Working Papers of the Finnish Forest Research Institute 74
http://www.metla.fi/julkaisut/workingpapers/2008/mwp074.htm
ISBN 978-951-40-2088-9 (PDF)
ISSN 1795-150X

Scientific Seminar on Forest Condition Monitoring and Ecosystem Functioning in Northern Europe under the Forest Focus and ICP Forests Programmes, Vantaa 27.–28.11.2007

Proceedings

John Derome, Antti-Jussi Lindroos and Tuire Kilponen (eds.)

METLA www.metla.fi

Working Papers of the Finnish Forest Research Institute publishes preliminary research results and conference proceedings.

The papers published in the series are not peer-reviewed.

The papers are published in pdf format on the Internet only.

http://www.metla.fi/julkaisut/workingpapers/
ISSN 1795-150X

Office
Unioninkatu 40 A
FI-00170 Helsinki
Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail julkaisutoimitus@metla.fi

Publisher
Finnish Forest Research Institute
Unioninkatu 40 A
FI-00170 Helsinki
Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail info@metla.fi
http://www.metla.fi/

Authors			
Derome, John, Lindroos, Antti-Jussi & Kilponen, Tuire (eds.)			
Title			
Scientific Seminar on Forest Condition Monitoring and Ecosystem Functioning in Northern Europe under the Forest Focus and ICP Forests programmes, Vantaa 27.–28.11.2007, Proceedings			
Year	**Pages**	**ISBN**	**ISSN**
2008	62	978-951-40-2088-9 (PDF)	1795-150X
Unit / Research programme / Projects			
Parkano Research Unit / Forest Focus Programme / 315310 coordination, 315311 forest condition Level I, 3153 Level II			
Accepted by			
Puttonen Pasi, Director of Research, 26. March 2008			
Abstract

The scientific seminar, held during 27.–28.11.2007 in Vantaa, Finland, was attended by 45 researchers from Denmark, Estonia, Finland, Norway, Russia and the UK who are participating in the EU/Forest Focus and UN-ECE/ICP Forests extensive and intensive forest monitoring programmes. The purpose of the meeting was to provide a forum where the researchers could present the results of the monitoring work and scientific studies carried out over the last two decades in northern Europe within the framework of the programmes. The presentations covered a wide range of topics including the optimization of techniques for monitoring carbon stocks and biodiversity in large-scale surveys, long-term changes in forest health, foliar, deposition and soil solution chemistry, carbon, nitrogen and nutrient fluxes in boreal forests, and nutrient and acidification processes in forest soils.
Keywords

EU/Forest Focus, ICP Forests, northern Europe, carbon stocks, biodiversity, forest health, foliar chemistry, deposition chemistry, soil solution chemistry, C fluxes, N fluxes, nutrient fluxes
Available at
http://www.metla.fi/julkaisut/workingpapers/2008/mwp074.htm
Replaces
Is replaced by
Contact information

John Derome, Finnish Forest Research Institute, Rovaniemi Research Unit, P.O. Box 16, FI-96301 Rovaniemi, Finland. E-mail john.derome@metla.fi

Other information

Contents

Preface

The scientific seminar, held during 27.–28.11.2007 in Vantaa, Finland, was attended by 45 researchers from Denmark, Estonia, Finland, Norway, Russia and the UK who are participating in the EU/Forest Focus and UN-ECE/ICP Forests extensive and intensive forest monitoring programmes. The purpose of the meeting was to provide a forum where the researchers could present the results of the monitoring work and scientific studies carried out over the last two decades in northern Europe within the framework of the programmes. The presentations covered a wide range of topics including the optimization of techniques for monitoring carbon stocks and biodiversity in large-scale surveys, long-term changes in forest health, needle, deposition and soil solution chemistry, carbon, nitrogen and nutrient fluxes in boreal forests, and nutrient and acidification processes in forest soils. The seminar was a great success and plans were made to intensify co-operation between the participating researchers. I wish to thank all the participants for the constructive discussions and their excellent presentations

John Derome
Co-ordinator of the Forest Focus and ICP Forests programmes in Finland

Forest monitoring and forest research – is there necessarily a relationship?

Dan Aamlid & Nicholas Clarke

Norwegian Forest and Landscape Institute, P.O. Box 115, N-1431 Ås, Norway
dan.aamlid@skogoglandskap.no

Introduction

Monitoring of forest condition in relation to effects of air pollution on forests has been performed in Europe since the mid 1980s, while monitoring regarding forest crops and production has been performed for at least the last 90 years in some European countries. Forest research has an even longer history. In many cases, forest monitoring and forest research are carried out by the same institutions. However, there remains the question of which relationships and dependencies exist between forest monitoring and forest research, and in particular whether, and if so in what ways, forest monitoring and forest research have benefited from each other? This paper will address these questions.

Historical background

Monitoring may be defined as studying "how is it changing?" while research deals with "why is it changing?" Monitoring and research on forest condition have a long history in Europe. More than 100 years of forest research has taken place in the Nordic countries on different topics such as forest growth and forest health. Forest monitoring with the aim of monitoring forest resources has been performed since 1919. The first Nordic national forest inventories (NFI) took place in Norway in 1919, in Finland in 1921 and in Sweden in 1923.

With the focus on the New Forest Decline (Waldsterben) in the early 1980s the European forest monitoring programme ICP Forests was initiated in 1985 (http://www.icp-forests.org). At the same time Nordic initiatives through the Nordic Forest Research Coordination Committee (SNS) were initiated, and Nordic meetings and workshops took place (Fig. 1). The interest of the media and the general public was huge. Some of the researchers that participated in the first meeting in the early 1980s are still active, and a huge amount of knowledge and expertise have been built up in the Nordic countries. At the same time, ICP Forests developed in Europe: Nordic specialists took a leading part in the build-up of the programme, e.g. by taking the chairs of several of the Expert Panels.

Important milestones in the history of ICP Forests are:

- ICP Forests launched in Freiburg on 4th October 1985.
- Topic for EU, 1986: Regulation 3528/86.
- First issue of the ICP Forests Manual, 2nd Task Force Meeting, Freiburg, 1986. Levels I, II and III established.
- Scientific Advisory Group (SAG) and the Forest Intensive Monitoring Coordinating Institute (FIMCI) (1995 – 2002) established. SAG gave a scientific basis for the work, and was important due to its scientific attitude to the programme, its strategies and data evaluations.

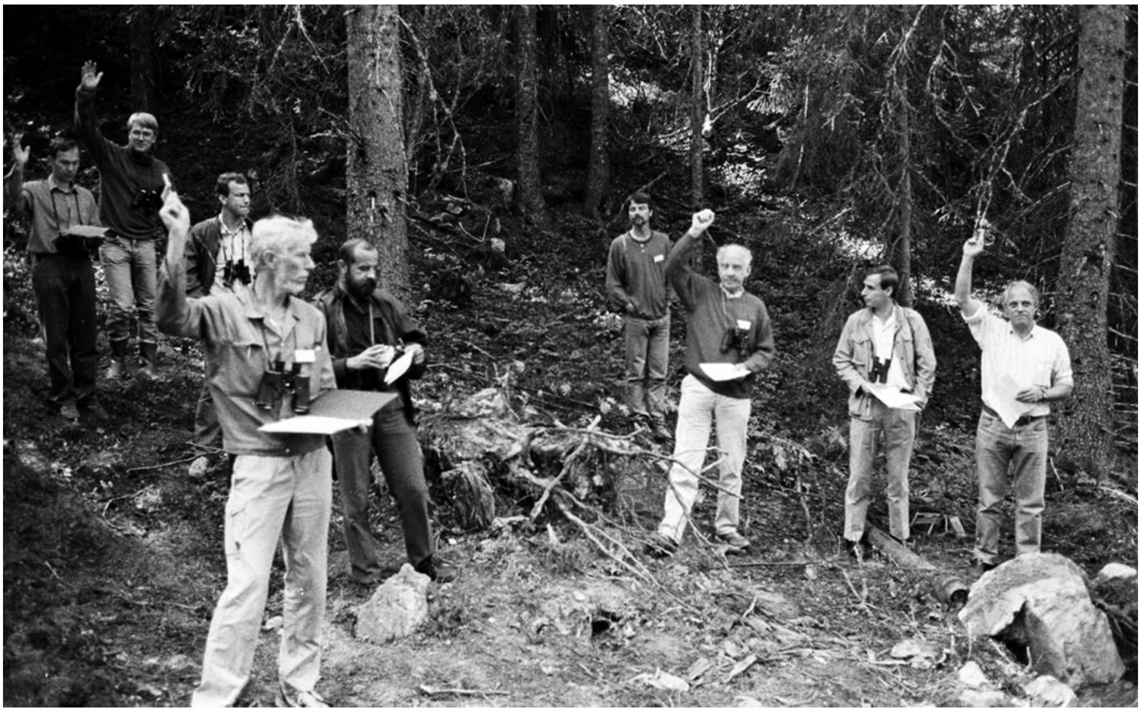

Figure 1. SNS ad hoc meeting on forest damage, mid 1980s.

Research and monitoring

In Norway, several other research projects have been important for forest monitoring:

- Research on bark beetles in the 1970s due to very severe attacks of *Ips typographus* in Norwegian forests led to the initiation of a monitoring programme for the population of *Ips typographus* in Norwegian spruce forests, established in 1979 and still going on.
- The project "Acid precipitation: Effects on forest and fish" (SNSF) was conducted in Norway in the period 1972–1980, and was probably one of the earliest research programmes on the effect of air pollution on forests. This project was an important basis for the Norwegian monitoring programme for soil and water acidification, the Norwegian monitoring programme for air pollution, and probably for EMEP and ICP Waters.
- Research on old forests in 1978 made use of crown condition evaluations (crown density and discoloration) as criteria of tree condition. It was found that the content of leaf/needle chlorophyll was much decreased even before it was possible to detect it as a visual yellowing.

In some programmes and projects, research and monitoring have been combined:

- In the project "Forest and the environment, growth and vitality" (SMVV) and The Norwegian Monitoring Programme for Forest Damage (OPS), research and the monitoring programme were launched side by side.
- In ICP Forests, monitoring results have been used for research. The technical reports from FIMCI and the 10-year report have been important, and many peer-reviewed papers have been produced.

The monitoring programme has helped in method development, for example in sampling technology (e.g. litterfall, throughfall and soil water samplers). Remote sensing has been used for mapping purposes. Recently, there has been an emphasis on quality assurance and quality control that is relevant for research projects as well.

Influence of the forest monitoring programme

Other terrestrial monitoring projects and programmes have adapted much of their methodology from the forest monitoring programme (Fig. 2):

- The TOV programme in Norway, with terrestrial monitoring in the sub-alpine birch forest belt. Initially the focus was on acid rain, while today it has shifted to climate and biodiversity.
- The Kvarken region (Finland and Sweden).
- Several projects have involved monitoring in the Pasvik region, in the border region between Norway, Finland and Russia. This monitoring was established in 1989 after public concern about damage to forest vegetation in the Pasvik/Nikel area. Initially, a Level 1-like 4x4 km observation system including abiotic and biotic damage observation and evaluation was established. This was later enlarged to a Level 2-like system in addition to the 4x4 km system. Today, there is the INTERREG Pasvik monitoring programme, involving Russia, Finland and Norway.
- The Acid Deposition Monitoring Network in East Asia (EANET).

Results / experience / benefits

What have we learnt more about after 20 years of monitoring? What could we learn more about?
- Variation in crown condition is mostly related to meteorological conditions.
- Variation in chemical content and concentrations in needles (and leaves).
- Variation in deposition of air pollutants in forests over Europe, including throughfall deposition.
- Chemistry in soil water (Al^{3+}, DOC, N and S, sea salts).
- Ground vegetation topics.
- Quality assurance and quality control in the field and laboratory.
- Development of new methods and equipment.
- Confirmed and new insights into ecological relationships.
- How our forests react to extreme weather conditions, which is very important in the development of prognoses for the effects of climate change.
- Validation of ecological models, which are important for future forecasting.
- Specific responses to air pollution, such as leaf symptoms from ozone and plant tissue damage from point sources.

Figure 2. Examples of projects using methodology adapted from the forest monitoring programme.

Other benefits have included:

- Learning about the building and validation of databases.
- The development of different information packages, including manuals and handbooks, and more focus on forests in general via newspapers, magazines and Internet.
- Education, including postgraduate, and development of expertise.
- AND, last but not least, **great insight and experience in cooperation** within our own institutions, own fields of expertise, own countries and internationally including all the (huge) challenges in a Europe in enormous development during the last 20 years, in the interface between the UN, the EU and the non-EU countries. This is also of special **personal importance** for all those researchers – where several were (even are) young people – who have been involved in forest monitoring, and shall now continue this work in a Europe where many borders have broken down. **New countries** have been included as the European forest monitoring developed. Also, we should not forget **a very successful and well established Nordic cooperation**.

What about the future?

At the risk of being proved wrong, we would like to share some thoughts about the future of forest monitoring:

- There might be a need to know about **our reference**: there may be a need for research on pristine forest types, as far as these still exist.
- Future needs may make monitoring even **more complex**. Climate change, biodiversity, bioenergy from forests, eutrophication, economics and ecosystem services (e.g. water, berries, health, and recreation) are all areas to which forest monitoring might contribute.
- Monitoring data are important for model validation. However, models need more than just average data; they need detailed, high-resolution data and extreme values. It is conditions and events giving extreme values that kill plants.
- Another challenge is to **widen** the current monitoring / research / modelling, i.e. to go out of the forest and seek cooperation with the socio-economic-landscape experts.
- Remote sensing is a promising method, which is likely to be more widely used in the future. However, it is unlikely that we can do <u>everything</u> remotely.

Conclusions

- The most important quality control for forest monitoring is research using monitoring data as input.
- To maintain a reliable and relevant forest monitoring in the future, research using monitoring data and improvement of methods is needed.
- Forest (and other environmental) research and monitoring thus benefit from each other.

Trends in throughfall and soil water chemistry (1997–2006) at Estonian ICP Forests Level II sites

Endla Asi [1)], Ülle Napa [2)] & Jane Frey [3)]

[1)] Bureau of Forest Monitoring, Estonian Centre of Forest Protection and Silviculture, 2 Rõõmu tee St, Tartu 51013, Estonia, endla.asi@metsad.ee
[2)] Institute of Ecology and Earth Sciences, University of Tartu, 46 Vanemuise St, Tartu 51013, Estonia, a30272@ut.ee
[3)] Institute of Ecology and Earth Sciences, University of Tartu, 46 Vanemuise St., Tartu 51013, Estonia, Jane.Frey@ut.ee

Introduction

Since 1980, European emissions of sulphur dioxide have been reduced by 70%, oxides of nitrogen by around 30%, and ammonia by 25%. The emissions of sulphur dioxide are today back at the same level as at the turn of the 19th century (Grennfelt and Hov 2005).

Estonian air pollution is at a turning point at the moment: total SO_2 emissions in Estonia have fallen by about 60% (Fig. 1), emissions of solid particles declined twenty-fold, and the acidity of precipitation has increased during the period 1990 – 2005 (Treier et al. 2007).

The aim of the present paper is to analyze the changes and trends in anion and cation concentrations in the throughfall and soil water data collected on the ICP Forests Level II monitoring plots.

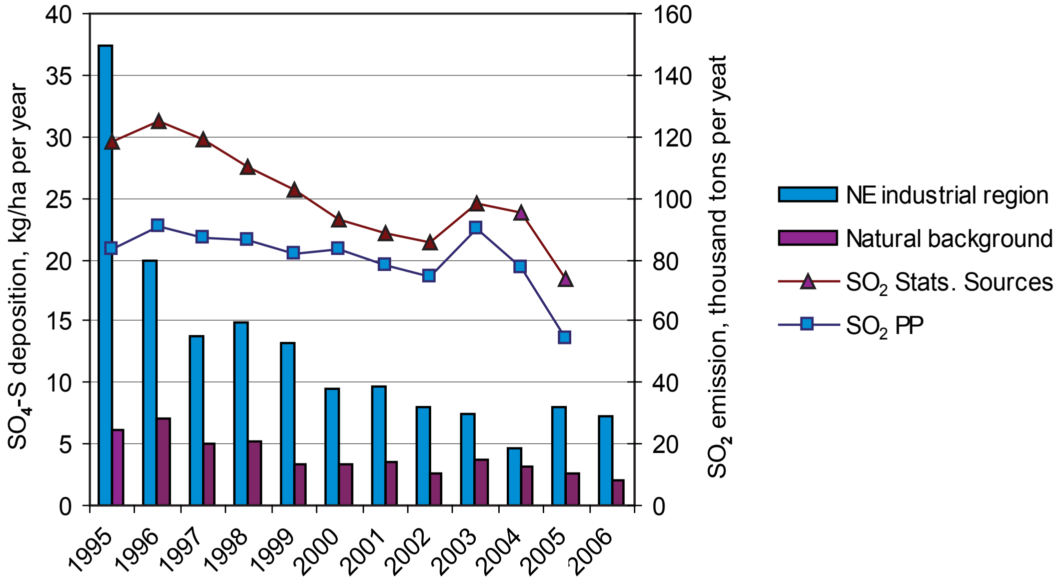

Figure 1. Comparision of declined SO_2 emissions from stationary sources and oil shale power plants (PP) with average bulk deposition of SO_4-S (kg per ha) in natural background open area stations (the longest time series for 7 stations) and in NE Estonia industrial region station (Saka and Jõhvi).

Material and methods

Bulk precipitation and throughfall measurements are carried out within the framework of the ICP Forests Level II programme on seven intensive monitoring plots by the Estonian Centre of Forest Protection and Silviculture. Four plots are located in Scots pine stands (Sagadi, Vihula, Pikasilla, Karula) and three in Norway spruce stands (Mäksa, Karepa, Tõravere). Continuous deposition monitoring on five of the plots (Sagadi, Vihula, Pikasilla Karula, Mäksa) started in 1997, at Karepa in 2003 and at Tõravere 2006. Soil water monitoring started on two plots (Vihula, Pikasilla) in 1999, at Karula in 2002, at Karepa in 2003 and at Tõravere in 2006.

Precipitation samples were collected with bulk deposition samplers (throughfall sampling area 0,30 m^2 in summer, and 0,88 m^2 in winter) once every two weeks during summer and once a month during winter. The volume of each sample was recorded separately, and the samples then bulked for chemical analysis.

Soil water was sampled with zero-tension plate lysimeters with a suface area of 0.065 m^2. The lysimeters were inserted at depths of 5 to 10 cm under the organic horizon, of about 10 cm within the rooting zone, and of about 50 cm below the rooting zone. There were at least 6 replications per depth. At all the sites percolation water was collected at approximately 1-month intervals during the snow-free period at the same time as the deposition samples.

The water samples were analyzed in the Environmental Studies Laboratory in Tartu. The laboratory has continuous quality control programmes, and participates regularly in international inter-calibration exercises.

Anions were determined by ion chromatography, and cations by atomic absorption spectroscopy and ion chromatography, pH was measured potentiometrically. The nonparametric Mann-Kendall test was used to estimate the significance ($p<0.05$) of the trends in annual values. The slope of a linear trend was estimated with the nonparametric Sen's method (Salmi et al. 2002).

Results

Trend analysis of the annual mean concentrations in throughfall indicate statistically significant decreasing trends for SO_4-S at all 7 intensive monitoring plots, and for Ca only in Karula, Pikasilla and Vihula. The mean Mg concentrations have also declined on all the plots, but the trends were not statistically significant.

Table 1 presents the results of the trend analyses of the monthly concentrations in soil water at four intensive monitoring plots in Estonia.

Monthly ion concentrations in soil water indicated statistically significant decreasing trends for SO_4-S at Vihula, Karepa and Pikasilla, but not in the Karula pine stand, which has the southernmost location and is located far away from the industrial region in NE Estonia.

The sulphate decline in deposition and in soil water was accompanied by a decrease in pH and an increase in most cations (except for K) in soil water in the Vihula, Karula, and Pikasilla pine stands. These trends in soil water collected in podzolizic soil indicate promoted podzolization and weathering processes.

Table 1. Trends in data series ("-"decreasing and "+" increasing) of monthly concentrations in soil water from 1997–2006 (2003–2006 for Karepa). Estimated by Mann-Kendall nonparametric test (significance levels ***p< 0.001; **p<0.01; *p<0.05).

Time series	Vihula podzol		Karepa albeluvisol		Karula podzol		Pikasilla podzol	
	10 cm	50 cm	10 cm	50 cm	under organic	10 cm	under organic	10 cm
pH		- ***		+*	- *	- *	- *	
$N\text{-}NH_4$					+ *	+ *		
$N\text{-}NO_3$				- *				+ *
Ntot				- ***	+ *	+ *		
Cl			- +	- **			+ *	+ **
$SO_4\text{-}S$	- +	- ***	- **	- **				- ***
Ca	+ +		- **	- **		+ *	+ +	+ **
Mg	+ *	+ **	- **	- ***		+ ***	+ +	+ ***
Fe			+ +		+ *	+ *		+***
Na			- **	-***			+ +	+ ***
K	- ***	- +	+ ***	- +	- *			
Al		+ **		- *		+ ***		
Mn						+ ***	+ *	+ +
DOC		+ +	+ *					

At Karepa the statistically significant decline in most cations (except for K and Fe) at both soil water depths most likely reflected the tremendous decline in air pollution from the Kunda cement industry during the last ten years.

