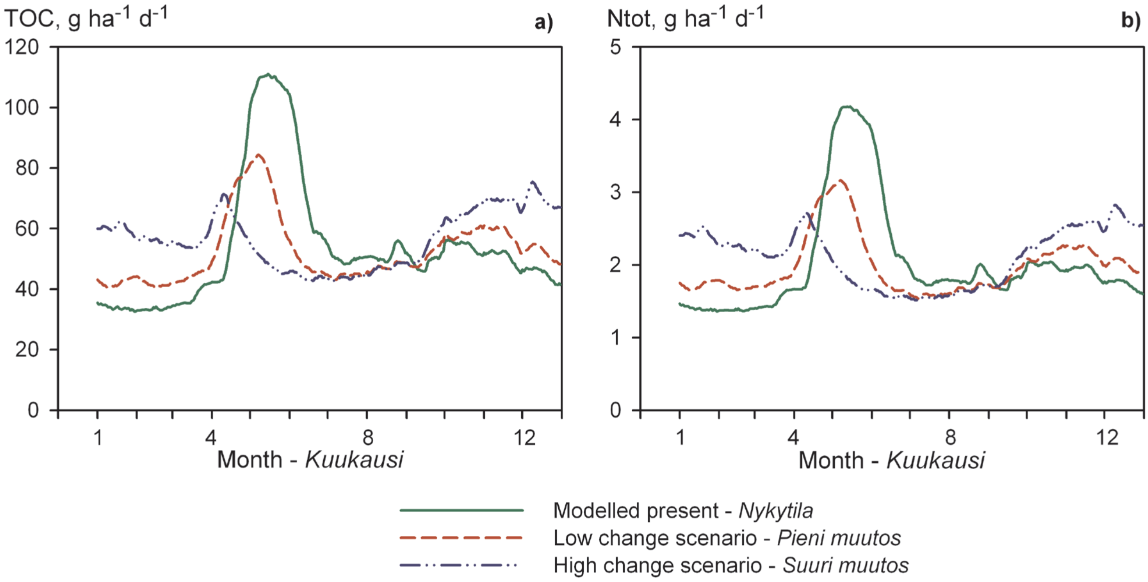

Figure 11. Predicted daily values of fluxes of a) total organic carbon (TOC) and b) total nitrogen (Ntot) at Hietapuro for present conditions (1990s) and for the low climate change scenario (2050s) and the high scenario (2050's) (Holmberg et al. 2006).
Kuva 11. Mallinnettu päivittäinen a) orgaanisen hiilen (TOC) ja b) kokonaistypen huuhtoutumisen muutos Hietajärven Hietapurolle. Kuvassa on esitetty nykytila ja kahden ilmastonmuutosskenaarion (pienet ja suuret muutokset) vaikutukset huuhtoutumiseen vuoden aikana (Holmberg ym. 2006).

well as catchment characteristics, such as catchment area and the area of lakes and peatland. The networks performed well in comparison with the alternative method, i.e. flow-weighted average concentrations.

Projected changes in monthly temperature and precipitation under ECHAM low and high climate change scenarios (section Climate change and the soil water balance) were used to generate daily temperature and precipitation series for the 2050s. These data were entered in to an operational runoff model to produce daily runoff values. Carbon and nitrogen loads were then calculated for the 2050s using the artificial neural network models of TOC, Ntot and Ptot concentrations and the simulated runoff values. The low climate change scenario resulted in annual fluxes close to present fluxes, while the high change scenario gave an increase of approximately 26% in annual TOC, Ntot and Ptot fluxes. Changes in seasonal fluxes were also predicted (Fig. 11).

Conclusions

A comprehensive and long-term dataset of national significance has been collected from Hietajärvi and the other Finnish ICP IM sites. These datasets are invaluable for assessing long-term environmental changes, complex element mass budgets, and for applying mathematical models. Such models can be used for assessing the impacts of air pollution and climate change. The undisturbed ICP IM sites also serve as reference sites for criteria development and pollution impacts assessment. Both the monitoring and modelling results from Hietajärvi have been reported and used in an international framework for the development of effects-based emission reduction policies of air pollutants.

References

Backman, B. 2004. Groundwater quality, acidification, and recovery trends between 1969 and 2002 in South Finland. Geological Survey 110 p., 8 apps.

Carter, T., Posch, M. & Tuomenvirta, H. 1995. SILMUSCEN and CLIGEN – User's guide. Publications of the Academy of Finland 5/95. Helsinki.