References

Grennfelt, P. & Hov, O. 2005. Regional air pollution at a turning point. Ambio 34: 2 – 10.

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T. & Amell, T. 2002. Detecting trends of annual values of atmospheric pollutants by Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS. In Publication on Air Quality 31, Finnish Meteorological Institute, Helsinki p. 1 – 35.

Treier, K., Kabral, N. & Frey, J. 2007. Changes in chemical composition of bulk precipitation at Estonian monitoring stations 2000 – 2006. Oil Shale (submitted).

DOC and DON fluxes in stand throughfall and soil water and their relationships with climatic and stand factors in Finland

Antti-Jussi Lindroos [1], Kaisa Mustajärvi [2], John Derome [3], Egbert Beuker [4], Päivi Merilä [2], Pekka Nöjd [1], Liisa Ukonmaanaho [1] & Heljä-Sisko Helmisaari [1]

[1] Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland
[2] Finnish Forest Research Institute, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland
[3] Finnish Forest Research Institute, Rovaniemi Research Unit, P.O.Box 16, FI-96301 Rovaniemi, Finland
[4] Finnish Forest Research Institute, Punkaharju Research Unit, Finlandiantie 18, FI-58450 Punkaharju, Finland

The aim of this study was to determine the magnitude and variation in dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) fluxes in stand throughfall and the percolation water passing down podzolic soil profiles to a depth of 40 cm. The relationships between these fluxes and climatic and stand factors were also investigated. The DOC fluxes were calculated for 7 Scots pine and 5 Norway spruce plots and DON fluxes for 8 pine and 8 spruce plots located on upland mineral soils in the Forest Focus/ICP Forests Level II plot network.

In order to determine the DOC and DON fluxes, bulk deposition was collected in an open area close to the forest plot. Stand throughfall was collected systematically within the forest stand. During the snow-free period rainwater collectors (funnel, diameter 20 cm), and during the winter period snow collectors (collection ring, diameter 36 cm), were used. Soil water percolating down the soil profile was collected using zero-tension lysimeters at depths of 5, 20 and 40 cm below the ground surface. The water fluxes down the soil profile form an important part of the flux calculations in element budget studies for forest ecosystems. In this study, the anion budget method was used to calculate the water fluxes in percolation water.

The DOC and DON fluxes in stand throughfall were higher in southern Finland than in northern Finland. The mean DOC flux in stand throughfall was slightly higher for the spruce plots than for the pine plots. The mean DON flux formed an important part of the total nitrogen flux in stand throughfall. The DON flux was about one half of the N deposition on the forest floor in the spruce stands. In the pine sites the proportion was somewhat smaller. The role of temperature, length of the growing season, amount of precipitation and certain stand parameters on these fluxes have been studied and will be discussed in this presentation.

The output fluxes of DOC and DON in soil water below the rooting zone were, in general, relatively low. The highest DOC fluxes were recorded below the organic layer, and the fluxes decreased strongly with increasing soil depth in these podzolic forest soils. The total flux of N in percolation water down to a depth of 40 cm was generally low, although the proportion of DON out of the total N flux in percolation water was very high. These fluxes will be compared in the presentation to the fluxes e.g. in deposition and in litterfall.

The nitrogen status of Norwegian Level II plots

Nicholas Clarke, Kjell Andreassen, Volkmar Timmermann,
Ingvald Røsberg & Dan Aamlid

Norwegian Forest and Landscape Institute, P.O. Box 115, N-1431 Ås, Norway

Introduction

Most Norwegian forest ecosystem sites, like many other boreal forests, are naturally nitrogen-limited. However, anthropogenic nitrogen deposition in the south of the country has been relatively high, reaching over 15 kg/ha/yr in the extreme south of the country. The aim of this paper is to examine the effect of this relatively high level of nitrogen deposition on the forest ecosystems of southern Norway, in comparison with the more pristine ecosystems of central and northern Norway.

Materials and methods

The Norwegian Monitoring Programme for Forest Damage has been collecting data on forest condition since 1984. The main objective has been to monitor forest condition in relation to air pollution, especially acid deposition. Of the 18 plots in Fig. 1 (there are two at Kårvatn), 16 are dominated by Norway spruce (*Picea abies* (L.) Karst.) and the remaining two (Svanhovd and one at Kårvatn) by Scots pine (*Pinus sylvestris* L.). One Norway spruce plot, at Kårvatn, was formerly a grey alder (*Alnus incana* (L.) Moench) site and this has influenced the nitrogen status of the plot.

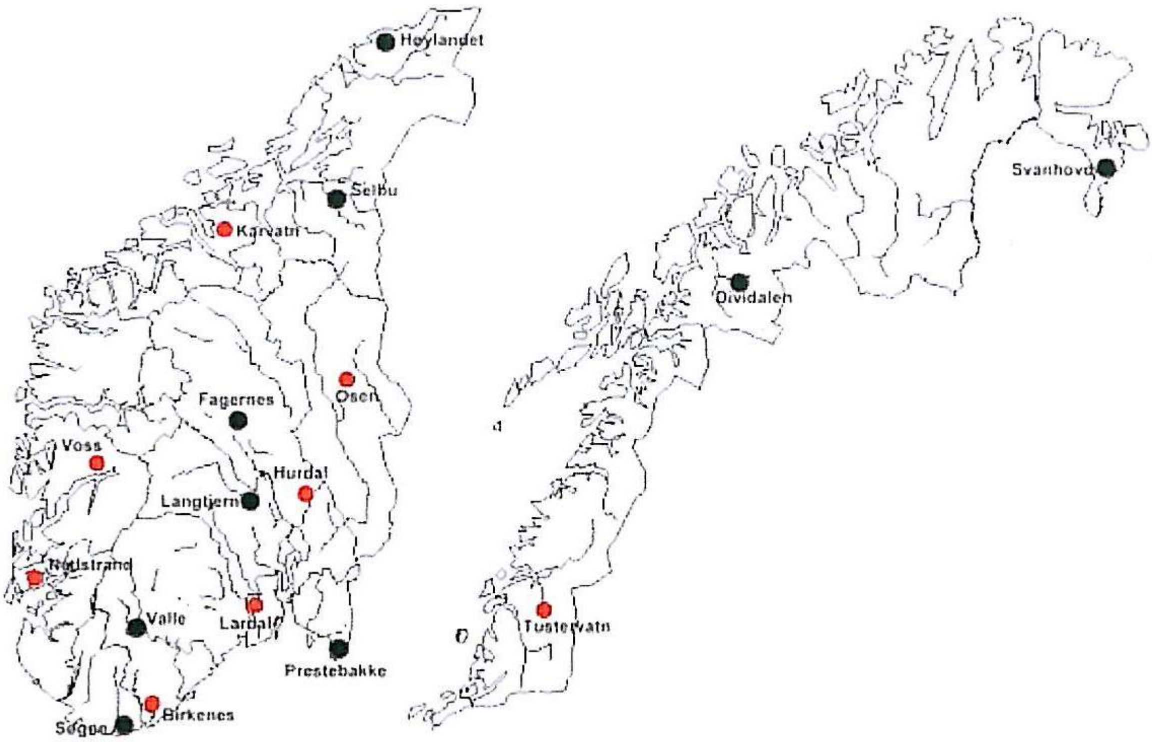

Figure 1. Locations of the Norwegian Level II plots. Only those marked with red are still active.

Results and discussion

Only in the southernmost counties of Norway has nitrogen deposition been high enough to have the potential to cause changes in the forest ecosystem. Bulk deposition of inorganic nitrogen has tended to decrease slightly over time (Fig. 2).

Concentrations of nitrate in soil water are normally low: organic nitrogen is most often the form of nitrogen found in highest concentrations. Leaching of inorganic nitrogen in nitrogen-limited forest ecosystems is generally very low, although it can be exported during periods of high flow, especially outside the growing season when uptake is low. Increased concentrations of nitrate have sometimes been observed in soil water, especially on some southern plots in the spring (Fig. 3). The reason for this is at present unclear.

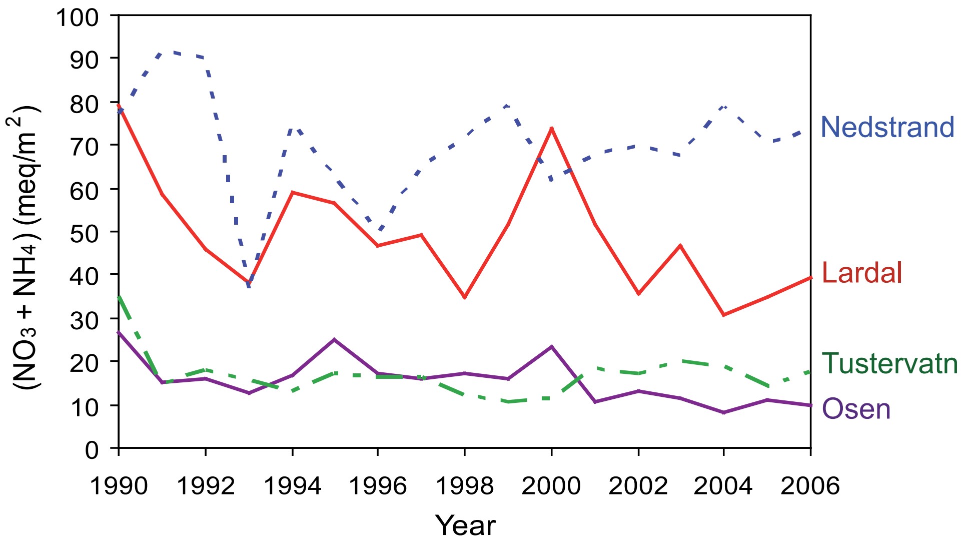

Figure 2. Time series for deposition of inorganic nitrogen in bulk deposition at four Norwegian Level II plots.

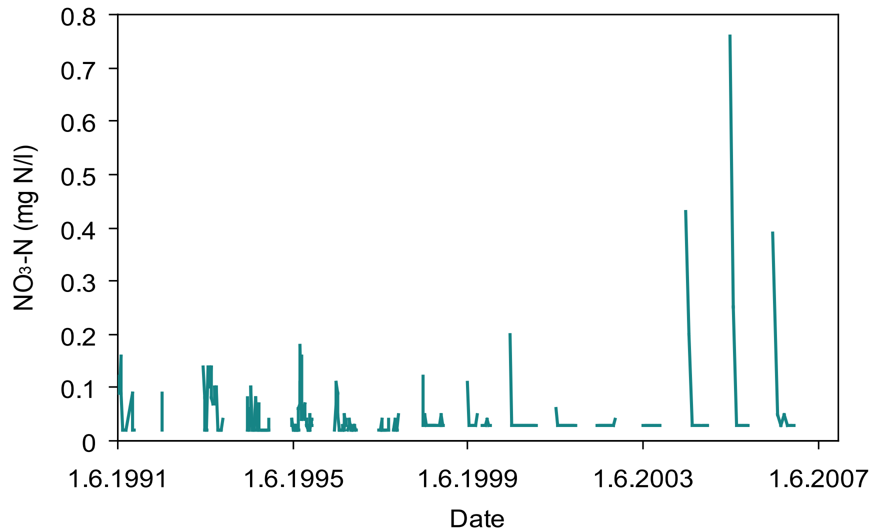

Figure 3. Time series for nitrate concentrations in soil water at 40 cm depth, Lardal.

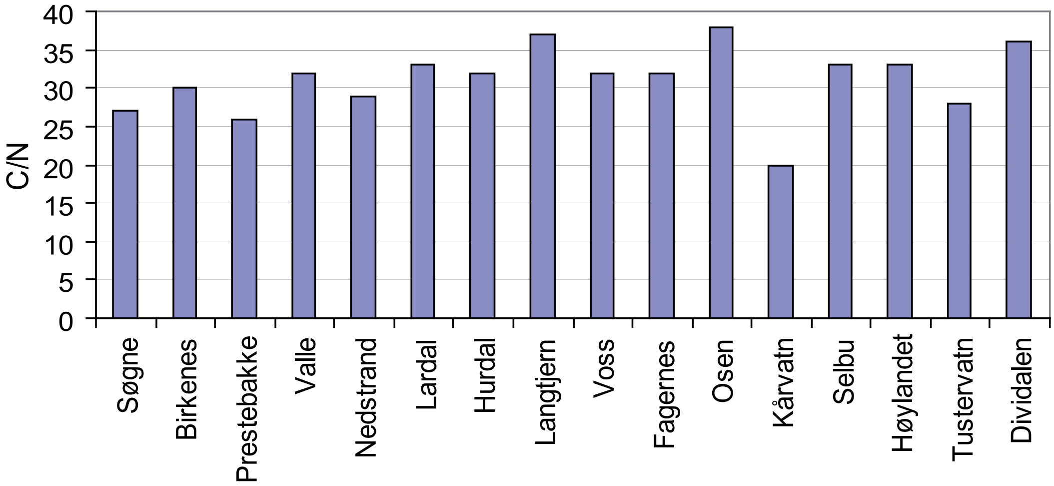

Figure 4. The C/N ratio in the soil organic horizon of the Norway spruce plots. The plots are sorted in the order south (left) to north (right).

The C/N ratio in the organic horizon of the soil on the Norway spruce plots tends to be lower in southern Norway, although above the threshold value of 25 given by e.g. Gundersen et al. (2006) for elevated nitrate leaching at all plots except at the former grey alder site at Kårvatn (Fig. 4).

Nitrogen concentrations in needles are often highest on plots in the south; they are, however, generally low, mostly below deficiency levels even on the southernmost plots (Fig. 5).

Nitrogen concentrations in above-ground tree litter on plots with Norway spruce have tended to be higher in southern Norway, except at the former grey alder plot (Fig. 6). For nitrogen fluxes, the pattern is less clear. Scots pine litter had lower nitrogen concentrations than Norway spruce litter.

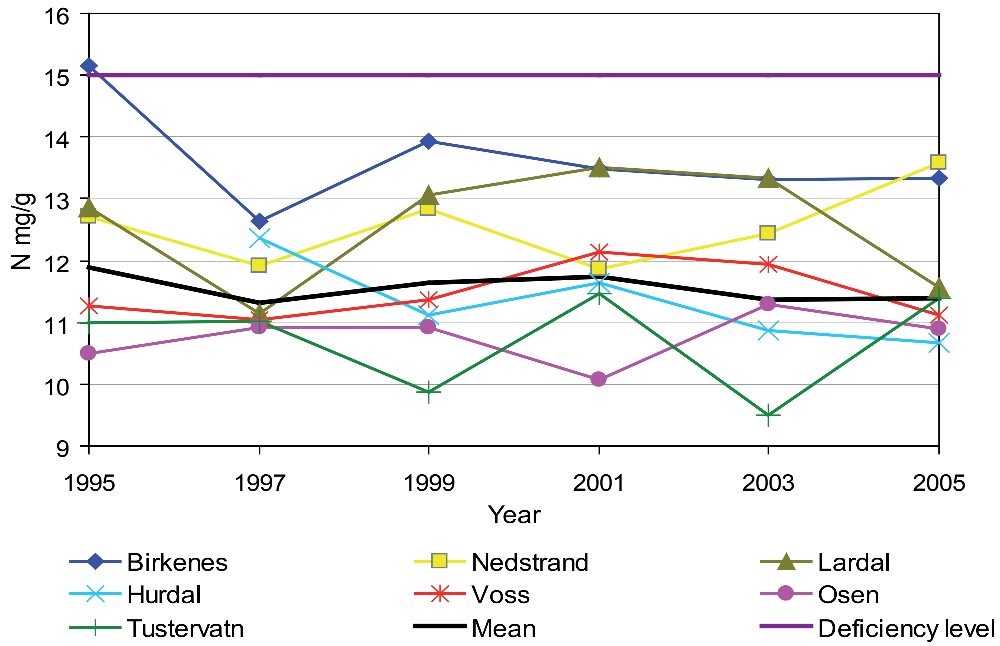

Figure 5. Time series for N concentrations in Norway spruce needles. Deficiency level according to Brække (1994).

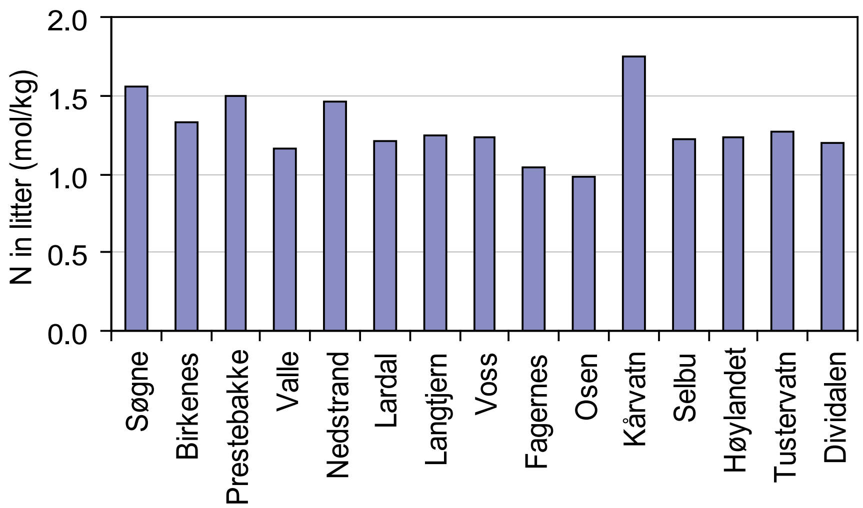

Figure 6. Mean N in above-ground tree litter for the Norway spruce plots for the period 1988/89 – 1991. The plots are sorted in the order south (left) to north (right).

Increased tree growth in southern Norway is compatible with higher nitrogen deposition there, as suggested by Solberg et al. (2004). This is in agreement with results from elsewhere in Europe.

Few changes in the ground vegetation of the plots can be linked with nitrogen deposition. Wavy hair-grass (*Avenella flexuosa* (L.) Drejer), which is an indicator of nitrogen deposition, has increased on plots in eastern Norway but decreased at Nedstrand and Kårvatn in western Norway.

In conclusion, there appear to be some indications of effects of higher nitrogen deposition in the south of Norway, including greater tree growth, higher concentrations of nitrogen in the soil and plant material, and an increase in wavy hair-grass at some plots. However, it remains uncertain whether nitrogen saturation has been reached in Norwegian forest ecosystems, with the exception of alder woodlands.

References

Brække, F.H. 1994. Diagnostiske grenseverdier for næringselementer i gran- og furunåler. Aktuelt fra skogforskningen 15/94: 1 – 11.

Gundersen, P., Schmidt, I.K. & Raulund-Rasmussen, K. 2006. Leaching of nitrate from temperate forests – effects of air pollution and forest management. Environmental Reviews 14: 1 – 57.

Solberg, S., Andreassen, K., Clarke, N., Tørseth, K., Tveito, O.E., Strand, G.H. & Tomter, S. 2004. The possible influence of nitrogen and acid deposition on forest growth in Norway. Forest Ecology and Management 192: 241 – 249.

Role of roots in boreal forest carbon and nutrient cycling

Heljä-Sisko Helmisaari[1)], Krista Lõhmus[2)], Ivika Ostonen[2)], John Derome[3)], Antti-Jussi Lindroos[1)], Päivi Merilä[4)] & Pekka Nöjd[1)]

[1)] Metla, Vantaa Research Unit, P.O.Box 18, FI-01301 Vantaa, helja-sisko.helmisaari@metla.fi
[2)] University of Tartu, Institute of Geography, Vanemuise 46, EE-51014 Tartu, Estonia
[3)] Metla, Rovaniemi Research Unit, P.O.Box 16, FI-96301 Rovaniemi
[4)] Metla, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano

Introduction

The assessment of root carbon quantity and longevity is important for the determination of carbon cycles in forest ecosystems. The active part of the roots, i.e. the fine roots with their mycorrhizas, liberate large amounts of assimilated carbon into the soil in the form of root litter and exudates. The carbon and nutrient inputs into forest soil in root litter may be several times larger than the inputs from aboveground litter (Ruess et al. 1996, Scheffer and Aerts 2000). Thus, there is a wide consensus in the scientific community that the roots of trees and ground vegetation play an important role in the carbon and nutrient dynamics of forest soils, but that there is not enough quantitative information about their contribution to the carbon and nutrient budgets (Gower et al. 1994, Matamala et al. 2003, Trumbore and Gaudinski 2003).

Most of the studies carried out on roots in forests have concentrated on tree roots only. Although the ground vegetation represents a relatively minor component of the whole biomass of boreal forests, it plays an important role in annual biomass production and C and nutrient cycling, especially in northern latitudes (Chapin 1980, Helmisaari 1995, Olsrud and Christensen 2004).

Fine roots with their mycorrhizas play a key role in most of the stages of nutrient cycling (uptake from the soil, utilization for growth and maintenance, return to the soil in litter, release in decomposition). Several reports have also shown their importance in the weathering of mineral nutrients (Jongmans et al. 1997), and in the mobilization of organic nitrogen (Näsholm et al. 1998).