Carter T.R., Hulme, M., Crossley, J.F., Malyshev, S., New, M.G., Schlesinger, M.E. & Tuomenvirta, H. 2000. Climate change in the 21st century – Interim characterizations based on the new IPCC emissions scenarios. The Finnish Environment 433. The Finnish Environment Institue. 148 p.

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

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

Forsius, M., Kleemola, S. & Starr, M. 2005. Proton budgets for a monitoring network of European forested catchments: impacts of nitrogen and sulphur deposition. Ecological Indicators 5(2): 73–83.

Hämäläinen, H., Luotonen, H., Koskenniemi, E. & Liljaniemi, P. 2003. Inter-annual variation in macroinvertebrate communities in a shallow forest lake in eastern Finland during 1990–2001. Hydrobiologia 506-509: 389-397.

Holopainen, A-L., Niinioja, R. & Rämö, A. 2003. Seasonal succession, vertical distribution and long term variation of phytoplankton communities in two shallow forest lakes in eastern Finland. Hydrobiologia 506–509: 237–245.

Holmberg, M., Forsius, M., Starr, M. & Huttunen, M. 2006. An application of artificial neural networks to carbon, nitrogen and phosphorus concentrations in three boreal streams and impacts of climate change. Ecological Modelling 195: 51–60.

Höytämö, J., Rämö, A. & Niinioja, R. 2004. The runoff in two pristine forest brooks in Hietajärvi catchment, Eastern Finland. In: Järvet, A. (ed.). XXIII Nordic Hydrological Conference, Tallinn, Estonia, 8–12 August, 2004. Selected articles, Nordic Hydrological Programme. NHP Report No. 48, Vol. I: 286–292.

International Cooperative Programme (ICP) on Integrated Monitoring of Air Pollution Effects on Ecosystems. [Internet site]. Available at: www.environment.fi/syke/im. [Cited 11 March 2006].

Jenkins, A., Larssen, T., Moldan, F., Hruška, J., Krám, P. & Kleemola, S. 2003. Dynamic modelling at Integrated Monitoring sites – Model testing against observations and uncertainty. The Finnish Environment 636, p. 37. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-1440-1.

Kurka, A.-M. & Starr, M. 1997. Relationship between decomposition of cellulose in the soil and tree stand characteristics in natural boreal forests. Plant and Soil 197: 167–175.

Kurka, A.-M., Starr, M., Heikinheimo, M. & Salkinoja-Salonen, M. 2000. Decomposition of cellulose strips in relation to climate, litterfall nitrogen, phosphorus and C/N ratio in natural boreal forests. Plant and Soil 219(1): 91–101.

Kurka, A.-M., Starr, M., Karsisto, M. & Salkinoja-Salonen, M. 2001. Relationship between decomposition of cellulose strips and chemical properties of humus layer in natural boreal forests. Plant and Soil 229(1): 137–146.

Niinioja, R. & Rämö, A. (eds.). 2006. Hietajärven alue – ympäristön seurannan helmi Pohjois-Karjalassa. Suomen ympäristö 59. 68 s.

Niinioja, R., Holopainen, A-L. & Rämö, A. 2002. Seasonal water quality variations in two pristine headwater lakes, boreal coniferous forest area, eastern Finland. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 28: 492–496.

Niinioja, R., Hämäläinen, H., Holopainen, A-L., Luotonen, H. & Rämö, A. 2003. Monitoring of biota and water quality in small forest lakes within the ICP IM programme. Finnish Environment Institute, Helsinki, Finland. The Finnish Environment 637: 48–54.

Niinioja, R., Höytämö, J. & Rämö, A. 2004. Colour, pH and phosphorus variations and phosphorus leaching of two pristine brooks in a forested catchment, Eastern Finland. In: Järvet, A. (ed.). XXIII Nordic

Hydrological Conference, Tallinn, Estonia, 8–12 August, 2004. Selected articles. Nordic Hydrological Programme, NHP Report No. 48, Vol. I: 277–285.

Rask, M., Holopainen, A.-L., Karusalmi, A., Niinioja, R., Tammi, J., Arvola, L., Keskitalo, J., Blomquist, I., Heinimaa, S., Karppinen, C. , Salonen, K. & Sarvala, J. 1998. An introduction to the limnology of the Finnish Integrated Monitoring Lakes. Boreal Environment Research 3: 263–274.

Roeckner, E., Arpe, K., Bengtsson, L., Christoph, M., Clauseen, M., Dümenil, L., Esch, M., Giorgetta, M., Schlese, U. & Schulzweida, U. 1996. The atmospheric general circulation model ECHAM-4: model description and simulation of present-day climate. Max-Planck Institute for Meteorology. Report No. 218. Hamburg.