Quantification of the role of fine roots in the biological cycling of nutrients requires estimations of root biomass, turnover rate, and nutrient concentrations. Empirical data have recently been used for developing models for quantifying fine root biomass (Finér et al. 2007, Helmisaari et al. 2007), whereas the estimation of root turnover rates and their relationship to environmental factors in different species and sites still remains a challenge. The rate of growth, as well as the longevity of fine roots, are affected by the availability of carbohydrates and mineral nutrients, and by environmental factors such as soil temperature and moisture. The relationships between fine root dynamics and these factors are not well known. This means that the spatial and temporal variability in root turnover rates still have to be incorporated in global change models (Matamala et al. 2003).

The aims of our study were 1) to quantify the variation in Norway spruce and Scots pine fine roots and ectomycorrhizas, and ground vegetation belowground biomass, in different sites in Finland,

and 2) to assess how fine roots and ectomycorrhizas, and their N concentrations, are related to site and stand characteristics.

Boreal forests are characterised by a cold climate, a long period of snow cover, and relatively slow decomposition of organic matter. N availability largely restricts the primary production of boreal forest, and different strategies have developed for increasing plant N uptake. Our aim was also to test the functional balance theory, which assumes that a plant allocates growth between its roots and shoots in such a way that the N concentrations in the assimilating foliage are kept at an optimal level.

Materials and methods

Sites

We studied the fine root distribution and root C and N concentrations in 16 coniferous stands in Finland. We also estimated the needle biomasses and N concentrations. The study was carried out in eight Norway spruce (*Picea abies* L. Karst.) and eight Scots pine (*Pinus sylvestris* L.) stands. The stands belong to the intensive monitoring network of the EU/Forest Focus and UN-ECE/ICP Forests Level II monitoring programmes (Merilä et al. 2007). The stands are located in different parts of Finland and represent relatively different climate, site types and stages of stand development. The site types varied from xeric to herb-rich. All the stands were mature: 10 stands were between 55 and 90 years old, and 6 between 120 and 200 years old. The managed stands were relatively homogeneous, but the unmanaged ones had a more uneven spatial distribution of the trees. In this study the stands located below latitude 64ºN were considered to be in southern Finland, and those to the north of this latitude in northern Finland.

Fine root and ectomycorrhiza sampling and analysis

Fine root samples for biomass and nutrient determinations were taken during July-August 1998 in all 16 stands. From each stand, 12 root cores were taken with a cylindrical soil corer from the buffer zone along the four sides of one of the sub plots. The cores were divided up into sections comprising the organic layer, and the 0 – 5 cm, 5 – 10, 10 – 20 and 20 – 40 cm mineral soil layers. The roots were separated from the soil by washing, sorted into living and dead roots, and further sorted into pine, spruce, birch and other broadleaved roots, and ground vegetation (mainly dwarf shrubs and grasses) roots and rhizomes, based on their microscopic morphology and colour. The roots smaller than 1 mm in diameter were also separated, and they included mycorrhizal short root tips. The roots smaller than 2 mm were regarded as fine roots, and roots with a diameter of 2 – 5 mm as small roots (Helmisaari et al. 2007).

Ectomycorrhiza (EcM) samples were taken in August 2007 from 10 of the stands – 5 spruce and 5 pine stands (organic layer and 10 – 15 cm mineral soil layer, 8 samples per plot) for analysis of their morphological parameters (Ostonen et al. 2007) and N concentration (Helmisaari et al., in prep.).

The root samples were dried at 70°C for 48 h, weighed and milled. Total N was determined, as well the ash content – which in all cases was less than 6%. The fine root biomasses in the mineral soil were corrected for the presence of stones using the stoniness index (Tamminen 1991).

Stoniness varied in the spruce stands between 16 and 51% of the soil volume (0 to 30 cm mineral soil layer), and in the pine stands between 0.5 and 9 %.

Aboveground measurements

Each stand contained three sub-plots, 30 x 30 m in size, and a surrounding buffer zone. The stand measurements used in this study were made in 1999 on all three sub-plots in each stand. Tree species, diameter, tree height and the crown length were measured on all the trees on the plot with a BHD of at least 4.5 cm. This allowed accurate determination of individual tree volumes and basal areas, as well as the respective stand level characteristics. Needle biomass estimates for individual trees were calculated using the functions of Marklund (1988). For the determination of needle N and C concentrations used in this study, sample branches with current needles were collected in 1997 from the uppermost third of the living crown on 10 predominant or dominant sample trees on each site, and pretreated and analysed as described in Merilä et al. (2007).

Results and discussion

There were more fine roots in the north than in the south, but there were no significant differences between the species. In the north, and on the least fertile site types, roots and rhizomes accounted for over one half of the ground vegetation plant biomass, and are thus important in ecosystem-level nutrient cycling (Helmisaari et al. 2007).

There was a negative relationship between fine root biomass and the effective temperature sum, and a positive relationship between the fine root biomass and the C/N ratio in the organic layer (Helmisaari et al. 2007). If fine root turnover rate is also higher (and fine root age shorter) in a resource-poor environment, then this would mean high C costs. Therefore, we can assume that fine roots live longer in the north and/or on less fertile sites with a high C/N ratio, and longer longevity could be related to the optimization of nutrient uptake (Helmisaari et al. 2007). The first results on fine root longevity using a minirhizotrone installed in Kivalo, northern Finland, support this hypothesis (Helmisaari et al., in prep.).

Our results, and recent other findings, showed that a low N availability (due to low soil fertility or a short growing season, or both) results in relatively more C allocated to fine roots and ectomycorrhizas and their external mycelia which, in turn, improves N uptake. The foliage/fine root ratio decreased in both spruce and pine on moving from south to north, as well as from fertile to more infertile site types (Helmisaari et al. 2007). The higher foliage/fine root ratio for spruce, and the more superficial rooting pattern compared with pine, reflect the sensitivity of spruce to extreme weather phenomena such as drought. Ostonen et al. (2007) reported that the short-root morphological parameters of Norway spruce were also more sensitive to different site and climatic conditions than those of Scots pine.

More fine roots and EcM´s are needed to maintain a specific amount of aboveground biomass when nutrient availability is lower. According to our results, a spruce or pine in the north had more than double the number of fine roots per basal area than a tree in the south (Helmisaari et al. 2007). The ranges of N concentrations in fine roots and ectomycorrhizas were broad and reflected site fertility, whereas the foliage N ranges were narrower, supporting our hypothesis (Helmisaari et al., in prep.).

Since the belowground and aboveground parts of woody plants are closely linked, a whole-tree/ecosystem approach is necessary for estimating and understanding the role of fine roots and their mycorrhizas in carbon and nutrient cycling. Such knowledge is needed in order to obtain a more accurate estimate of the role played by the soil in the global carbon budget, a better understanding of plant productivity under changing water and nitrogen regimes, and to achieve sustainable ecosystem management. For this purpose, the EU/Forest Focus and UN-ECE/ICP Forests Level II monitoring programmes provide an excellent network.

References

Chapin, F.S. III. 1980. Nitrogen and phosphorus nutrition and nutrient cycling by evergreen and deciduous understory shrubs in an Alaskan black spruce forest. Can. J. For. Res. 13(5): 773–781.

Finér, L., Helmisaari, H-S., Lõhmus, K., Majdi, H., Brunner, I., Børja, I., Eldhuset, T., Godbold, D., Grebenc, T., Konôpka, B., Kraigher, H., Möttönen, M-R., Ohashi, M., Oleksyn, J., Ostonen, I., Uri, V. & Vanguelova, E. 2007. Variation in fine root biomass of three European tree species: Beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* L. Karst.) and Scots pine (*Pinus sylvestris* L.). Plant Biosystems 141(3): 394–405.

Gower, S.T., Gholz, H.L., Nakane, K. & Baldwin, V.C. 1994. Production and allocation patterns of pine forests. Ecological Bulletins 43: 115–135.

Helmisaari, H.-S. 1995. Nutrient cycling in *Pinus sylvestris* stands in eastern Finland. Plant and Soil 168–169: 327–336.

Helmisaari, H.-S., Derome, J., Nöjd, P. & Kukkola, M. 2007. Fine root biomass in relation to site and stand characteristics in Norway spruce and Scots pine stands. Tree Physiology 27: 1493–1504.

Jongmans, A.G., van Breemen, N., Lundström, U., van Hees, P.A.W., Finlay, R.D., Srinivasan, M., Unestam, T., Giesler, R., Melkerud, P-A. & Olsson, M. 1997. Rock-eating fungi. Nature 389: 682–683.

Marklund, L.G. 1988. Biomassafunktioner för tall, gran och björk i Sverige. Institut av skogstaxering, Sveriges Lantbruksuniversitet. Rapp. No 45.

Matamala,R., Gonzàlez-Meler, M.A., Jastrow, J.D., Norby, R.J.& Schlesinger, W.H. 2003. Impacts of Fine Root Turnover on Forest NPP and Soil C Sequestration Potential. Science 302(5649): 1385–1387.

Merilä, P., Kilponen, T. & Derome, J. (eds.). 2007. Forest condition monitoring in Finland – National report 2002–2005. Working Papers of the Finnish Forest Research Insitute 45. 166 p. Available at: http://www.metla.fi/julkaisut/workingpapers/2007/mwp045.htm.

Näsholm, T., Ekblad, A., Nordin, A., Giesler, R., Högberg, M.& Högberg, P. 1998. Boreal forest plants take up organic nitrogen. Nature 392: 914–916.

Olsrud, M. & Christensen, T.R. 2004. Carbon cycling in subarctic tundra: seasonal variation in ecosystem partitioning based on in situ ^{14}C pulse-labelling. Soil Biology and Biogeochemistry 36: 245–253.

Ostonen, I., Lõhmus, K., Helmisaari, H.-S., Truu, J. & Meel, S. 2007. Fine root morphological adaptations in Scots pine, Norway spruce and silver birch along a latitudinal gradient in boreal forests. Tree Physiology 27: 1627–1634.

Ruess, R.W., Van Cleve, K., Yarie, J. & Viereck, L.A. 1996. Contributions of fine root production and turnover to the carbon and nitrogen cycling in taiga forests of the Alaskan interior. Can. J. For. Res. 26: 1326–1336.

Scheffer, R.A. & Aerts, R. 2000. Root decomposition and soil nutrient and carbon cycling in two temperate fen ecosystems. Oikos 91: 541–549.

Tamminen, P. 1991. Kangasmaan ravinnetunnusten ilmaiseminen ja viljavuuden alueellinen vaihtelu Etelä-Suomessa. Summary: Expression of soil nutrient status and regional variation in soil fertility of forested sites in southern Finland. Folia Forestalia 777. 40 p.

Trumbore, S.E. & Gaudinski, J.B. 2003. The Secret Lives of Roots. Science 302: 1344–1345.

Litterfall production and element return to the soil in Scots pine and Norway spruce stands in Finland

Liisa Ukonmaanaho [1], Päivi Merilä [2], Pekka Nöjd [1] & Tiina M. Nieminen [1]

[1] Metla, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland, liisa.ukonmaanaho@metla.fi
[2] Metla, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland

Introduction

A significant proportion of terrestrial net primary production is recycled from the trees as litterfall to the forest floor and, subsequently, into the detritus food web. Therefore in forest ecosystems litterfall is the major pathway through which soils, depleted by nutrient uptake and leaching, are replenished (Morrison 1991). Moreover, litterfall represents one of the primary links between producers and decomposers (Fyles et al. 1986). Thus litterfall provides considerable information about the dynamics of nutrient cycling within forest ecosystems.

Foliar litter is the major component of aboveground litterfall in boreal forest ecosystems, although other components like bark can be important in some areas, e.g. in eucalyptus forests (Kimmins 1987). The quantity of aboveground litterfall is closely linked to the proportion of senescent foliage biomass, which varies from year to year and between species: the longer the retention of foliage, the smaller the amount of litterfall. The element concentration of needle litter is affected by several factors, of which tree species, soil properties and the growth rate of the trees have generally been considered to be the most important factors (e.g. Miller et al. 1979, Boerner 1984, Nambiar and Fife 1987, Helmisaari 1992). Element concentrations in other above-ground tree compartments (bark, branches, stemwood) vary according to the intensity of element uptake, the phase in the annual cycle (e.g. Tamm 1955, Fife and Nabiar 1982, 1984, Helmisaari 1990), and the size and age of the tree (e.g. Mälkönen 1974, Helmisaari 1990).

The main objective of this study was to compare the above-ground tree biomass and litterfall and their element concentrations, pools and fluxes in different types of stand, including element return to the soil. Six Scots pine and eight Norway spruce dominated plots were included in the study. The elements studied were: nitrogen (N), calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), sulphur (S), manganese (Mn), zinc (Zn) and iron (Fe).

Materials and methods

Study area

The study was carried out on eight Norway spruce (*Picea abies* L. Karst.) and eight Scots pine (*Pinus sylvestris* L.) plots in Finland. These plots are being monitored as part of the UN-ECE/ICP Forests, UN-ECE/Integrated Monitoring and EU/Forest Focus forest condition monitoring programmes. The design of the monitoring plots is described in detail in Merilä et al. (2007).

Sampling

Litterfall was collected using 12 funnel-shaped traps (collecting area = 0.5 m^2) during 1996 to 2003. Litterfall was sampled bi-weekly during the snow-free period (May to November, depending on the latitude of the plot), and once at the end of the winter. After collection, all the litter samples were air-dried and sorted into at least four fractions: green pine needles/senescent needles, spruce needles and miscellaneous litter (twigs, leaves, cones, bark, flowers etc.). Living needles were collected from the uppermost third of the predominant or dominant trees (n = 10) on each study plot during October – November, 2005. The shoots were dried at 40°C for 10 days and the needles then removed from the shoots. In addition, 5 trees were felled during spring 2006 on each of the plots. A 5 cm thick disc was taken from each trunk at a height of 1.3 m above ground level (breast height). The living canopy of each tree was divided into four sectors, and living branches and young shoots were randomly taken from each sector. In addition, dead branches were taken from each felled tree and bulked on the site. Biomass estimates for the individual trees were calculated using the functions of Marklund (1987, 1988). These functions were used to depict the biomass components (stemwood, bark, living and dead branches, needles) as a function of tree species.

Chemical analyses and data analysis

The different biomass components (stemwood, bark, living branches, dead branches), needles and litterfall samples were dried at a temperature of 40ºC, milled and digested using microwave-assisted digestion with HNO_3 acid + H_2O_2. The concentrations of Ca, K, Mg, Mn, P, S, Fe, Zn were determined by inductively coupled plasma emission spectrometry (ICP-AES). The total N concentration was determined on a LECO CHN analyser.

In order to estimate the proportions of the above-ground tree biomass and nutrient pool that are annually returned to the soil as litterfall, the turnover rate % was calculated: Nutrient amount in the annual litterfall (kg ha^{-1} yr^{-1}) * 100 / Nutrient pool in the above-ground tree biomass (kg ha^{-1}).

Results and discussion

Biomass amounts and element concentrations

The above-ground tree biomass ranged from 83 600 kg ha^{-1} to 174 900 kg ha^{-1} on the pine plots and 42 600 kg ha^{-1} to 209 000 kg ha^{-1} on the spruce plots, and was higher on the average on the spruce plots. Stemwood composed on the average 80% of the biomass of pine, the remaining 20% representing living branches (9%), bark (6%), needles (3%) and dead branches (2%). For spruce on the average only 63% of the biomass represented stemwood, and the remainder consisted of living branches (19%), needles (10%), bark (6%) and dead branches (2%). The concentrations of all the studied elements in different above-ground tree biomass components were also higher on the spruce plots than on the pine plots. For most of the elements, needle concentrations were the highest, followed in decreasing order by bark, living branches, dead branches, stemwood. On both the spruce and pine plots N, Ca and K comprised the major element pool in the different above-ground tree biomass components.

The mean total annual litterfall production varied between the years and plots. The mean amount of annual litterfall on the spruce plots ranged from 651 to 4 912 kg ha^{-1}, and on the pine plots from 1 325 to 3 402 kg ha^{-1}, being on the average higher on the spruce plots (2 768 kg ha^{-1}) than on the pine plots (2 225 kg ha^{-1}). The lowest litterfall production in both the pine and spruce stands was on the northernmost plots at Kivalo (plots 5 and 6) and at Pallasjärvi (3). There was also considerable variation in needle litterfall production between the plots and years. On the average there was a slightly higher needle litterfall production on the spruce plots (58%) than on the pine plots (56%). In general, the element concentrations in the litterfall were also higher on the spruce plots, which is consistent with the results of earlier studies (e.g. Johansson 1995). The concentrations of Ca, Mg and Mn were higher in needle litterfall, while the Al, Fe, N, P and S concentration were higher in miscellaneous litter for both species.

Element turnover rate

The annual return of N through litterfall to the forest floor was the highest of all the elements studied; the annual return of N in total litterfall was on the average 21 kg ha^{-1} yr^{-1}, with a higher rate of return on the spruce plots (x = 27 kg ha^{-1} yr^{-1}) than on the pine plots (x = 14 kg ha^{-1} yr^{-1}). For Ca the annual return was on the average 15 kg ha^{-1} yr^{-1}, being higher on the spruce plots than on the pine. The mean annual return of the other elements in litterfall were much smaller than those for N and Ca: for K 5 kg ha^{-1} yr^{-1}, Mg 2 kg ha^{-1} yr^{-1}, S 2 kg ha^{-1} yr^{-1}, Mn 2 kg ha^{-1} yr^{-1}, P 2 kg ha^{-1} yr^{-1}, Fe 0.4 kg ha^{-1} yr^{-1} and Zn 0.1 kg ha^{-1} yr^{-1} (average of the both spruce and pine plots).These return values are similar to those reported in other studies (e.g Edmonds and Murray 2002).

The mean turnover rate % (= the ratio between element return to the soil within litterfall and elements immobilized within above-ground tree biomass) for both tree species was at a similar level. However, the turnover rate for each of the elements was greater on the pine than on the spruce plots, apart from Mg. The N and S turnover rates appeared to decrease on moving towards the north, especially in the case of pine. This decreasing trend seemed to be related more to latitude and annual litterfall production than to site fertility.

References

Boerner, R.E.J. 1984. Foliar nutrient dynamics and nutrient use efficiency of four deciduous tree species in relation to soil fertility. J. Appl. Ecol. 21: 1029 – 1040.

Edmonds, R.L. & Murray, G.L.D. 2002. Overstorey litter inputs and nutrient returns in an old-growth temperate forest ecosystem, Olympic National Park, Washington. Canadian Journal of Forest Research 32: 742 – 750.

Fife, D.N. & Nambiar, E.K.S. 1982. Accumulation and retranslocation of mineral nutrients in developing needles in relation to seasonal growth of young Radiata pine trees. Ann. Bot 50: 817 – 829.

Fife, D.N. & Nambiar, E.K.S. 1984. Movements of nutrients in Radiata pine needles in relation to the growth of shoots. Ann. Bot 54: 303 – 314.

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

Helmisaari, H-S. 1990. Nutrient retranslocation within Pinus sylvestris. University of Joensuu 17. 13 p. (thesis summary)

Helmisaari, H-S. 1992. Nutrient retranslocation in three Pinus sylvestris stands. Forest Ecology and Management 51: 347 – 367.

Johansson, M-B. 1995. The chemical composition of needle and leaf litter from Socts pine, Norway spruce and whte birch in Scandianavian forests. Forestry 68(1): 49 – 63.

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

Marklund, L.G. 1987. Biomass functions for Norway spruce in Sweden. Swedish University of Agricultural Sciences, Department of Forest Survey. Report 43. 127 p.

Marklund, L.G. 1988. Biomassafunktioner för tall, gran och björk i Sverige. Sveriges landsbruksuniversitet, Inst. Skogstaxering. Rapp. No 45. 73 p.

Merilä, P., Kilponen, T. & Derome, J. 2007. Forest Condition Monitoring in Finland. National Report 2002 – 2005. Working Papers of the Finnish Forest Research Institute 45. 166 p.

Miller, H.G., Cooper, J.M, Miller, J.D. & Pauline, O.J. 1979. Nutrient cycles in pines and their adaptation to poor soils. Canadian Journal of Forest Research 9: 19 – 26.

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.

Mälkönen, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Communicationes Instituti Forestalis Fenniae 84.5. 87 pp.

Nambiar, E.K.S. & Fife, D.N. 1987. Growth and nutrient retranslocation in needles of Radiata pine in relation to nitrogen supply. Ann. Bot. 60: 147 – 156.

Tamm, C.O. 1955. Studies on forest nutrition. I Seasonal variation in the nutrient content of conifer needles. Medd. Stat. Skogsforsken. Inst. 45(5): 1 – 34.

Short-term changes (1998 – 2003) in the boreal understorey vegetation on the Finnish Level II plots

Maija Salemaa [1], John Derome [2] & Antti-Jussi Lindroos [1]

[1] Vantaa Research Unit, Finnish Forest Research Institute, P.O. Box 18, FI-01301 Vantaa, Finland, maija.salemaa@metla.fi
[2] Rovaniemi Research Unit, Finnish Forest Research Institute, P.O. Box 16, FI-96301 Rovaniemi, Finland

Background and aims

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 florestic composition, and 2) to detect temporal changes in the vegetation in relation to natural and anthropological environmental factors. The state of the vegetation provides important background data for understanding forest ecosystem dynamics. In boreal forests, the understorey vegetation plays an important role in e.g. the regeneration of trees, and in belowground processes such as decomposition, nutrient flow, and the accumulation of soil nutrients (Nilsson and Wardle 2005). Changes in plant populations and communities have great indicative value in detecting climatic change and the effects of deposition (Kokko et al. 2002, Økland et al. 2004). In this presentation we analyse the short-term changes (1998 – 2003) in the understorey vegetation of the mineral soil Level II plots in Finland in relation to changes in the weather, chemical composition of the organic layer and atmospheric deposition.

Material and methods

Understorey vegetation on all the Level II plots (n = 31) has been surveyed twice: in 1998, and again after five years in 2003. The sampling design and the methods used have been described in Salemaa et al. (1999), and Salemaa and Hamberg (2007). For the present analysis we chose only the mineral soil plots (n = 26), apart from no. 19 at Evo, southern Finland, because it was inventoried in 1998 using a different sampling design than on the other plots. Plotwise changes in the weather factors (temperature sum and annual precipitation) between 1998 and 2003 were derived from model interpolations (Ojansuu and Henttonen 1983). The samples for determining the chemical composition of the organic layer (pH, total N and exchangeable nutrient concentrations extracted by ammonioum acetate, pH 4.65) were taken simultaneously on the vegetation sub-plots in 1998 and 2003. The relationship between the changes in vegetation and N deposition were studied only in a smaller set of "core plots" (n = 15) where deposition monitoring is carried out. Plotwise deposition levels have been published in the national reports (e.g. Lindroos et al. 2000, 2007).

The change in the cover % in four plant groups (dwarf shrubs, herbs & grasses, bryophytes and lichens) between 1998 and 2003 was studied by paired t-tests. Ordination patterns (Non-metric multidimensional scaling) of the whole plant communities in 1998 and 2003 were compared using Procrustes rotation (Vegan library, Oksanen 2004). The relationships between vegetation and environmental changes were studied using Pearsson correlations.

Results and discussion

The understorey vegetation has remained relatively constant during the period 1998–2003. The main compositional variation in the vegetation ordinations represented the site fertility gradient, combined with climatic factors, in both study years. Comparison of the ordination patterns by Procrustes errors did not indicate any general directional change in the species composition between the two years (Fig. 1). However, individual plots showed discrete changes that were probably regulated by the local conditions.

In general, the cover % of bryophytes and lichens increased on the northern Scots pine plots, whereas the cover % of dwarf shrubs slightly decreased on the northern Norway spruce plots (Fig. 2a,b). On the other hand, an increasing trend in the cover % of dwarf shrubs was found in southern Finland, but the cover of bryophytes as well as herbs and grasses simultaneously decreased (Fig. 2c,d).

2003 was a warmer and dryer year than 1998. In northern Finland the mean difference in the temperature sums between 2003 and 1998 was +175°C (n = 12 plots) and in southern Finland +143°C (n = 14). The mean difference in the precipitation sums in the corresponding period was -198 mm in northern and -127 mm in southern Finland. The slight increase in the cover of bryophytes correlated with the increase in temperature on the northern plots ($r = 0.554$, $p = 0.062$, $n = 12$), but the change in precipitation had no clear effect. On the other hand, the decreased precipitation was reflected as a decreasing trend in the cover of dwarf shrubs, especially on the northern plots ($r = 0.433$, $p = 0.160$, $n = 12$). The few significant correlations between the

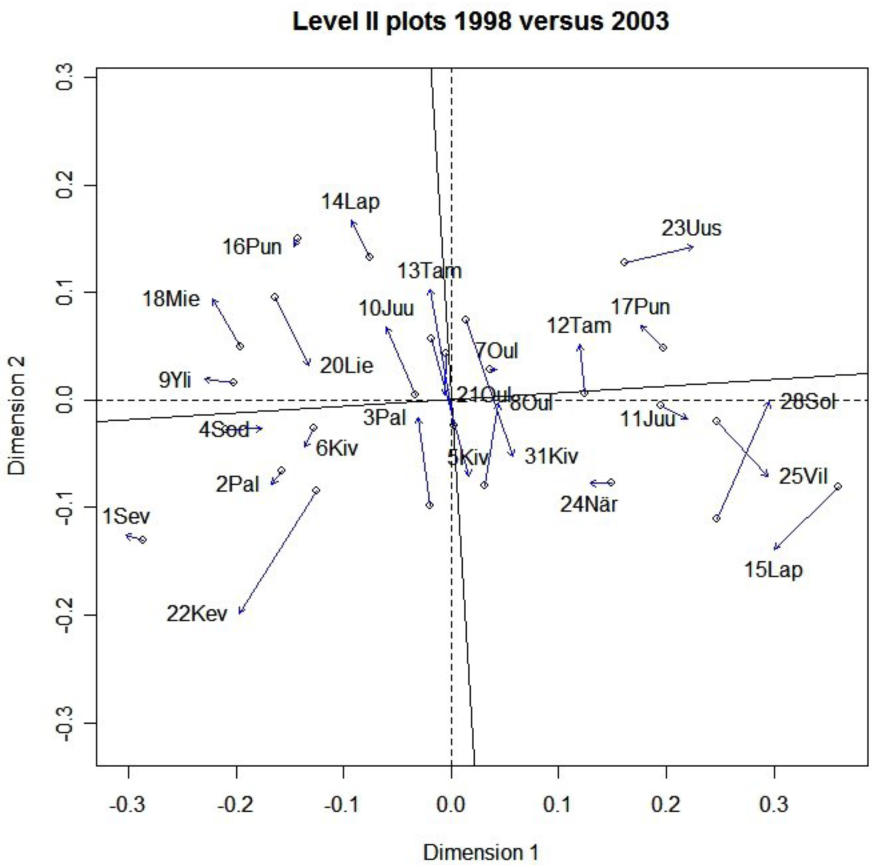

Figure 1. Change in the ordination of 26 mineral soil sample plots (Global non-metric multidimensional sacling) in 1998 (base) and 2003 (point of the arrow) using Procrustes rotation.

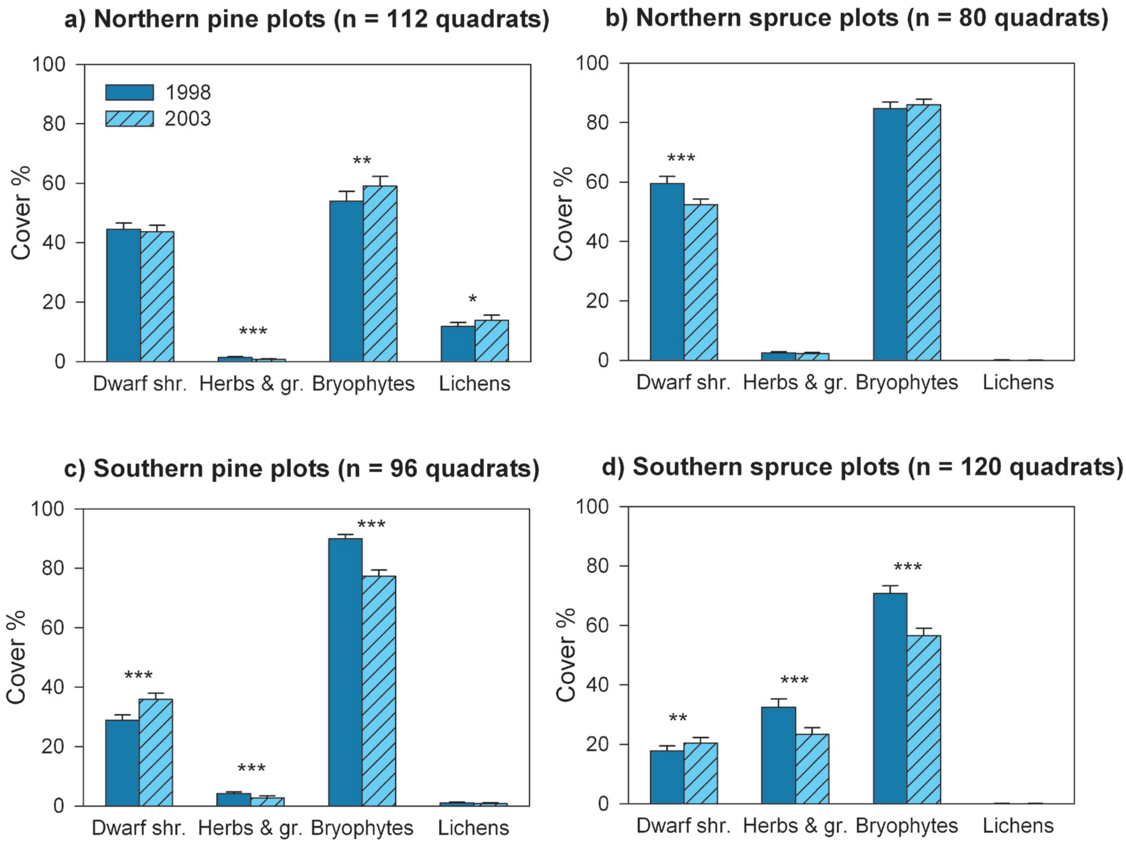

Figure 2. Mean cover % (+se) of dwarf shrubs, herbs and grasses, bryophytes and lichens on a) the northern pine plots, b) northern spruce plots, c) southern pine plots, and d) southern spruce plots in the same quadrats in 1998 and 2003. Data from 26 mineral soil plots. Years compared by paired t-tests: *** : $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$.

vegetation and weather changes may be due to the use of modelled climatic parameters (Ojansuu and Henttonen 1983), which can differ from the actual situation on the plots.

The change in the chemical composition of the organic layer was small between the two study years, and may reflect the high spatial variability in the chemical properties of the organic layer. Generally, there were no significant correlations between the change of the cover of plants and the change of the nutrient concentrations in the organic layer. The cover of *Vaccinium myrtillus* showed an increasing trend with the increase in the total nitrogen concentration in the organic layer in southern Finland ($r = 0.300$, $p = 0.298$, $n = 14$). The clearest factor affecting the cover of bryophytes was the amount of needle litter on the forest floor. The greater the increase in the cover of needle litter, the stronger was the decrease in the cover of bryophytes ($r = -0.754$, $p = 0.000$, $n = 26$). There was a positive relationship between the amount of needle litterfall in 2002 (Ukonmaanaho 2007) and the % cover of shed needles on the forest floor in 2003 ($r = 0.723$, $p = 0.043$, $n = 8$). Thus the crown dynamics of the trees may regulate the abundance of understorey species. Furthermore, the increase in the cover of dwarf shrubs correlated negatively with the change of cover of bryophytes ($r = -0.432$, $p = 0.028$, $n = 26$), reflecting the negative effect of shading by vascular plants on the moss layer.

Although nitrogen deposition was lower in 2003 than in 1998 on the Level II core plots, there was no decreasing trend during the five-year period due to the high annual variation (Lindroos et al. 2000, 2007). Deposition is dependent on the amount of precipitation, and it is difficult to separate the effect of moisture from the effect of nitrogen input on plant occurrence. Nitrogen is a limiting factor for the growth of boreal vegetation, and species with a high nitrogen use efficiency (i.e. productivity per unit nitrogen taken up) may receive a competition advantage. Bryophytes are an interesting plant group in the respect that they obtain most of their water and nutrients from atmospheric deposition. On the Level II core plots the cover of bryophytes decreased with a decrease in the amount of total nitrogen in bulk deposition ($r = 0.574$, $p = 0.025$, $n = 15$). The decline varied between the individual bryophyte species, and was the highest in the most dominant species *Pleurozium schreberi*. *Hylocomium splendens*, in contrast, showed no decline. It is possible that even small changes in the amount of nitrogen deposition may affect the growth rate of plant species and therefore change the between species interactions.

Conclusions

Five years is a short period to detect any major changes in the understorey vegetation. No general trend in the species composition was found, but the direction of the changes varied plotwise. Weather factors (precipitation and temperature), the suppressing effect of needle litter and between-species competition appear to explain the observed changes.

References

Kokko, A., Mäkelä, K. & Tuominen, S. 2002. Aluskasvillisuuden seuranta Suomen ympäristön yhdennetyn seurannan alueilla 1988–1998. Summary: Understorey vegetation monitoring at the Finnish Integrated Monitoring areas in 1988–1998. The Finnish Environment 544. 97 p.

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.

Lindroos, A.-J., Derome, J. & Derome, K. 2007. Open area bulk deposition and stand throghfall in Finland during 2001–2004. In: Merilä, P., Kilponen, T. & Derome, J. (eds.) Forest condition monitoring in Finland. National report 2002–2005. Working Papers of the Finnish Forest Reserach Institute 45: 81–92.

Nilsson, M.-C. & Wardle, D.A. 2005. Understorey vegetation as a forest ecosystem driver: evidence from the northern Swedish boreal forest. Frontiers in Ecology 3(8): 421–428.

Ojansuu, R. & Henttonen, H. 1983. Kuukauden keskilämpötilat, lämpösumman ja sademäärän paikallisten arvojen johtaminen ilmatieteen laitoksen mittaustiedoista. Summary: Estimation of the 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.

Oksanen, J. 2004. 'Vegan' Community Ecology Package: ordination methods and other functions for community and vegetation ecologists. University of Oulu, Oulu, FI. Available at: http://cc.oulu.fi/~jarioksa/softhelp/vegan.html

Økland, T., Bakkestuen, V., Økland, R.H., Halvorsen, R. & Eilersten, O. 2004. Changes in forest understorey vegetation in Norway related to long-term soil acidification and climatic change. Journal of Vegetation Science 15: 437–448.

Salemaa, M. & Hamberg, L. 2007. Understorey vegetation on the Level II plots during 1998–2004. In: Merilä, P., Kilponen, T. & Derome, J. (eds.) Forest condition monitoring in Finland. National report 2002–2005. Working Papers of the Finnish Forest Reserach Institute 45: 69–80.

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.

Ukonmaanaho, L. 2007. Litterfall production on 14 Level II plots during 1996–2003. In: Merilä, P., Kilponen, T. & Derome, J. (eds.). Forest condition monitoring in Finland. National report 2002–2005. Working Papers of the Finnish Forest Reserach Institute 45: 63–68.

BioSoil in Finland

Hannu Ilvesniemi, Pekka Tamminen, Tiina Tonteri & Leila Korpela

Finnish Forest Research Institute (Metla), Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland
e-mail: firstname.surname@metla.fi

Background

BioSoil is a demonstration project co-funded under the EU Forest Focus forest monitoring programme. The objective of BioSoil is to measure, using harmonized methods, soil and stand properties and the ground vegetation species composition, in European forests. Harmonization of the methods and evaluation of the project implementation are also among the main aims set for BioSoil.

In Finland, the BioSoil project is being carried out by the Finnish Forest Research Institute (Metla). The data are collected on the plots of the Forest Focus/ICP Level I network (a subset of the 8^{th} NFIpermanent plots). The 636 plots included in Biosoil are located in a systematic 16 km x 16 km grid in southern Finland and a 32 km x 24 km grid in northern Finland.

Soil survey

In the BioSoil soil survey the soils are classified into groups according to the World Reference Base (WRB, FAO et al. 1998) system. At the same time, the field teams have taken samples for soil physical and chemical analysis. Possible changes in soil properties can be detected by comparing the results obtained in 2006 – 2007 with those for the same sites sampled in 1985 and 1995.

The soil survey

The sample plot is a circle with a radius of 11.28 m (400 m^2). Samples were taken from the organic layer (divided into litter (L) and humus (H/O) horizons) and from the 0–10 cm, 10–20 cm, 20–40 cm and 40–80 cm mineral soil layers. 10 sub-samples were taken in the upper layers, and the 40–80 cm sample was taken from the soil pit used for soil type classification. The volume of stones and boulders in the surface soil layer was measured in the field using the Viro rod penetration method.

CEC, BS, pH, organic carbon and total nitrogen concentrations and Aqua regia extractable P, Ca, K, Mg, Mn were determined in the laboratory. The particle size distribution of the mineral soil was measured by either the laser diffraction method or manually, and the results classified according to the USDA-FAO textural classes. All the analyses performed in the participating countries are inter-calibrated, and the quality assurance and quality control organized by INRA (France).

The biodiversity survey

The overall objectives of the biodiversity component of BioSoil are to make an inventory of components of forest biodiversity such as forest structure and species diversity. The results of this inventory can be used as the baseline in the future detection of changes in terrestrial vascular plant species resulting from anthropogenic disturbances and succession cycles.

This is the first time that biodiversity has been surveyed on such a broad, systematic scale in the EU area. Conducting the research with harmonized methods makes it possible to evaluate biodiversity and to compare its state in different countries.

The biodiversity study is based on the measurement of living and dead trees and on the inventory of the ground vegetation. The material can be used to study relationships between the soil, vegetation and trees, because all the measurements have been made on the same plots. The data will also be utilized in other studies, such as improving forest site classification systems and analysing the impacts of atmospheric deposition or climate change on the forests.

On each plot the field team determined the site fertility class and canopy closure, measured the trees and the amount of dead wood, and took photographs of the stand, ground vegetation and canopy. Samples were also taken for ground vegetation biomass determination. Four 2 m^2 permanent monitoring quadrats were established within the plot. All the plant species in the ground and bottom layers and the aerial coverage % of each species were estimated on these quadrats. In addition, all the vascular plant species on the 11.28 m radius plot were identified. More than 1200 plant species were found.

Implementation of the BioSoil project

The field work in 2006 was carried out with 8 field teams for soil sampling and 11 field teams for the biodiversity measurements. The field work was finalized and control measurements were carried out in 2007. The field work is now complete and a large proportion of the laboratory analyses, as well as data quality control, have been perfomed. The total number of working days used so far has been 5,389, of which 3,360 days were spent in the field, 1,128 days on research, and 878 in the laboratory. A total of 107 persons have been involved in the BioSoil Project.

Table 1. The number of species in different plant groups.

		number of species
1	Trees	26
2	Shrubs	42
3	Tree or shrub seedlings	41
4	Dwarf shrubs	20
5	Graminoids (grasses, sedges and rushes)	88
6	Herbs	226
7	Mosses	286
8	Sphagnum-mosses	26
9	Lichens	56

Changes in forest health during 1995–2006 in Finland

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

[1)] Finnish Forest Research Institute, Joensuu Research Unit, P.O. Box 68, FI-80101 Joensuu, Finland
seppo.nevalainen@metla.fi
[2)] Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland

Finland has been participating since 1985 in the ICP Forests Programme, and since 1995 in the EU co-funded forest condition monitoring programme, Forest Focus. The Finnish Forest Research Institute carries out the annual survey of crown condition (defoliation, discoloration, biotic and abiotic damage) on a nationwide network. The results for mineral soil plots of the Level I network during 1995–2006 are presented in this study. The study includes a description of the state of forest condition, as well as a spatial and temporal analysis of the changes.

In general, there were no notable changes in the average defoliation level of Scots pine or Norway spruce during the period 1995 to 2006. The average defoliation degree of pine and spruce in the whole survey period was 10.3% and 19.9%, respectively. The lowest average defoliation level in pine (9.5%) occurred in 1999 (Fig. 1). Since 1999 there has been a slight increase in defoliation in pine, and the highest defoliation degree (11.3%) occurred at the end of the survey period in 2006. In contrary to pine the lowest defoliation degree in spruce was in the last year of the survey period, 2006. The highest defoliation degree in spruce occurred in 2000 and 2002 (Fig. 1).

The proportion of needle discolouration (extent of discoloured needle mass more than 10%) on pine remained at a low level (under 1%) during most of the period, but increased clearly in 1999 and especially in 2006 (Fig. 2). In general, the proportion of discoloured spruce was higher, except in 2006, and varied annually more than that in pine (Fig. 2).

The temporal patterns of the most important causes of damage were evident in the Level I data, and

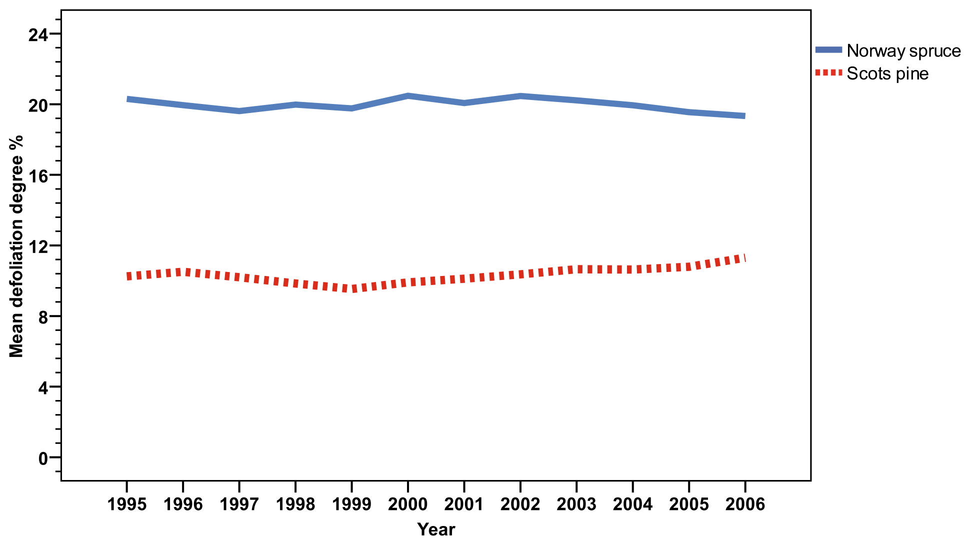

Figure 1. The average defoliation level of Scots pine, and Norway spruce on mineral soil plots during 1995–2006 in Level 1.