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

Ruoho-Airola, T., Syri, S. & Nordlund, G. 1998. Acid deposition trends at the Finnish Integrated Monitoring catchments in relation to emission reductions. Boreal Environment Research 3: 205–219.

Ruoho-Airola, T., Anttila, P. & Salmi, T. 2004. Airborne sulphur and nitrogen in Finland — trends and exposure in relation to air transport sector. Journal of Environmental Monitoring 6: 1–11.

Starr, M. 1999. WATBAL: A model for estimating monthly water balance components, including soil water fluxes. In: Kleemola, S. Forsius, M. (eds.). 8th Annual Report 1999 UN ECE ICP Integrated Monitoring. Finnish Environment Institute, Helsinki, Finland. The Finnish Environment 325: 31–35.

Starr, M. 2004. Changes in soil drainage fluxes: what the future has in store. Silva Carelica 43: 39–42.

Starr, M. & Hartman, M. 2003. Tree biomass and soil carbon densities and stocks for a small forested catchment in eastern Finland. In: Honkanen, J.O. & Koponen, P.S. (eds.). Proceedings, Sixth Finnish Conference of Environmental Sciences, Current Perspectives in Environmental Science and Technology. Joensuu, May 8–9, 2003. Finnish Society for Environmental Sciences. University of Joensuu Press. 190–193 p.

Starr, M. & Ukonmaanaho, L. 2001. Results from the first round of the Integrated Monitoring soil chemistry subprogramme. In: Ukonmaanaho, L. & Raitio, H. (eds.). Forest Condition Monitoring in Finland. National report 2000. The Finnish Forest Research Institute, Research Papers 824: 140–157.

Starr, M. & Ukonmaanaho, L. 2004. Levels, trends and characteristics of TOC in throughfall and soil water in remote, undisturbed, boreal forest ecosystems. Water, Soil and Air Pollution, Focus 4: 715–729.

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

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

Starr, M., Lindroos, A.-J., Ukonmaanaho, L., Tarvainen, T. & Tanskanen, H. 2003. Weathering release of heavy metals from soil in comparison to deposition, litterfall and leaching fluxes in a remote, boreal coniferous forest. Applied Geochemistry 18(4): 607–613.

Starr, M., Vanhala, P. & Forsius, M. 2005. Progress report on calculation of carbon and nitrogen budgets for Finnish ICP IM catchments. In: Kleemola, S. & Forsius, M. (eds.). 9th Annual Report 2000. UN ECE ICP Integrated Monitoring. Finnish Environment Institute, Helsinki, Finland. The Finnish Environment 788: 44–49.

Starr, M., Forsius, M., Hartman, M., Ukonmaanaho, L. & Vanhala, P. 2006. Carbon and nitrogen mass balance budgets for a forested catchment in Finland. BIOGEOMON 5th International Symposium on Ecosystem Behaviour, June 25–30, 2006, Santa Cruz, CA, USA. Conference Program and Abstracts. p. 211.

Tammi, J., Rask, M., Vuorenmaa, J., Lappalainen, A. & Vesala, S. 2004. Population responses of perch (Perca fluviatilis) and roach (Rutilus rutilus) to recovery from acidification in small Finnish lakes. Hydrobiologia 528: 107–122.

Ukonmaanaho, L. & Starr, M. 2002. Major nutrients and acidity: budgets and trends at four remote boreal stands in Finland during the 1990s. The Science of the Total Environment 297: 21–41.

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

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

Ukonmaanaho, L., Starr, M., Mannio, J. & Ruoho-Airola, T. 2001. Heavy metal budgets for two headwater forested catchments in background areas of Finland. Environmental Pollution 114(1): 63–75.

Waldén, J., Saari, H. & Ruoho-Airola, T. 2002. Background air quality in Finland in 2000. In: Rautjärvi, H., Ukonmaanaho, L. and Raitio, H. (eds.). Forest Condition Monitoring in Finland. National report 2001. The Finnish Forest Research Institute, Research Papers 879: 23–41.

Wright, R.F., Aherne, J., Bishop, K., Camarero, L., Cosby, B.J., Erlandsson, M., Evans, C.D., Forsius, M., Hardekopf, D., Helliwell, R., Hruska, J., Jenkins, A., Moldan, F., Posch, M. & Rogora, M. 2006. Modelling the effect of climate change on recovery of acidified freshwaters: relative sensitivity of individual processes in the MAGIC model. Science of the Total Environment 365: 154–166.