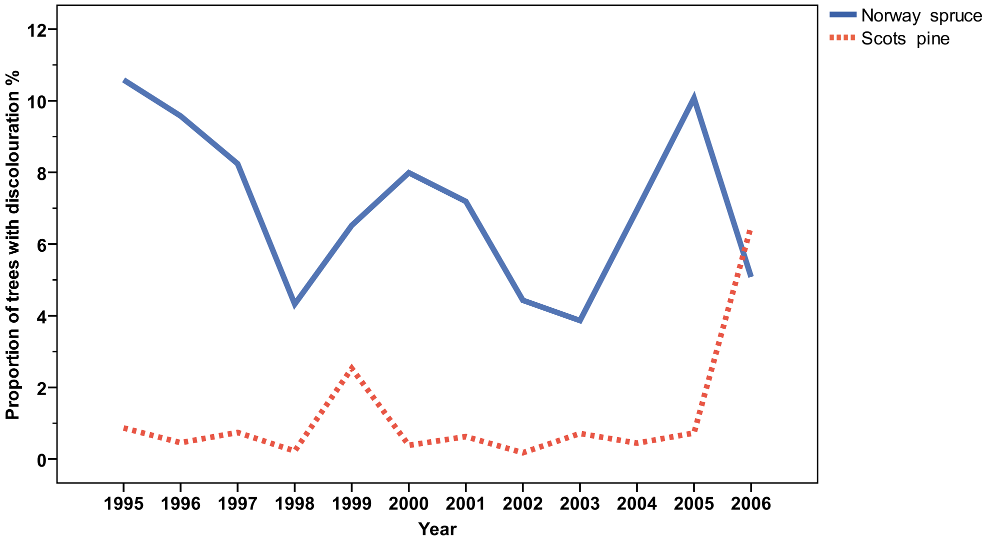

Figure 2. The proportion of discoloured Scots pines and Norway spruces on mineral soil plots during 1995–2006 in Level 1.

coarse spatial distributions were also obtained. There were considerable changes in the occurrence of the different damaging agent groups and specific agents over the years. The proportion of symptomless pines was the lowest in 1997. The year was characterized by a high occurrance of damage by *Gremmeniella abietina*. Other peak years of new infections by this fungus were 2001 and 2004. The pine sawflies (Diprionidae, (*Neodiprion sertifer* and *Diprion pini*) had a distinct peak in 2000. The symptoms caused by edaphic factors (mainly drought) turned out to be very common in 2006. In spruce, the proportion of symptomless trees was the lowest in 2001. The most conspicuous epidemic on spruce was caused by needle rust fungi (mostly *Chrysomyxa ledi*) in 2001 and 2005.

Analysis of the trends showed that the defoliation of pine had increased slightly in the central parts of Finland over the whole period. The defoliation of spruce had increased in the southernmost part of the country and slightly also in the north-western part. Although the changes in the annual mean defoliation were relatively small over the whole country, considerable regional changes were seen between the years. Abrupt temporal and spatial changes were caused by abiotic and biotic factors. Apart from competition, the most important identified abiotic and biotic causes that had directly increased defoliation were *Gremmeniella*, *Tomicus* and Diprionids in pine, and soil factors, *Chrysomyxa*, harvesting injuries and decay fungi in spruce. The overall contribution of abiotic and biotic damage to the defoliation was about 20% in both spruce and Scots pine. The importance of various damaging agents varied both yearly and regionally.

It proved very difficult to model the defoliation or the changes. Most of the weather variables were significant at least once, but the estimates of the effects were not coherent in different years. The model results suggest that the variation between the years was negligible, and that the variation between the plots was larger than that between the trees within the plots. According to regression models, slight but clear effects of air pollution, mainly modelled sulphur deposition, were evident in the defoliation level of spruce in southern Finland, even after the interactions with biotic damage (e.g. decay) were taken into account.

The results of this study confirm that the main threats to the health and condition of Finland's forests are abiotic factors, such as storms, drought, extreme winter conditions, and biotic factors such as insect pests and fungal pathogens.

Water seepage and nitrogen input-output budgets for 8 Danish Level II plots

Lisbeth Sevel, Lars Vesterdal, Karin Hansen, Annemarie Bastrup-Birk & Jesper Riis Christiansen

Forest & Landscape Denmark, University of Copenhagen

Introduction

In Denmark, concern about a shortage of clean ground water in the future has increased the focus on the protective functions of forests. Attention has been paid to the amount of water leached from different forest types, and hence the potential water input into the ground water reserves. The quality of the ground water has also been in focus, especially concerning the risk of nitrate leaching into the ground water reserve.

The aim of this study was to evaluate the difference in the water balance between different tree species and subsequently to estimate the amount of seepage water potentially leaching into the ground water. This work was based on the 8 Danish Level II sites. Leaching of nitrate from a soil depth of 90 cm was estimated and compared with the N input to the forest floor. An input-output budget was estimated in order to evaluate the ability of different types of forest to retain incoming N and hence minimize the risk of nitrate leaching.

Seepage water was sampled using teflon suction cup lysimeters (Prenart Super Quartz, Denmark) installed at 90 cm depth. Throughfall was sampled with polyethylene funnels placed beneath the forest canopy. Both seepage water and throughfall were sampled on a monthly basis during the period 2002–2005. The hydrological balance was modelled using the hydrological COUP model (Jansson and Karlberg 2004). TDR probes were installed on all the Level II sites, and the data were used to calibrate COUP.

Table 1. Site information for the 8 Level II sites. 11 (Ulborg, Klosterheden), 26 (Lindet), 34 (Frederiksborg), 51 (Gludsted), 64 (Als), 74 (Suserup), 85 (Vestskoven), 95 (Hald Ege).

ID	Tree species	Forest practice	Former land use	Planting year	Soil
11	Norway spruce	Plantation	Heathland	1964	Sand
26	Sitka spruce/ Norway spruce	Plantation	Seminatural oak forest	1968	Sand
34	Beech	Plantation	Agricultural land	1964	Clay
51	Norway spruce/Beech	Shelter for beech understory	Plantation/heathland	1942	Sand
64	Beech	Close-to-nature forestry	Forest	1895	Clay
74	Beech/ash/oak	Forest reserve, untouched	Forest	-	Clay
85	Oak	Afforestation/plantation	Agricultural land	1970	Clay
95	Oak	Untouched	Seminatural oak forest	-	Sand

Results

Water balance

Beech and spruce had relatively similar seepage water fluxes of around 200–300 mm, whereas oak had higher seepage fluxes (350–420 mm). However, the precipitation rates differed between the sites, with higher rates on the spruce sites than on the beech sites. Therefore, seepage water fluxes expressed as a percentage of precipitation more clearly showed the influence of tree species. Seepage water fluxes under beech consistently accounted for a higher proportion of the precipitation (28–37%) than under spruce (18–26%). However, the oak stands had the highest seepage fluxes (44% of precipitation at both sites). This difference between the tree species can probably be attributed to different evaporation rates in deciduous and coniferous stands because, in the latter, less water reaches the forest floor and therefore a smaller amount of water can potentially be leached down into the ground water table (Christiansen et al. 2006, Christiansen et al. 2007).

Nitrate input-output budget

Monthly estimates of nitrate leaching varied between the years within the different sites. In some sites there was no leaching of nitrate, whereas other sites exhibited marked annual variability. Summer and early autumn were, in general, periods with limited nitrate leaching, whereas nitrate was leached from several of the sites during winter and early spring. The highest monthly leaching rate was 22 kg N/ha, and the annual average rates of nitrate leaching ranged from 0 to 44 kg N/ha (Sevel et al. 2006).

The highest nitrate leaching rates were estimated for deciduous stands on nutrient-rich, fine-textured soils. At these sites, the measured nitrate concentrations (12–24 mg NO_3^--N/l) exceeded the threshold value for nitrate in drinking water (11.8 mg NO_3^--N/l). High nitrate concentrations at 90 cm depth cannot, however, be taken as evidence for contamination of the groundwater reserves. In clayey soils, nitrate may be reduced to gaseous N_2 in lower anoxic layers.

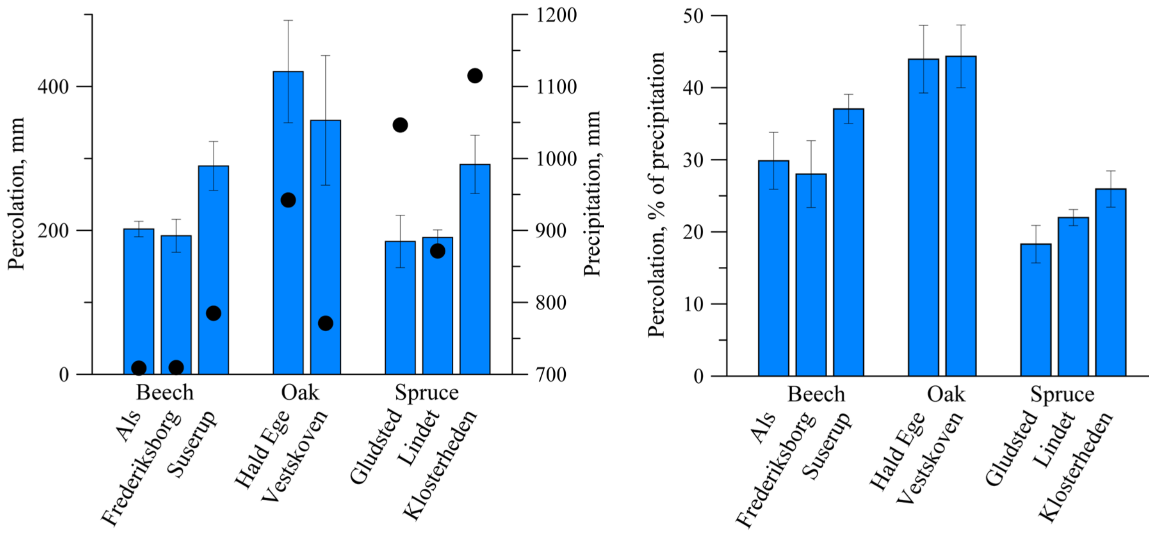

Figure 1. Left: Average annual percolation (blue bars) and average annual precipitation (black dots) in mm per year for the period 2002–2005 for the 8 investigated locations. Error bars show the standard error of the mean annual percolation for 2002–2005. Right: Average annual percolation as a fraction (%) of the average annual precipitation in the years 2002–2005 for the 8 investigated locations. Error bars show the standard error of the mean fraction of the annual percolation for 2002–2005.

The largest N inputs via throughfall were found at Ulborg, Lindet, Gludsted and Als Nørreskov, the first three of which are spruce stands. High N deposition on the forest floor in spruce stands is caused by the larger canopy surface and thus greater ability to capture atmospheric N. However, N emissions from agriculture (husbandry) are also highest in the region of Denmark where these plots are situated.

The Level II plots can be separated into three groups according to the characteristics of their N budgets. The first group contains stands that are able to almost completely retain the input of N within the trees or soil. Ulborg, Gludsted and Als Nørreskov belong to this group, although these stands do experience relatively high deposition of N. This is the most common situation in Danish forests (Callesen et al. 1999).

The second group includes stands where the rates of N leaching were approximately equal to the input of N. This is the case at Hald Ege and Vestskoven, whereas the spruce stand at Lindet only leaches half of the N input. During the last 30–40 years N deposition in Danish forests has increased. In some sites N saturation may therefore have developed, i.e. the available pool of N exceeds the demand for N by the plants and soil organisms. Consequently, nitrate-N is leached at a rate that more or less equals the N input.

The third group of stands leaches more N than that supplied in throughfall. At Suserup, 2.5 times the amount of N in throughfall and at Frederiksborg twice the amount is leached. In principle, this situation would not be possible over longer periods within a closed stand as the forest will experience a net N loss over time. This situation has primarily been observed in Danish beech forests on fine-textured, nutrient-rich soils (Gundersen 2006, Christiansen et al. 2006). At Suserup, which is a forest reserve, part of the reason may be the limited harvesting over the last century, where there has been no export of N via wood products compared to the situation in other Danish forests. In combination with increased N deposition, a large pool of soil N has accumulated and is now leaching out. However, we cannot generalise this to mean that other, non-intervention forests will exhibit the same magnitude of N leaching as at Suserup.

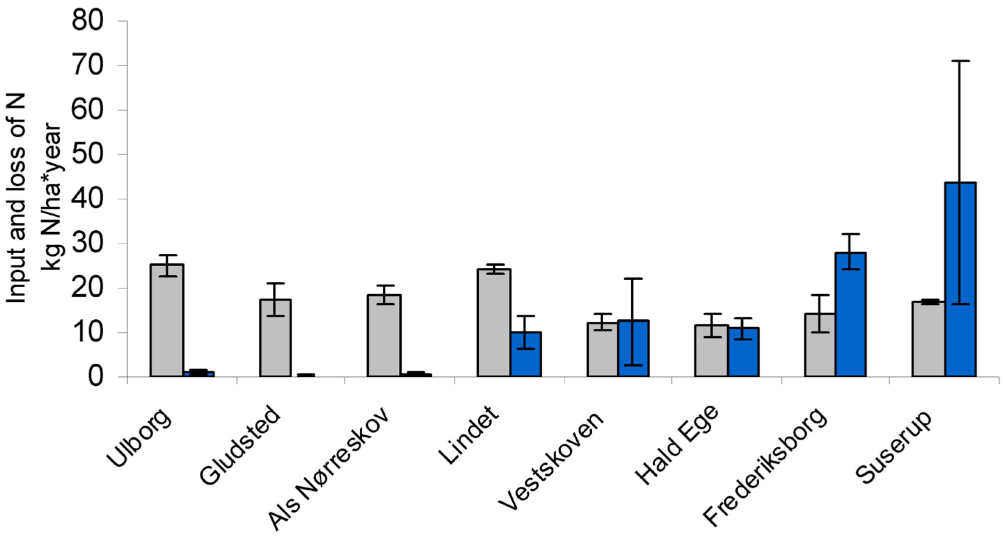

Figure 2. Mean annual N input (grey bars) and N leaching loss (blue bars) (kg/ha/year). Error bars show the standard error of the mean annual value for 2002–2005.

Conclusion

The results from the 8 Level II sites suggest that it is possible to increase seepage water fluxes to groundwater reserves by converting coniferous stands to deciduous stands. The leaching rates of nitrate were relatively different among the Level II sites, and were not directly related to the input of N via throughfall. In contrast, tree species and soil type may significantly influence the N dynamics. Intensive monitoring of forest N budgets is needed in order to assess the protective functions of forests in terms of eutrophication and ground water resources. This is needed in order to be able to perform more detailed mapping of future groundwater resources, including evaluation of the effects of climate change.

References

Callesen, I., Raulund-Rasmussen, K., Gundersen, P. & Stryhn, H. 1999. Nitrate concentrations in soil solutions below Danish forest. Forest Ecology and Management 144: 71–82.

Christiansen, J.R., Vesterdal, L., Sevel, L.,Hansen, K. & Bastrup-Birk, A. 2006. Hvor stor er nedsivningen til grundvandet under skov? Skoven 12: 562–565.

Christiansen, J.R., Elberling, B. & Jansson, P.-E. 2007. Modelling water balance and nitrate leaching in temperate Norway spruce and beech forests located on the same soil type with the CoupModel. Forest Ecol. Manage. 237: 545–556.

Gundersen, P. 2006. Nitratudvaskning for skovarealer – Model til risikovurdering. Forest and Landscape Denmark, Report (In press).

Jansson, P. E. & Karlberg, L. 2004. COUP manual – Coupled heat and mass transfer model for soil-plant-atmosphere systems. Technical manual for the CoupModel, pp. 1–453. Department of Land and Water Resources Engineering, The Royal Institute of Technology, Stockholm, Sweden.

Sevel, L., Vesterdal, L., Christiansen, J.R., Hansen, K. & Bastrup-Birk, A. 2006. Nitratudvaskning fra skove – hvad betyder kvælstoftilførsel og skovtype? Skoven 12: 566–569.

How are N and S in deposition, in percolation water and in the upper soil layers reflected in the chemical composition of needles in Finland?

Päivi Merilä [1], John Derome [2], Sebastiaan Luyssaert [3], Mika Sulkava [4], Jaakko Hollmén [4], Kaisa Mustajärvi [1] & Pekka Nöjd [5]

[1] Finnish Forest Research Institute (Metla), Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland, paivi.merila @ metla.fi
[2] Metla, Rovaniemi Research Unit
[3] Antwerp University, Research Group of Plant and Vegetation Ecology
[4] Helsinki University of Technology, Laboratory of Computer and Information Science
[5] Metla, Vantaa Research Unit

Introduction

The impact of atmospheric deposition of nitrogen and sulphur on forest ecosystems is the main focus of the ICP Forests/Forest Focus monitoring programme. On the other hand, both of these elements are essential macronutrients the availability of which strongly regulates plant growth. The monitoring of foliar chemistry is one of the central activities of the programme because it has proved to be a useful and practical tool for diagnosing the nutrient status of the trees and to monitor the large-scale effects of atmospheric deposition on forest ecosystems. In principle, chemical analysis of the soil reflects the potential availability of nutrients, while plant analysis indicates the actual nutrient status of the plants (Marschner 1995). The aim of this study is to investigate how the concentrations of sulphur and nitrogen in the nutrient sources of plants, i.e. in deposition, in percolation water and in the upper soil layers, are reflected in the nutrient status of Scots pine and Norway spruce in Finland.

Material and methods

In Finland, the nutrient status of conifer needles has been monitored on both the Level I (extensive monitoring) and Level II (intensive monitoring) networks of the ICP Forests/Forest Focus programme. Needles have been sampled on a sub-set of the Level I plots almost every year since 1987. This has provided a useful time series for evaluating the extent to which elevated N and S deposition has affected the mineral nutrient composition of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L. Karst.) needles during the period 1987–2000 (Luyssaert et al. 2004, 2005). Needle chemistry has been monitored biannually on 27 (on mineral soil sites) of the Level II plots since 1995, thus allowing us to explore the relationships between the elemental composition of needles and the concentrations of the respective elements in the soil and in percolation water.

The effect of N and S deposition on needle chemistry based on the Level I data

Needle samples were collected from 36 (16 spruce, 20 pine) of the Level I plots located on mineral soil sites in background areas in different parts of the country. The stands were sampled almost every year between 1987 and 2000, resulting in 367 needle samples (Luyssaert et al.

2005). Sampling and chemical analysis of the needles were carried out according to the ICP Forests Manual, and are presented and discussed in Luyssaert et al. (2004).

Tree nutrition was described by means of nutrient profiles (NPs) (Luyssaert et al. 2004, 2005). The NP of tree foliage is defined as the nutrient status that accounts for all the element concentrations, contents and interactions between two or more elements. Stands with similar NPs, and thus a similar elemental composition of the foliage, were characterized by a group nutrition profile (GNP). Current-year N, S and P concentrations and needle mass were used in calculating the GNPs. The values for Mg, Ca and Al were added when presenting the profiles. A neural network, in this case a self-organizing map (SOM) (Kohonen 2001) and an agglomerative clustering algorithm with pruning (Vesanto and Sulkava 2002), were used in calculating which NPs were members of a given GNP.

A two-step approach was applied in calculating the relationship between N deposition and the elemental composition of the needles. (1) The hypothesis was tested that the mean N deposition between already established GNPs could statistically not be considered equal. (2) The conditional probability was calculated that, given the GNP, the total N deposition was higher than 4.0 kg $ha^{-1}year^{-1}$, which was considered to be an elevated deposition level (i.e. above the threshold level) in Finland. The same two-step approach was used to determine the relationships between the NPs and S deposition, using a threshold deposition of 5.0 kg $ha^{-1}year^{-1}$.

A literature study of controlled experiments revealed that acidifying deposition mediates increasing N and S concentrations, and decreasing Mg:N and Ca:Al ratios in the needles. When this fingerprint for elevated N and S deposition in tree foliage was observed simultaneously with increased N and S inputs, it was considered sufficient evidence to assume that acidifying deposition had altered the elemental composition of the tree needles on that plot in the given year. Evidence for deposition-induced changes in the elemental composition of the tree foliage was calculated on the basis of a simple frequency model.

Relationships between soil and soil solution chemistry and needle chemistry

The organic and uppermost mineral soil layers were sampled once for chemical analyses at the beginning of the monitoring programme (1995–1997) on the 27 Level II plots located on mineral soil sites. Percolation water has been collected continuously at 4-week-intervals during the snow free period using zero tension lysimeters on 16 of the Level II plots. Sampling and chemical analysis of the needles, soil and soil percolation water were carried out according to the ICP Forests Manual (Manual on... 2006), and are presented and discussed in Merilä (2007) and in Derome et al. (2007).

Annual plot averages for S and N concentrations in current (c) needles, in the upper soil layers (organic and 0–5 cm mineral soil) and in percolation water (5 cm depth) were utilized in calculating Spearman rank correlation coefficients. Nitrogen and S in the needles were calculated per dry weight of needles (mg kg^{-1}), per needle and per needle biomass. Needle biomass was estimated using equation presented by Marklund (1987, 1988), and the N and S pools in needle biomass were then calculated by multiplying the biomass by the corresponding needle concentrations. Nitrogen and S in the organic and in the upper mineral soil (0–5 cm) layer were calculated per dry weight (mg kg^{-1}), and in case of the organic layer also on an areal basis (g m^{-2}).

Results and discussion

The effect of N and S deposition on needle chemistry based on Level I data

The chemical composition of the tree needles (NPs) was classified into six distinct GNPs (Luyssaert et al. 2004, 2005). The relationship between the N and S deposition and the established GNPs showed that high N deposition coincided more often within two groups (1 and 5) than within the other GNPs for spruce. For pine, on the other hand, there was no evidence to show that the mean N deposition values were different for different GNPs. However, there was a significant relationship between the exceedance of the threshold for N or S deposition and the occurrence of GNPs 1 or 5 for both tree species. In addition, GNPs 1 and 5 were best described as profiles that are consistent with the expectations of the needle composition for simultaneously elevated N and S deposition. On the average, the elemental composition of <13% of the spruce samples and 6% of the pine samples was associated with elevated N and S deposition during 1987–2000. The extent to which elevated deposition affected the elemental status of spruce needles decreased during 1987–2000. The same trend was not apparent in pine. When fitted using Logit models, the relationships between the NPs and selected stand, site and climatic variables were found to be non significant.

Relationships between soil and soil solution chemistry and needle chemistry

The N concentrations in the organic and 0–5 cm mineral soil layers correlated strongly with the respective concentration in the c needles on the spruce plots. On the pine plots, however, the correlations were non-significant (Table 1). On the spruce plots, the correlation between the N status of the organic layer and N in the needles was also significant when the needle N status was expressed as the N content per needle. There were no significant correlations between the N pool in the needle biomass and the N concentrations in the uppermost soil layers.

On the spruce plots, the concentration of total N and dissolved organic N (DON) in percolation water consistently showed positive correlation ($0.047 < p < 0.10$) with the N concentration in the c needles in every year of needle sampling (1999, 2001, 2003 and 2005, $n = 6–8$). In contrast, there were only sporadic significant correlations between the inorganic forms of N in percolation water and the needle N concentrations. On the pine plots, only DON in percolation water correlated positively with the N concentration in the c needles; this occurred in 2003 ($p = 0.071$, $n = 8$) and in 2005 ($p = 0.094$, $n = 7$).

The S concentration in the c needles correlated significantly only with the amount of S in the organic layer, calculated on an areal basis (combined dataset of pine and spruce; Table 1). On the spruce plots, the total S and SO_4-S concentrations in percolation water were consistently positively correlated with the S concentration in the needles in every sampling year (1999, 2001, 2003 and 2005). On the pine plots, positive correlation between the total S and SO_4-S concentrations in percolation water and needle S was found only in 1999 ($p < 0.076$).

In conclusion, the needle S and N concentrations showed significant correlations with the concentrations of N and S in the organic layer, in the upper mineral soil layer, and in percolation water, more consistently on the spruce than on the pine plots. One reason behind this difference might be that in pine plots water availability limits nutrient uptake. The consistent significant

Table 1. Spearman rank correlation coefficients between a) nitrogen (N) and b) sulphur (S) concentrations in the organic layer, in the uppermost mineral soil layer (0-5 cm) and in current (c) needles sampled in 1997 (n = 13, 13 and 26 in pine, in spruce and on all plots, respectively; $p < 0.001$ ***, $p < 0.01$**, $p < 0.05$*).

a)	N, mg kg^{-1} in organic layer			N, mg kg^{-1} in mineral soil			N, g m^{-2} in organic layer		
	Pine	Spruce	Total	Pine	Spruce	Total	Pine[1]	Spruce[2]	Total[3]
N, mg kg^{-1} dwt. needles	0.391	0.802 **	0.494 *	0.352	0.749 *	0.299	0.433	0.786 *	0.772 **
N, needle^{-1}	0.360	0.773 *	–0.047	0.108	0.351	–0.316	0.082	0.357	–0.174
N, needle biomass^{-1}	0.074	0.470	0.363	–0.230	0.225	0.362	–0.209	0.500	0.146
b)	S, mg kg^{-1} in organic layer						S, g m^{-2} in organic layer		
	Pine	Spruce	Total				Pine[1]	Spruce[2]	Total[3]
S, mg kg^{-1} dwt. needles	0.434	0.295	0.351				0.414	0.679	0.538 *
S, needle^{-1}	0.148	0.192	–0.151				0.009	0.071	–0.203
S, needle biomass^{-1}	–0.011	0.302	0.210				–0.182	0.107	0.075

[1]n = 11, [2]n = 7, [3]n = 18

relationship between the DON concentration in percolation water and the N status of the trees suggests that DON may serve as an important indicator of N availability in boreal forest ecosystems.

References

Derome, J., Lindroos, A.-J. & Derome, K. 2007. Soil percolation water quality during 2001 – 2004 on 11 Level II plots. In: Merilä, P., Kilponen, T. & Derome, J. (eds.). Forest Condition Monitoring in Finland – National report 2002 – 2005. Working Papers of the Finnish Forest Research Institute 45. p. 93 – 98.

Kohonen, T. 2001. Self-Organizing Maps. Springer-Verlag, Berlin.

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.

— 2005. Are N and S deposition altering the mineral composition of Norway spruce and Scots pine needles in Finland? Environmental Pollution 138: 5 – 17.

Marklund, L.G. 1987. Biomass functions for Norway spruce in Sweden. Report 43. Swedish University of Agricultural Sciences, Department of Forest Survey. 127 p.

— 1988. Biomassafunktioner for tall, gran och björk i Sverige. Rapport 45. Sveriges lantbruksuniversitet, Inst. Skogstaxering. 73 p.

Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. 2006. Parts IIIa, IIIa (Annex), IIIb, IV. [Internet site]. UN-ECE. Programme coordination centre, Hamburg. Available at: http://www.icp-forests.org/manual.htm.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press, London. 889 p.

Merilä, P. 2007. Needle chemistry on the intensive monitoring plots 1995 – 2003. In: Merilä, P., Kilponen, T. & Derome, J. (eds.). Forest Condition Monitoring in Finland – National report 2002 – 2005. Working Papers of the Finnish Forest Research Institute 45. p. 46 – 62.

Vesanto, J. & Sulkava, M. 2002. Distance matrix based clustering of the Self-Organizing Map. Artificial Neural networks – ICANN 2002, Lecture notes in Computer Science 2415: 951 – 956.

Monitoring changes in the carbon stocks of forest soils

Raisa Mäkipää [1)], Mikko Peltoniemi [1)], Margareeta Häkkinen [1)], Juha Heikkinen [1)], Kristiina Karhu [3)], Aleksi Lehtonen [1)], Marcus Lindner [2)], Jari Liski [3)], Petteri Muukkonen [1)] & Taru Palosuo [2)]

[1)] Finnish Forest Research Institute (Metla), P.O. Box 18, FI-01301 Vantaa, Finland
raisa.makipaa@metla.fi
[2)] European Forest Institute (EFI), Torikatu 34, FI-80101 Joensuu, Finland
[3)] Finnish Environment Institute (SYKE), P.O. Box 140, FI-0251 Helsinki, Finland

Introduction

Forests are included in the Climate Convention and the Kyoto Protocol because of their importance as regulators of atmospheric carbon dioxide concentrations (UNFCCC 1992, UNFCCC 1997). The potential of forests in mitigating climate change has created a need to develop and improve methods for estimating the carbon budgets of forests. Among other parties to the Climate Convention and signatory countries of the Kyoto Protocol, the EU has commitments to report changes in the carbon stocks of forests, including the carbon stock of forest soils. The IPCC (2003) has set general requirements for soil inventories, but operational soil monitoring methods applicable at the large scale in question are still under development. Both national and European forest soil carbon inventory can be based on soil carbon modelling or on empirical data from repeated soil carbon measurements, or on a combination of the two. National and international soil surveys are carried out in and among the European countries, but none of them have been designed to generate a reliable carbon inventory of forest land, and there are large uncertainties associated with the estimates of changes in soil carbon stocks. Due to the high costs of regionally representative soil surveys, sampling efforts need to be effectively allocated within a monitoring programme. Furthermore, the results and experiences gained in earlier surveys may provide a sound basis for the soil carbon monitoring to be carried out at the EU level.

The objectives of this study were to provide means to improve the efficiency of soil sampling and analysis of soil survey data, and to improve transparency and consistency of model-based soil carbon inventories. Specific objectives of the sub-studies were

- to improve the transparency of model-based soil carbon inventories by reviewing (i) evaluated known soil models, and (ii) inventories integrating forest inventory data with the modelling of biomass, forest litter and soil,
- to compare the sensitivity of the modeled predictions of soil carbon dynamics to the choice of model,
- to test the efficiency of soil sampling stratified according to model predictions of changes in soil carbon stocks,
- to develop statistical methods for efficient analysis of previous and current soil survey data that were collected using different sampling designs, and
- to provide guidance for the design of soil sampling (number and location of sampling points at the plot scale, and number of sampled plots in large-scale inventories).

This article provides a summary of the results of this study. Details of the methods and sources of information are reported in the original publications resulting from the study.

Summary of the results

Soil modelling

Various soil carbon models are available, and many of them have been (or can be) applied in national GHG reporting. In this study, we evaluated 7 well-known soil models with the aim of increasing the transparency of models that can be applied for soil carbon inventories (Peltoniemi et al. 2007). We concluded that simple models may be the only reasonable option to estimate soil carbon changes in the face of limited resources, but the role of process-based soil carbon models in the GHG inventories is likely to increase due to the flexibility they offer for conducting studies on soil carbon stock changes in a changing environment.

Numerous soil carbon models can be used in carbon inventories, but little is known about the sensitivity of the predictions on model choice. We evaluated the effect of model choice on predictions of the changes in soil carbon stocks resulting from different management practices (Palosuo et al. 2007). The sensitivity of the predicted soil carbon dynamics to different management practices was simulated with two different combinations of stand development and soil models (MOTTI-YASSO and EFIMOD-ROMUL). The management practices considered were the current standard ones and the intensified collection of biomass in final felling. The results showed that the empirical stand model with a simple decomposition model predicted smaller effects of this change in forest management than the process-based model. This indicates that special emphasis should be put on model selection when studying the effects of forest management on forest carbons stocks. The feedback mechanism from the soil to forest productivity is important, and approaches that do not take this into account may underestimate the total effect of intensified biomass collection.

The effect of climate variability on monitoring changes in the carbon stock of forest soils was analysed in a simulation study. We simulated stand development and soil carbon dynamics with the MOTTI-YASSO model in the current climate, and in a changing climate with and without annual variations in climate (Karhu and Liski 2007). Inter-annual variation in climatic conditions caused substantial variability in the annual estimates of changes in the soil carbon stocks. In actual fact, this variation was more important than the trend-like change in soil carbon stocks resulting from a changing climate. On an annual basis, this stochastic variability decreases the efficiency when stratifying study sites in an attempt to improve the efficiency of monitoring soil carbon changes. Increasing the interval between monitoring rounds from 5 – 10 years, for example, is an efficient way to overcome this negative effect.

We carried out a review of state-of-the-art carbon inventories and ways in which they can be used in carbon cycle research (Mäkipää et al. in press). This review improves the transparency of carbon inventories that integrate forest inventory data with the modelling of biomass, litter and soil. Furthermore, it discusses the applicability and reliability of the applied methods in nation-wide carbon inventories.

Soil survey

In this sub-project, we introduced a method to stratify soil sampling according to model predictions of changes in soil carbon stocks, developed statistical methods for efficient combination of old and new soil survey data to estimate soil C stock changes, and analyzed within-site spatial variation in the amount of soil carbon. We answered the questions: How much is model-based stratification expected to improve the efficiency of soil sampling? How to analyse soil data resulting from sampling of different design (old pooled sampling and current sampling with spatial information) and how many plots need to be re-measured in order to be able to detect a change in soil carbon stocks? What is the location and number of sampling points within a plot needed to obtain a reliable carbon stock estimate?

Soil models can help to design effective soil sampling. In this project, we stratified sampling on an existing grid of forest inventory plots on the basis of model-predicted changes in soil C during an assumed sampling interval of 10 years (Peltoniemi et al. 2007). Model-based stratification improved the sampling efficiency, even though the uncertainties in both model predictions and measurements are large. Stratification with optimal allocation of the plots can reduce the standard error of the mean by 20 – 34% relative to simple random sampling, with different assumptions of harvesting (and thinning) timing uncertainties. The use of optimal allocation (Neyman) is recommended for a soil C-change sampling design, since it was up to 10% better (relative to SRS) than proportional or equal allocation.

Soil survey data have, up to now, usually been collected as composite samples. In composite sampling, the spatial reference of sampling locations and information on within-site variance in soil C amounts, which could be used to enhance the power of change detection, are lost. We performed a spatially explicit soil sampling (40 soil samples) on 38 plots where sampling had earlier been carried out using composite sampling (Häkkinen et al. submitted manuscript). Samples of the organic layer were collected in the stands of intermediate age classes where a steady increase in soil C can be expected, and the data were analysed using geo-statistical techniques. We detected a statistically significant increase in carbon amounts in 7 of the 38 single plots. For the mean of all the re-sampled plots, the measured increase of 23 ± 10 g C m^{-2} a^{-1} was significant. With a sampling interval of 10 years such a change can be detected with less than 100 sample plots if the between-site variation and within-site spatial variation are similar to the data from managed forests of intermediate age classes.

In clear-cut stands, the soil carbon stock is expected to decrease as a result of the decomposition of harvesting residues and changed site conditions. In this study, we quantified the spatial variation of the soil carbon stock on the basis of repeated measurements (before and 12 years after clear-cut), and tested the changes in different soil layers (Liski et al. manuscript). We observed a significant increase in the organic and 20 – 40 cm mineral soil layer and a decrease in 0 – 10 cm layer. These results confirmed the model-predicted decrease in the soil carbon stock during the early phases of stand development, and they provided guidance for the design of soil surveys in such situations.

The within-site spatial variation in the carbon stock of the organic layer was analysed in more detail on the basis of a total of 1107 soil samples taken in 11 stands (6 Scots pine stands and 5 Norway spruce stands) (Muukkonen et al. manuscript). Spatial autocorrelation of the carbon stock was lost at distances greater than several meters, depending on the site. This indicates that the distance between non-correlated sampling points should be up to 8 m. More than 20 sub-samples per site should be sampled in order to obtain a reliable plot-level estimate of the mean carbon stock in the organic layer.

Monitoring costs

This study compared different sampling intensities on a plot in terms of time consumption, costs and estimate precision (Mäkipää et al. submitted manuscript). The study focused on the organic layer, which is the major rooting zone in boreal forests and the layer where the largest changes in soil carbon stocks are expected to take place. We also formulated potential sampling protocols for a monitoring plot network that can be applied to improve the efficiency of sampling, and compared the costs of carbon measurements in the organic and mineral soil layers between these sampling protocols (Mäkipää et al. submitted manuscript).

Soil carbon measurement costs increased linearly from 400 to 800 euros with an increase in the number of samples per plot from 10 to 30. The gain offsetting the increased sampling costs was improved precision of the estimate. At the plot level, a change of 50 g C m^{-2} in the carbon stock in the organic layer can be detected by repeated sampling with costs of 400 euros per plot, while the costs of detecting a smaller change of 30 g C m^{-2} are double.

The costs of remeasuring an existing network of sample plots are dependent on the selected sampling protocol. The total costs of remeasurements of the carbon stock in the organic layer and three mineral soil layers on a network of 2000 sample plots are over 2 million euros. Sampling efficiency can be improved and the costs reduced by model-based stratification that allows us to reduce the number of sampled plots by 25%. Assuming a constant trend in the change in the soil carbon stock, an extension of the sampling interval from 5 years to 10 years allows us to reduce the number of sample plots without decrease in the probability of detecting the change.

Conclusions

The methods developed in this project produce statistically reliable information on changes in soil carbon stocks, and provide guidance for the design of soil surveys. In our review of the available soil models, we conclude that models can be used in the national GHG inventory for the estimation of changes in the soil carbon stock, and the reliability of the model-based estimates can be improved by calculating estimates with several soil models that have appropriate requirements for input data.

This study provided means to improve the efficiency of soil sampling and the analysis of soil survey data. We proposed a new stratification method that can improve sampling efficiency by 10–30%. However, the usefulness of stratification depends on the precision of the simulations and on expected precision of the soil measurements. In general, soil monitoring with repeated measurement is laborious, but sampling efficiency can be improved and monitoring costs reduced by (i) using existing networks of measured plots, (ii) by extending the sampling time interval, and (iii) by stratification according to the predicted changes in soil carbon.

In this study we combined the strengths of an existing, well-validated soil carbon model, knowledge on the spatial variation in soil carbon, and sound statistics to provide quantitative information on the reliability and efficiency of different sampling methods. The methods developed and tested in this project can be applied in the national greenhouse gas reporting of forest soils.

Further information on this project is available from www.metla.fi/hanke/843002.

References

Häkkinen, M., Heikkinen, J. & Mäkipää, R. Soil carbon changes detected with repeated soil sampling – spatial within-site variation accounted in statistical analysis. Manuscript submitted in June 2007.

IPCC 2003. Report on good practice guidance for land use, land-use change and forestry, Japan.

Karhu, K. & Liski, J. 2007. Effects of climate variability on monitoring changes in the carbon stock of forest soils. Technical Report.

Liski, J., Häkkinen, M. & Heikkinen, J. Soil carbon changes at a clear-cut forest site. Manuscript in preparation.

Mäkipää, R., Lehtonen, A. & Peltoniemi, M. 2007. State-of-the-art carbon inventories and ways to use them for carbon cycle research. Springer, Ecological Studies, manuscript accepted for publication.

Mäkipää, R. et al. Monitoring changes in the carbon stocks of forest soils – efficiency of different sampling methods and costs of the monitoring. Manuscript to be submitted by November 2007.

Muukkonen, P., Häkkinen, M. & Mäkipää, R. Spatial variability of soil organic carbon in humus layer of boreal forest soil. Manuscript in preparation.

Palosuo, T., Peltoniemi, M., Komarov, A., Mikhailov, A., Faubert, P., Thürig, E. & Lindner, M. Projecting effects of intensified biomass extraction with alternative modelling approaches. Forest Ecology and Management (Accepted manuscript).

Peltoniemi, M., Thürig, E., Ogle, S., Palosuo, T., Shrumpf, M., Wützler, T., Butterbach-Bahl, K., Chertov, O., Komarov, A., Mikhailov, A., Gärdenäs, A., Perry, C., Liski, J., Smith, P. & Mäkipää, R. 2007. Models in country scale carbon accounting of forest soils. Silva Fennica 41: 575 – 602.

Peltoniemi, M., Heikkinen, J. & Mäkipää, R. 2007. Stratification of regional soil sampling by model-predicted change in soil carbon in forested mineral soils. Silva Fennica 41: 527 – 539.

UNFCCC 1992. United Nations Framework Convention on Climate Change. Available at: http://www.unfccc.de/resource/convkp.html.

UNFCCC 1997. Kyoto Protocol. Available at: http://www.unfccc.de/resource.

Plant-induced variability in soil acidity and nutrient status of boreal forest ecosystems

Natalia V. Lukina

Centre for Forest Ecology and Productivity, RAS, 117997, Profsouznaya str., 84/32, Moscow
lukina@cepl.rssi.ru

Introduction

The effects of plant species on soil acidity and nutrient status vary according to the different processes involved, e.g. nutrient inputs in litterfall, stemflow and canopy throughfall, nutrient uptake, chemical weathering of the parent material etc. It is generally considered that 1) Norway spruce acidifies the soil due to the accumulation of strongly acidic organic matter, and 2) Norway spruce degrades the soil (Binkley and Giardina 1998). The first generalization has been confirmed in garden studies, but so far no empirical evidence has been presented to support the second one. Norway spruce is known to accumulate more base cations in its biomass and the exchangeable cation pools in the soil under a spruce stand to be larger than those in adjacent stands of birch (*Betula pendula*) and beech (*Fagus sylvatica*) (Berkvist and Folkeson 1995). The above-ground net primary production in spruce is higher than that in beech stands. Furthermore, studies carried out in adjacent stands have shown that net N mineralization is equal or greater in the soil under spruce (Nihlgard 1971, Berkvist and Folkenson 1995).

The goal of the study was to investigate plant-induced variability in the acidity and nutrient status in the soil of boreal forest ecosystems. We carried out a comparison a) between compartments dominated by different plants within different forest types/succession stages, and b) between different forest types/succession stages.

Materials and methods

The sites selected for the study are located in the Komi Republic (Lyali Station of the Biology Institute of the Komi Scientific Centre, and the Pechora-Ilych Reserve), on the Kola Peninsula (Lapland Biosphere Reserve), and in Karelia (forest area along the border between the Paanajarvi National Park and the Kostomuksha Reserve). The selected forest types were spruce forests with fir and Siberian pine in the Komi Republic (*P. myrtilloso-hylocomiosum, P. myrtilloso-filicosum*), pine and spruce forests on the Kola Peninsula (*Pinetum cladinosum, P. cladinoso-hylocomioso-myrtillosum, P. hylocomioso-myrtillosum,* and *Piceetum fruticuloso- hylocomiosum, P. fruticuloso-cladinosum, P. myrtilloso-hylocomioso-parviherbosum*), spruce forests along the border of the Paanajarvi National Park (*Piceetum myrtilloso-hylocomiosum, P. myrtilloso-hylocomioso-parviherbosum, P. magnoherbosum*), and pine and spruce forests in the Kostomuksha Reserve (*Piceetum fruticuloso- hylocomiosum , Pinetum cladinoso-fruticulosum)*.

The predominant soil type in the Lapland and Kostomuksha reserves was podzol on unsorted sandy and stony till, in Komi podzolic soil on loamy till, and at the site close to the Paanajarvi National Park the soil type in a spruce forest with tall herbs dominated by *Cicerbita alpina* and *Actaea erythrocarpa* was cambic podzol on early proterozoic rock.

Soil samples were taken from the main soil horizons below and between the crowns in the different forest compartments. Soil pH was measured potentiometrically, exchangeable acidity and aluminium were determined by extraction with 1N KCl followed by titration, and total acidity by extraction with 1M ammonium acetate (pH 7) followed by titration. Total (dry digestion) and bio-available (ammonium acetate extraction, pH 4.65) concentrations of metals in the soil were determined by atomic absorption spectrometry. Total N was determined by the Kjeldahl method, and total P and S by colorimetry. Potentiometric titration of water extracts from the L, F and H horizons in spruce forests on the Kola Peninsula was carried out according to Sokolova et al. (1996).

The microbial population and biomass in the soil were studied in different types of forest on the Kola Peninsula (Lapland Biosphere Reserve) using the methods described in detail in Nikonov et al. (2006) and Fomicheva et al. (2006).

Results and discussion

Comparisons between different forest compartments

In the spruce forests (*Piceetum myrtilloso-hylocomiosum*, *P. myrtilloso-filicosum*) in Komi, the acidity of the organic layer below the crowns of Siberian spruce (*Picea abies subsp. obovata)* and Siberian fir (*Abies sibirica)* was significantly lower than that below the crowns of Siberian pine (*Pinus sibirica*). Overall, the organic layer in the spruce and fir compartments had higher base cation concentrations. We considered that this phenomenon was caused by a) significantly higher Ca concentrations in the senescent needles of spruce and fir (up to 13 g/kg in spruce needles), and b) a smaller amount of precipitation reaching the forest floor below the denser, longer crowns of spruce and fir compared to that in pine. The lower precipitation resulted in considerably lower leaching of base cations from the organic horizon below the crowns of spruce and fir. The mineral soil horizons below the crowns of spruce and fir were more acidic and had higher mineral nutrient concentrations than in the mineral soil below the crowns of pine. Berkvist and Folkeson (1995) suggested that the faster rates of mineral weathering account for the higher base cation concentrations in the soil in spruce stands.

Comparison of soil acidity and nutrient accumulation below the crowns of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in pine and spruce forests on the Kola peninsula and in the Kandalaksha reserve indicated that the acidity of the organic layer below the crowns of spruce in all types of forest was significantly lower than that below the crowns of pine (Fig. 1). In the mineral horizons the situation was the opposite. The nutrient concentrations were, as a rule, higher in all the soil horizons below the crowns of spruce than under pine.

The species composition of the ground vegetation and the microbial population and biomass in the soil also had an important effect on the spatial variability of soil acidity and nutrient status in the soil.

In all the pine forests, the bio- available Ca and total N concentrations and acidity of the soil horizons below the crowns were higher than in the compartments between the crowns dominated by lichens, by lichens and dwarf shrubs, and by green mosses and dwarf shrubs (Fig. 1). The microbial population and biomass in the organic and mineral soil horizons below the pine crowns were significantly higher than those in the soil between the crowns (Nikonov et al. 2006). The

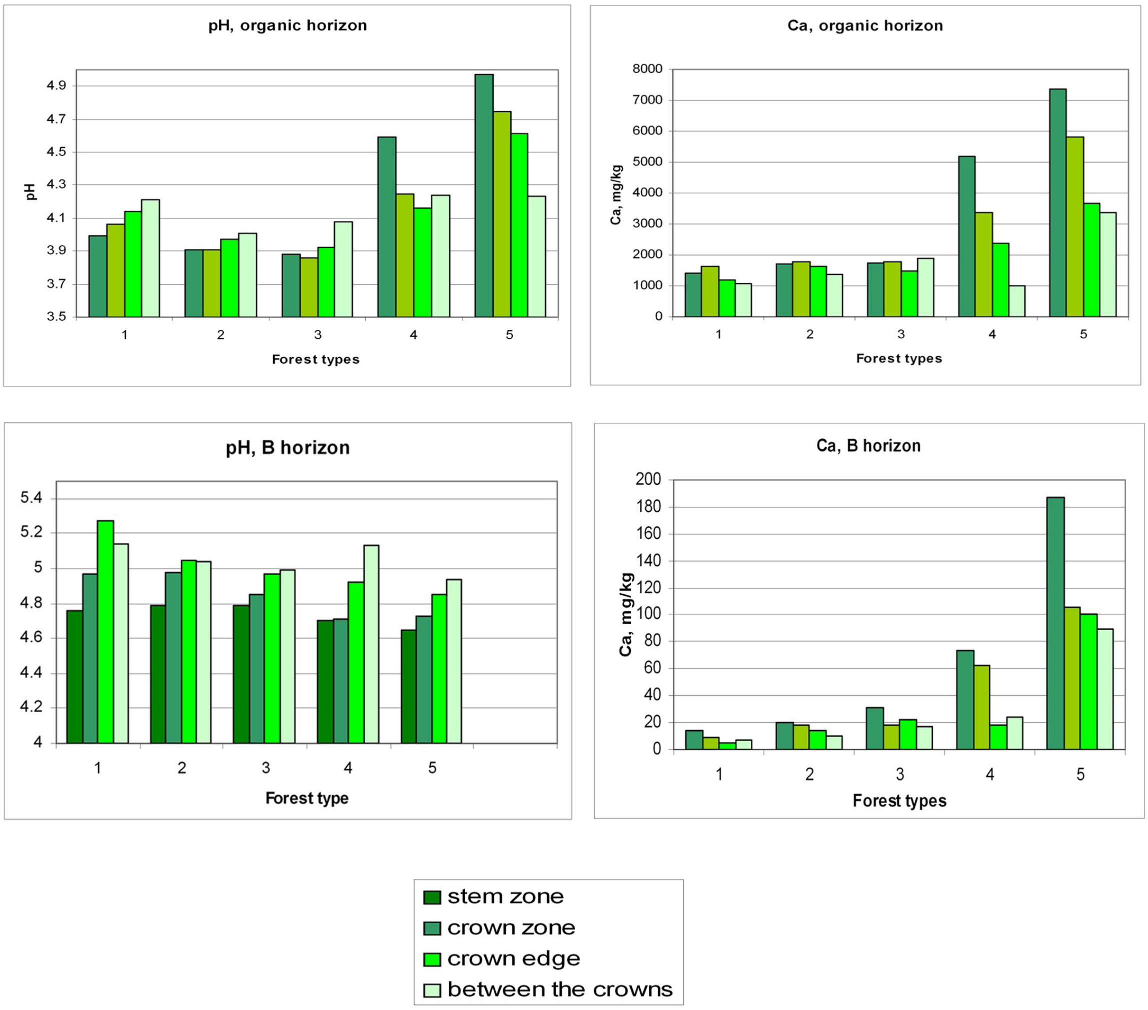

Figure 1. pH and Ca in soils of coniferous forests in the Kola peninsula forest types: 1 = Pinetum cladinosum, 2 = Pinetum cladinoso-hylocomioso-myrtillosum, 3 = Pinetum myrtilloso-hylocomiosum, 4 = Piceetum fruticuloso-hylocomiosum + Piceetum-fruticuloso-cladinosum, 5 = Piceetum myrtilloso-hylocomioso-parviherbosum.

microbial community in the soil in boreal forests is dominated by fungi that excrete organic acids and are primarily responsible for decomposing the organic matter. Between the crowns, the soil that was the most acidic and had the highest nutrient (e.g. N, Ca, Mg, K, P, Mn, Zn) concentrations occurred in the compartments with green mosses and dwarf shrubs; the lowest acidity and nutrient concentrations, as well as the smallest microbial population and biomass in the organic horizons, occurred in the lichen compartments.

In the spruce forests on the Kola peninsula, in the Kandalaksha Reserve and along the border of the Paanajarvi National Park, the organic horizons below the tree crowns were less acidic and had higher total N, bio-available Ca and Mn concentrations than in the corresponding horizons between the crown compartments dominated by lichens and by green mosses, dwarf shrubs and low herbs. As in the case for the differences between the tree compartments, this was presumably due to the higher Ca and also Mn concentrations in senescent spruce needles and the lower amount of precipitation penetrating the canopies of the spruce trees. The variability in the bio-available K, P and Mg concentrations between the compartments was relatively insignificant, and was probably related to the higher mobility of these cations compared to that of Ca.

In the forests on the Kola Peninsula the microbial population and biomass, which are strongly dominated by fungi, were significantly lower in the organic horizon below the crowns of spruce than those between the crowns (Fomicheva et al. 2006), whereas in the mineral soil horizons the situation was the opposite. Taking into account the fact that fungi excrete relatively strong acids, their lower biomass may also partly explain the lower acidity of the organic horizon below the crowns of spruce.

According to the potentiometric titrations of water extracts of samples from the L, F and H horizons, the organic horizons close to the trunk and below the crown in the spruce compartments had a relatively strong buffering capacity, whereas there was almost no corresponding buffering capacity in the organic horizons between the crowns. In the case of the L horizon, and partly also in the F horizon, this may be due to the higher concentrations of salts, formed between strong bases and organic acids like citric or oxalic acid in these horizons below the crowns. Interactions between these salts and the acidic stemflow and canopy throughfall may account for the partial neutralization of the acids, and the subsequent formation of relatively week acids that migrate down the soil profile (Lukina et al. 2002, 2003). The neutralization mechanisms in the H horizon are probably cation exchange reactions and/or the non-exchangable protonation of organic matter. Correlations ($p<0.05$) were found between the Ca concentrations and the C concentration in humus acids in the H horizon of the spruce forests, and it can be assumed that this is related to the formation of Ca humates and fulvates. The acidity of the mineral soil horizons below the crowns of spruce and pine was higher, and the nutrient concentrations higher than in the corresponding horizons between the crown compartments. Only in the spruce forests with tall herbs (*Piceetum magnoherbosum*) was the organic horizon between the crown compartments with tall herbs (*Cicerbita alpina, Actaea erythrocarpa*) less acidic and had higher nutrient concentrations than in the spruce compartments.

We also compared the effects of about 40-year-old and more than 120-year-old spruce trees on the soil in *Piceetum hylocomioso-myrtillosum* sites on the Kola Peninsula. Major differences were found: the organic horizons below the crowns of the younger trees were more acidic than those below the crowns of the older trees and between the crown compartments. The crown structure of young spruces is different (less dense) than that of older trees, and the number of needle age classes is lower. Because Ca is not a mobile element, the Ca concentrations in the old senescent needles were the higher, the greater the number of needle age classes. As a result, Ca accumulation in the senescent needles of the young trees and in the organic horizons below their less dense crowns were significantly lower. This supports the assumption of Binkley and Giardina (1998) concerning the acidification of soil (all soil horizons) by relatively young (about 50 years) Norway spruce.

Comparison between different forest types/stages of succession

In the pine forests on the Kola Peninsula, the acidity of the organic horizon on the *Pinetum myrtilloso - hylocomiosum* sites was significantly higher than that in the pine forests with lichens (*P. cladinosum, P. cladinoso-hylocomioso-myrtillosum)*. This was due to differences in the concentrations of base cations and protons in the raw acidic humus. The total C and N concentrations in all the soil horizons of the *Pinetum myrtilloso -hylocomiosum* sites were significantly higher, and the ratio between the concentration of C in the humic and fulvic acids was smaller, indicating a higher contribution by fulvic acids.

The organic horizons in all the spruce forests were less acidic and had higher nutrient concentrations than in the pine forests. The lowest soil acidity and highest accumulation of nutrients occurred in the spruce forests with low (*Piceetum myrtilloso-hylocomioso-parviherbosum*), and especially tall (*Piceetum magnoherbosum*) herbs. The mineral soil horizons in the spruce forests were more acidic and had higher bio-available nutrient concentrations than in the pine forests.

We compared the soils in forests growing on the same type of parent material under similar geomorphological conditions in Lapland biosphere reserve (Kola Peninsula) (Fig. 2). This has enabled us to draw conclusions about changes in soil properties during the course of autogenic succession. Taking into account the fact that, in boreal forests, the wide distribution of pine forests is related to the periodic forest fire events, spruce forests can be considered to be a form of late successional stage. Pine forests with lichens are subjected to fires more frequently, and represent the pioneer stages of succession. When green mosses colonize pine forests, the soil becomes more acidic owing to the accumulation of fulvic acids. This stage has the most acidic organic horizons during the course of the autogenic succession of boreal forests. In spruce forests with green mosses, the concentrations the acidity of the organic horizons was significantly lower owing to the higher concentrations of base cations, particularly Ca, in the senescent needles, and to the smaller amount of precipitation penetrating though the very dense, low spruce canopy. In spruce forests the concentration of Ca salts formed with organic acids, like citric or oxalic in the L and F horizons, and the concentration of Ca humates and fulvates in the H horizon, are probably higher than in pine forests.

The accumulation of total N, and bio-available Ca, Mg, K, P, S in the soil in spruce forest (in both the organic and mineral soil horizons) could be related to the absence of catastrophic events for a long period during autogenic succession. In the organic horizons the C/N ratio decreased from 45 on the *Pinetum cladinosum* sites to less than 30 on the *Piceetum myrtilloso-hylocomioso-parviherbosum* sites. Unlike the organic horizon, the acidity of the mineral soil horizons increased during the course of succession.

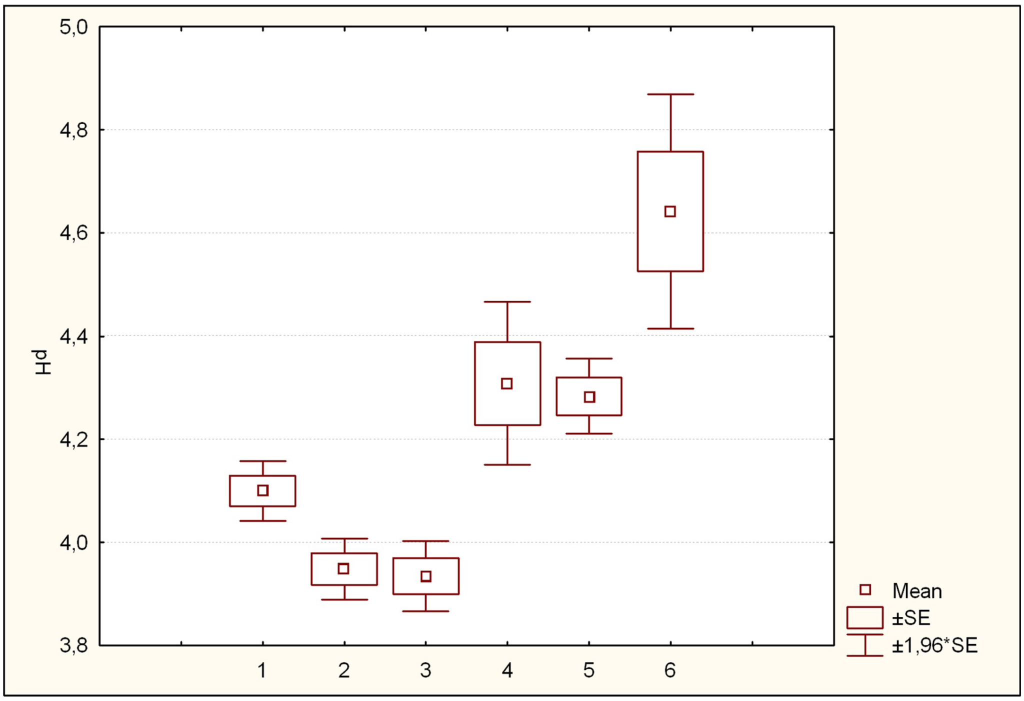

Figure 2. Actual acidity in the organic horizons of coniferous forests in the Kola peninsula forest types: 1 = Pinetum cladinosum, 2 = Pinetum cladinoso-hylocomioso-myrtillosum, 3 = Pinetum myrtilloso-hylocomiosum, 4 = Piceetum fruticuloso-hylocomiosum, 5 = Piceetum-fruticuloso-cladinosum, 6 = Piceetum myrtilloso-hylocomioso-parviherbosum.

Conclusions

Comparisons between different boreal forest compartments showed that the concentrations of total N and base cations, especially Ca, were higher in the organic horizons, and the acidity lower, below the crowns of late successional species like Norway spruce and Siberian fir than those below Scots pine and Siberian pine, as well as between the crown compartments with lichens, green mosses and low herbs. Only the organic layer between the crown compartments with tall herbs had a lower acidity and higher total N and bio-available nutrient concentrations. This was attributed to the high Ca concentrations in the senescent needles of spruce and fir, and the dense, low canopies of these tree species that reduces the leaching of base cations from the organic horizons. Despite the acidic canopy throughfall and stemflow falling on the ground surface below the crowns of spruce, the organic horizons was less acidic than that of the organic horizons between the crowns. Different mechanisms were proposed for neutralization processes in the different organic horizons. In the L horizon, and partly in the F horizon, neutralization is probably due to interaction between Ca salts with organic acids, such as citric or oxalic, and the acidic stemflow and canopy throughfall, with the formation of relatively weak acids migrating down the soil profile. In the H horizon the mechanisms of neutralization are probably cation exchange and/or the non-exchange protonation of the organic matter.

Comparisons of soil acidity and nutritional status between different pine and spruce forest types/ stages of succession allow us to conclude that the most acidic organic horizons are in pine forests with green mosses. This could be related to the higher concentrations of fulvic acids. In the spruce forests the acidity of the organic horizon was significantly lower, whereas the nutrient concentrations were higher. The acidity of the mineral horizons was higher in the spruce forests.

References

Berkvist, B. & Folkeson, L. 1995. The influence of tree species on acid deposition, proton budgets and element fluxes in south Sweden forest ecosystems. Ecol. Bull. 44: 90 – 99.

Binkley, D. & Giardina, Ch. 1998. Why do trees affect soils? The Warp and Woof of tree-soil interactions. Biogeochemistry 42: 89 – 106.

Fomicheva, O.A., Polyanskaya, L.M., Nikonov, V.V., Lukina, N.V., Orlova, M.A., Isaeva, L.G. & Zvyagintsev, D.G. 2006. Population and biomass of soil microorganisms in old-growth primary spruce forests in the northern taiga. Eurasian Soil Science 39(12): 1323 – 1331.

Lukina, N.V., Gorbacheva, T.T., Nikonov, V.V. & Lukina, M.A. 2002. Spatial variability in Al-Fe humus podzol acidity in the Northern Taiga. Eurasian Soil Science 35 (2): 163 – 176.

Lukina, N.V., Gorbacheva, T.T., Nikonov, V.V. & Lukina, M.A. 2003. Spatial Variability of Soil Acidity in the Course of Human-Induced Succession of Forest Biogeocenoses. Eurasian Soil Science 36 (1): 32 – 45.

Nihlgard, B. 1971. Pedological influence of spruce planted on former beech forest soils in Scania, South Sweden. Oikos 22: 195 – 207.

Nikonov, V.V., Lukina, N.V., Polyanskaya, L.M., Fomicheva, O.A., Isaeva, L.G. & Zvyagintsev, D.G. 2006. Population and Biomass of Microorganisms in Soils of Pyrogenic Succession in the Northern Taiga Pine Forests. Eurasian Soil Science 39 (4): 484 – 494.

Sokolova, T.A., Dronova, T.Ya., Artjukhov, D.B., Korobova, N.L., Pahomov, A.P. & Tolpeshta, I.I. 1996. Field modeling of the initial stages of interaction between acidic precipitation and forest podzolic soils. Soil Science 7: 847 – 856 (in Russian).

Above- and belowground N stocks and fluxes along a latitudinal gradient in boreal pine and spruce forests in Finland

Kaisa Mustajärvi [1)], John Derome [2)], Heljä-Sisko Helmisaari [3)], Sari Hilli [2)], Antti-Jussi Lindroos [3)], Päivi Merilä [1)], Pekka Nöjd [3)], Maija Salemaa [3)] & Liisa Ukonmaanaho [3)]

[1)] Metla, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, kaisa.mustajarvi@metla.fi
[2)] Metla, Rovaniemi Research Unit, P.O. Box 16, FI-96301 Rovaniemi
[3)] Metla, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa

Introduction

Boreal forests may act as a biotic feedback for climate change as they store large amounts of carbon, which can be sensitive to temperature changes (Kauppi et al. 1995, Liski and Westman 1997). Thus the carbon (C) cycles of northern forest ecosystems have been recognised as playing an important role in climate change (Woodwell et al. 1998, Chapin et al. 2000). Nitrogen (N) is usually the growth-limiting factor in forest ecosystems and C and N cycles in terrestrial ecosystems are therefore tightly linked. As a result, in addition to traditional approaches to the N status of forest stands, predicting and modelling the effects of global warming, e.g. on C sequestration, also require information on the fluxes and pools of N.

N pools and fluxes have earlier been reported for some forest stands in Finland, but more information is needed about N behaviour along latitudinal gradients, and in different types of soil and forest in the boreal region. In a recent study on long-term carbon dynamics in boreal forests Nalder and Wein (2006) highlighted the need for better data in several areas, particularly root litter, woody detritus dynamics, coniferous foliage litter and N budgets.

Generalisations based on short-term studies on a limited number of study plots or over different countries are difficult due to differences in ecosystem characteristics, climate, variation between years and N deposition rates. Long-term monitoring studies, such as those carried out on the Forest Focus/ICP Forests Level II network, serve as a reliable source of information for use, e.g. in larger-scale modelling of changes in nutrient budgets and stocks caused by environmental changes such as global warming.

In this paper we present nitrogen (N) stocks and fluxes in Scots pine and Norway spruce stands along a latitudinal gradient in Finland.

Materials and methods

Sample plots

The data were collected in 8 Scots pine (*Pinus sylvestris* (L.)) and 8 Norway spruce (*Picea abies* (L.) Karst) stands during 1998 – 2004 The sites belong to the Finnish network of intensively monitored forest plots (Level II) (Raitio and Kilponen 1999), and are located in semi-natural, even-aged stands subjected to commercial forestry. Most of the pine plots are located on sorted glacifluvial material, and the spruce plots on till soils. In this study, total C and N concentrations were determined on a CHN analyser (Leco) unless stated otherwise.

Stand biomass and N concentration of needles, stems and branches

Tree species, diameter, tree height and crown length were measured on every tree with a BHD of at least 4.5 cm. The tree biomasses were estimated according to Marklund (1987, 1988). Five randomly selected trees from the dominant canopy layer were harvested on each of the sites (for details, see Ukonmaanaho et al., in this special number) and discs were cut at 1.3 m height above ground level. The bark, sapwood and heartwood were separated, dried, milled and total C and N determined. For the determination of needle N and C concentrations, sample branches bearing current and previous-year needles were collected from the uppermost third of the living crown on 10 predominant or dominant sample trees on each site, and pre treated and analysed as described in (Merilä et al. 2007). N and C pools were then calculated by multiplying the corresponding biomasses and concentrations.

Understorey vegetation, litter layer and fine root biomass

12 root cores were taken in each stand with a cylindrical soil corer (diameter 40 mm) (Helmisaari et al. 2007). Both understory and tree roots were separated from the soil by washing, and sorted into living and dead fractions. The roots were further sorted into fine roots (< 2mm) (Persson 1983, Vogt et al. 1983), including mycorrhizal root tips, and small roots (25mm). The samples were dried at 70ºC and weighed.

Litterfall, deposition and percolation water N and C fluxes

Litterfall was collected using 12 funnel-shaped traps, with a collecting area of 0.5 m^2. Litterfall was sampled at two-week intervals during the snow free period, and once at the end of winter. The samples were air-dried and weighed prior to chemical analyses. Bulk (BD) and throughfall (TF) deposition and soil percolation water (PW) was collected at 2- to 4-week intervals. Bulk deposition was collected in an open area using 3 (Ø 20 cm, h = 0.4 m) precipitation collectors during the snowfree period and 2 snow collectors (Ø 36 cm, h = 1.8 m) during winter. TF samples were collected with 20 precipitation collectors and 6 – 10 snow collectors located systematically within the stand. Soil percolation water was collected using five zero tension lysimeters located at depths of 5, 20 and 40 cm. The water flux was estimated by the conservative anion (sulphate) budget method. The water samples were pre-treated as described in the ICP Forests Manual (1998). Total N was determined on a flow injection analyser (FIA), and dissolved organic carbon (DOC) on a TOC analyser.

Results and discussion

The tree biomass and N stocks in the stands only are presented here because the ground vegetation N analyses are still being carried out. However, the results will be included in the presentation. The following tree fractions were included in this study: needles, branches, dead branches, stems, bark, stump and roots, and fine roots. The total biomass of the stands ranged from 84 500 – 22 700 kg ha^{-1} in the pine stands and from 80 700 – 274 800 kg ha^{-1} in the spruce stands. No clear relationship was found between biomass and latitude, but the three northernmost spruce stands had less biomass than the ones located in the southern of Finland.

The N stocks in the tree stands ranged from 170 – 658 kg/ha. The N stocks in the pine stands (mean 301 ± 25 kg N ha^{-1}) were, on the average, 35% lower than in the spruce stands (mean 465 ± 57 kg N ha^{-1}). This is expected because spruce stands are usually growing on more fertile soils than pine stands.

More N was stored in the pine stems (13%) than in the spruce stems. Although the stems accounted for the major proportion (28 – 74%) of the total biomass in the stands, the branches (12 – 42%) and needles (11 – 34%) represented the dominant stocks of N in the tree biomass in both the pine and spruce stands. The N stocks in the fine roots accounted for only a small proportion of the N stocks in stand biomass (3.31 – 17.70%). According to Helmisaari (2002), however, this pool accounts for a major part of the N used for annual biomass production (45 kg ha^{-1}, 45 – 63%, in mature pine stands). The N stocks and biomass values reported here were comparable to those reported by Helmisaari et al. (2002) for a mature pine stand in Finland.

In this study the biomass of stumps was calculated according to the equation of Marklund (1988), which combines the root and stump biomasses and therefore makes it difficult to calculate the above- and belowground biomasses separately. The equation also slightly underestimates the root biomass, but does provide some information about the amount of N lost from stands when stumps are removed and used for bioenergy production (pine mean 49.7 ± 10.33 kg ha^{-1}, spruce mean 29.57 ± 7.1 kg ha^{-1}). The stumps and roots accounted for 13 – 35% of the biomass in the spruce stands and 14 - 28 % in the pine stands. The average N stocks in the roots and stumps was 15.7 ± 3% of the total N stock in the pine stands and 6.7 ± 1.3% in the spruce stands.

The litterfall input to the forest floor was related to the total N stock in the stands. The output N flux (N in percolation water at depth of 40 cm) from the spruce stands was 56% (0.78 kg ha^{-1}) lower than that from the pine stands, although the N stock in the spruce stands was higher. This may be partly due to the lower water fluxes in the fine-textured soils under spruce, as well as to the high retention of the input of soluble N in BD by the spruce canopies and soil. The relatively high output N flux at 40 cm depth in the pine stands does not, however, necessarily mean that more N is lost from the stand because pines have a much deeper rooting system than spruces.

We will further analyse the data to study the N stocks in the understorey vegetation and soil, N retention by the canopy and individual soil layers, as well as estimate the C stocks in these stands in relation to the N stocks and fluxes.

References

Chapin, F.S., McGuire, A.D., Randerson, J., Pielke, R., Baldocchi, D., Hobbie, S.E., Roulet, N., Eugster, W., Kasischke, E., Rastetter, E.B., Zimov, S.A. & Running, S.W. 2000. Arctic and boreal ecosystems of western North America as components of the climate system. Global Change Biology 6: 211 – 223.

Helmisaari, H.-S., Derome, J., Nöjd, P. & Kukkola, M. 2007. Fine root biomass in relation to site and stand characteristics in Norway spruce and Scots pine stands. Tree Physiology 27: 1493 – 1504.

Helmisaari, H.S., Makkonen, K., Kellomaki, S., Valtonen, E. & Mälkonen E. 2002. Below- and above-ground biomass, production and nitrogen use in Scots pine stands in eastern Finland. Forest Ecology and Management 165: 317 – 326.

Kauppi, P.E., Tomppo, E. & Ferm, A. 1995. C and N storage in living trees within Finland since 1950s. Plant and Soil 169: 633 – 638.

Liski, J. & Westman, C.J. 1997. Carbon storage in forest soil of Finland.1. Effect of thermoclimate. Biogeochemistry 36: 239–260.

Marklund, L.G. 1987. Biomass functions for Norway spruce in Sweden. Swedish University of Agricultural Sciences, Department of Forest Survey. Report No. 43. 127 p.

Marklund, L.G. 1988. Biomassafunktioner för tall, gran och björk i Sverige. Sveriges Lantbruksuniversitet, Institut av skogstaxeringpp. Rapp. No 45. 73 p.

Merilä, P., Kilponen, T. & Derome, J. (eds.). 2007. Forest condition monitoring in Finland, National report 2002–2005. Working Papers of the Finnish Forest Research Insitute 45. Finnish Forest Research Institute. 166 p.

Nalder, I.A. & Wein, R.W. 2006. A model for the investigation of long-term carbon dynamics in boreal forests of western Canada – I. Model development and validation. Ecological Modelling 192: 37–66.

Persson, H. 1983. The distributon and productivity of fine roots in boreal forests. Plant and Soil 71: 87–101.

Raitio, H. & Kilponen, T. (eds.). 1999. Forest Condition Monitoring in Finland, National report 1998. The Finnish Forest Research Institute, Research Papers 743. 147 p.

Vogt, K.A., Grier, C.C., Meier, C.E. & Keyes, M.R. 1983. Organic matter and dynamics in forest floors of young and mature Abies amabilis stands in Western Washington, as suggested by fine root input. Ecological Monographs 53: 139–157.

Woodwell, G.M., Mackenzie, F.T., Houghton, R.A., Apps, M., Gorham, E. & Davidson, E. 1998. Biotic feedbacks in the warming of the earth. Climatic Change 40: 495–518.

Assessing and monitoring biodiversity in boreal forests

Juha Siitonen

Finnish Forest Research Institute, Vantaa Research Unit, P. O. Box 18, FI-01301 Vantaa, Finland

Several international and pan-European initiatives, processes and resolutions, including CBD, MCPFE and SEBI2010, call for the monitoring of biodiversity in European forests. This requires the development and testing of methods and indicators suitable for monitoring purposes. Furthermore, biodiversity indicators need to be adapted to the specific conditions of each biogeographical region and main forest type. The aims of the pilot study were 1) to develop stand-level inventory methods for three species groups (epiphytic lichens, polypore fungi and beetles), 2) to study the effects of present biodiversity-oriented forest management methods on species diversity in boreal forests, 3) to explore and model the relationships between stand structural features and diversity of the focal taxa, 4) to develop planning tools for multi-purpose forest management, and 5) to develop validated biodiversity indicators suitable for monitoring purposes.

Three types of window-flight traps for sampling forest beetles were compared. In order to detect 50% of the saproxylic species present in one stand, a set of 7–13 traps catching 750–1900 individuals was required. Identification of invertebrates is time consuming and therefore expensive. The effect of plot size on the cumulative number of polypore species was also studied. Species accumulation curves differed among the stands depending on the amount (density) of dead wood. In order to detect 50% of the species present, a sample plot of 0.56 ha was needed in an old-growth stand, whereas a 1 ha plot was needed in a managed stand. It is relatively easy to standardize and perform polypore sampling that detects the desired proportion of species present. Furthermore, perennial species with long-lived fruiting bodies explain about 70% of the richness of annual species, and these can be used as a surrogate for the overall species richness of polypores. Inventory of perennial species is possible throughout the year and, in contrast to annual species, they are not sensitive to short-term variation in precipitation.

Dead-wood variables (total volume, diversity etc.) generally explained a large proportion of the variation in the species richness of polypores and saproxylic beetles. However, except for the dead-wood variables, correlations between species richness and stand characteristics were relatively weak in all the studied species groups. Moreover, there were large regional differences in species richness, and especially in the occurrence of red-listed species, probably due to differences in land-use history in the study regions in southern Finland. In practice, this means that stand characteristics alone cannot be used as a surrogate for monitoring biodiversity but that some species groups need to be included.

Our results substantiate the importance of dead wood as a biodiversity indicator. In the future, measurement of both dead-wood volume and quality should be included in forest monitoring schemes. Among the taxa that were studied, epiphytic lichens and perennial polypores proved to be good candidates as species groups that could be included in large-scale monitoring.

Changes in the rainfall, throughfall and soil solution chemistry in the Level II forest monitoring plots in UK between 1995 and 2006

Elena Vanguelova, Sue Benham & Rona Pitman

Environmental & Human Science Division, Forest Research, Farnham, Surrey, GU10 4LH

Introduction

Detrimental changes to soils and water ecosystems from the impact of acid deposition and acidification have lead to the development of national and international policies aimed at reducing emissions of acidifying pollutants. For example, in Europe reductions have been agreed as part of the Gothenburg Protocol in 1999, which targets emissions reductions for sulphur dioxide, nitrogen oxides and ammonia of 75%, 50% and 12%, respectively, by 2010 compared with the 1990 baseline (Jenkins and Cullen 2001). Increasingly, such policies have required an effects-based approach to proposing solutions for environmental problems and implementing emissions reductions in a targeted and cost-effective way. As a part of this process there is a need to provide policy makers with information showing the consequences of changing emissions on the environment and their associated ecosystems. The European intensive forest monitoring (ICP Level II sites) have been established in 1995 monitoring the chemical inputs and outputs of the forest ecosystems, thus it can evaluate the implementation of the emission reduction policies.

The main objectives of this study were:

1) to evaluate the long term (10 years) trends, their magnitude and significance in rainfall, throughfall and soil solution chemistry in the Level II plots in the UK
2) to understand the nature, sources and causes of the identified trends
3) to establish the links between rainfall, throughfall and soil solution chemistry and their relationships with measured response variables such as foliar and litterfal chemistry and leaf biomass and also with calculated variables such as canopy exchange properties and leaching.

Material and methods

Environmental data for the last 10 years from the ICP Level II forest monitoring network in the UK have been summarised. Data from ten Level II sites across the UK was used. Monthly data for rainfall, throughfall and soil solution chemical data were used together with rainfall, evapotranspiration and stemflow to calculate elemental fluxes. Dry deposition, canopy nutrient uptake and leaching of the above nutrients were also calculated and their change in the last ten years was also evaluated. Seasonal Mann- Kendall modelling (Mann 1945, Kendall 1975, Claudia Libiseller 2004) was carried out on all datasets and each variable separately to identify any trends and evaluate their magnitude, seasonally and significance. Correlation between variables were also calculated and evaluated for significance.

Results and discussion

Significant decline in rainfall and throughfall acidity in most of the sites was observed which is in line with the reduction of acidity in rainfall monitored for the last 16 years in the 32 Acid Deposition Monitoring Network sites in the UK (Fowler et al. 2005). However, recovery of soil pH was observed only on two previously very polluted sites and the recovery is slow because the very low buffering capacity of the soils at these sites. Sulphur in rainfall declines significantly only in the upland sites with high rainfall precipitation while sulphur in the throughfall declines significantly in all of the sites. Annual dry deposition of SO_2 at the sites is relatively high (up to 47% of total S deposition) especially in lowland sites and sites previously heavy polluted. The change in the dry deposition of SO_2, which declines significantly over the monitoring period, is the largest contributor to the change in the throughfall S. The reason for this is that the throughfall consists of wash-off of previously dry-deposited sulphate particles and SO_2 and leaching of internal plant sulphur from foliage. Level II data shows two to three times more sulphate in throughfall as compared to rainfall. Other studies have found that particulate deposit adds 3 to 4 times as much S as it is deposited by rain (Nyborg et al. 1977). Dry deposition of > 85% of the enrichment of sulphate in the throughfall flux to soils is reported for different tree species at low elevation sites in the United States (Lindberg and Garten 1988). This explains the steeper and significant decline in sulphate in throughfall as a comparison to more gradual and in most cases not significant decline of sulphate in rainfall. Soil solution sulphate declines in all sites but significant downward trends were only observed at the previously very polluted sites. The above long term trends in acidity and sulphate highlight and confirm the successful implementation of emission reduction policies.

Ammonium in rainfall and throughfall is significantly declining in one lowland oak site and all upland sites while nitrate in rainfall and throughfall shows significant decline only in few of these sites. Contribution of reduced nitrogen to the total N is high in all sites. On the contrary, dry deposition of both N forms and also the rainfall DON have been found to significantly increase in some of the upland sites. Given the large decline in SO_4 and acidity, the scavenging of NH_4 would be also expected to change, and in particular the increase in travel distance of NH_4 and a gradual change in the partitioning of NH3/NH4 (Fowler et al. 2005). Emission of NO_x and NH_3 in the UK were reduced by 35% and 15% respectively over the monitoring period (Goodwin et al. 2004) and the reduction of NH_4 and NO_3 concentrations seen at our sites are broadly consistent with the change expected through the emission reduction.

Significant increase in throughfall K, DON and DOC at some sites were detected. Detailed examination of the data suggest that these trends are due to repeatedly episodic peaks of either K, DON or DOC in the throughfall which are clearly not detected in the rainfall but are detected in the soil. This excludes an additional source of pollution as a possible cause and some of these trends can be linked with episodic events of insect attacks at these sites. Bernhard and Michalzik (1998) found significantly higher DOC in throughfall of infested trees by aphid than under not infested Norway spruce trees. The results from the UK's Forest Condition Survey for the period 1993–2003 clearly show two occasions on which the crown density of Sitka spruce has deteriorated markedly (at a national level) in 1996 and 1997, and between 2001 and 2002 (Hendry 2005) which supports the evidence from the intensive Level II monitoring (Vanguelova et al. 2007).

Throughfall Na and Cl increased significantly at some of the upland sites and especially pronounced increase in two upland and very exposed sites. Since Na and Cl are assumed to be derived mainly from the sea, these results are most likely to show the increased number of storm events occurring at these sites. These increases are observed only in throughfall but not in rainfall and it is assumed that this is due to the water, fog and mist interception by forests (Hutberg and Grennfelt 1992, Chiwa et al. 2004) as opposed to open field.

Conclusions

The evaluation of the long term trends in rainfall and dry deposition at the Level II intensive forest monitoring sites provides evidence for changes in important deposition chemistry which confirm the successful implementation of the emission reduction policies in the UK. Long term trends in throughfall and soil solution chemistry at these sites show the ecosystem response to changes in deposition and the rate of chemical recovery. This helps the evaluation of air pollution and climate change direct and indirect impacts on forest biogeochemisty and health. The detailed analysis also suggest the importance of biological influence on the chemical cycling as well as improves our understanding on the chemical versus biological impacts and responses, their magnitude and nature. It is suggested that many insect pests may become more damaging as a result of climate change, in part, driven by expectations that more frequent and severe summer droughts will make trees more susceptible to biotic agents. The integrated nature of monitoring across the Level II network enables the relationships between climate, pollutant exposure, crown condition and insect populations to be explored.

References

Bernhard, S. & Michalzik, B. 1998. Linking aphid honeydew, throughfall, and forest floor solution chemistry of Norway spruce. Ecology Letters 1: 13–16.

Claudia, L. 2004. A Program for the Computation of Multivariate and Partial Mann-Kendall Test. Manual, 2004.

Chiwa, M., Crossley, A., Sheppard, L.J., Sakugawa, H. & Cape, J.N. 2004. Throughfall chemistry and canopy interactions in a Sitka spruce plantation sprayed with six different simulated polluted mist treatments. Environmental Pollution 127 (1): 57–64.

Fowler, D., Smith, R.A., Muller, J.B.A., Hayman, G. & Vincent, K.J. 2005. Changes in atmospheric deposition of acidifying compounds in the UK between 1986 and 2001. Environmental Pollution 137: 15–25.

Goodwin, J.W.L., Salway, A.G., Dore, C.J., Murrells, T.P., Passant, N.R., Watterson, J.D., Hobson, M.M., Haigh, K.E., King, K.R., Pye, S.T., Coleman, P.J. & Conolly, C.M. 2004. UK Emissions of Air Pollutants 1970 to 2000. AEA Technology plc, Abingdon, Oxfordshire, UK, July 2002.

Hendry, S.J. 2005. Forest Condition 2004. Information Note 75. Forestry Commission, Edinburgh. [Internet site]. Available at: http://www.forestry.gov.uk/website/publications.nsf/.

Hultberg, H. & Grennfelt, P. 1992. Sulphur and seasalt deposition as reflected by throughfall and runoff chemistry in forested catchments. Environmental Pollution 75 (2): 215–222.

Jenkins, A. & Cullen, J.M. 2001. An assessment of the potential impact of the Gothenburg Protocol on surface water chemistry using the dynamic MAGIC model at acid sensitive sites in the UK. Hydrol and Earth Sys Sci 5: 529–541.

Kendall, M.G. 1975. Rank Correlation Methods, Charles Griffin, London.

Lindberg, S.E. & Garten, C.T. 1988. Sources of sulphur in forest canopy throughfall. Nature 336: 148–151.

Mann, H.B. 1945. Nonparametric Tests against Trend. Econometrica 13: 245–259.

Nyborg, M., Repin, D., Hocking, D. & Baker, J. 1977. Effect of sulphur dioxide on precipitation and on the sulphur content and acidity of soils in Alberta, Canada. Water, Air and Soil Pollution 7 (4): 1977.

Vanguelova, E.I., Barsoum, N., Benham, S., Broadmeadow, M., Moffat, A., Nisbet ,T. & Pitman, R. 2007. Ten years of intensive environmental monitoring of British forests. Forestry Commission Information note 088.