Working Report 2013-56

Results of Forest Monitoring on Olkiluoto Island in 2012

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August 2014

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ABSTRACT

Forest investigations carried out at Olkiluoto aim to monitor the state of the forest ecosystems, quantify Olkiluoto-specific processes taking place in the forests producing input data for the safety assessment of spent nuclear fuel disposal, and follow possible changes in the forest condition resulting from the intensive construction activities currently being carried out in the area. The forest investigations form a part of the monitoring programme being carried out on Olkiluoto Island under the management of Posiva Oy. This report focuses on activities performed on bulk deposition and forest intensive monitoring plots (MRK and FIP plots) in 2012. In general, the clearest changes in the deposition levels in 2012 were associated with the NH_4-N deposition that decreased compared to the situation in 2011. The NO_3-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004-2012. The increase in NO_3-N in bulk deposition was probably due to the construction activities in the area (e.g. rock detonations). The soil solution quality in 2012 was also quite comparable to that in earlier years. Annual total litterfall production (158-380 g_{dw}/m^2 without larger branches) was quite comparable in 2011 to that in 2010. High Al and Fe concentrations were found in remaining litter, and were most likely due to soil dust. The pines were classified as non-defoliated indicating good crown condition of the trees. However, the spruces were classified as moderately defoliated, probably due to natural aging of trees. The foliar concentrations of most of the studied elements in Scots pine and Norway spruce were not affected by the different washing procedures, which clearly indicated that most of the elements had not accumulated on the needle surfaces. However, on the spruce plots close to the soil and rock landfill site the effect of elements (e.g. Al and Fe) originating from soil material was clearly visible. No harmful effects of human activities on the forest condition were observed in the Nature conservation area.

Keywords: Bulk deposition, defoliation, forest ecosystems, litterfall production, needle analysis, soil solution chemistry, stand throughfall, tree stand transpiration.

OLKILUODON METSIEN TILAN SEURANTA 2012

TIIVISTELMÄ

Olkiluodon metsäntutkimusten tavoitteena on seurata metsien tilaa ja mitata metsissä tapahtuvia prosesseja. Tuloksia tarvitaan käytetyn ydinpolttoaineen loppusijoituksen turvallisuusarvioinnissa. Lisäksi tutkimuksilla seurataan alueen voimakkaan rakennustoiminnan mahdollisesti aiheuttamia muutoksia metsissä. Metsäntutkimukset ovat osa Posivan toteuttamaa ympäristön seurantaohjelmaa Olkiluodossa. Tässä raportissa esitetään keskeiset tulokset laskeuma-alojen ja metsien intensiiviseurannan alojen (MRK- ja FIP-alat) seurannasta vuonna 2012. Vuoden 2012 laskeumassa selvin muutos tapahtui avoimen alan NH_4-N -laskeumassa, joka pieneni edelliseen vuoteen verrattuna. Sen sijaan nitraattitypen (NO_3-N) laskeuma lisääntyi 2012, ja se oli suurin koko seurantajakson 2004-2012 aikana. Tämä saattoi olla seurausta Olkiluodossa tehdyistä kallioräjäytyksistä. Maaveden ominaisuuksissakaan ei ollut pääsääntöisesti havaittavissa muutoksia aikaisempiin vuosiin verrattuna. Vuonna 2011 puuston maanpäällinen kokonaiskariketuotanto (158-380 g_{dw}/m^2 ilman suuria oksia) oli samalla tasolla kuin 2010. Muussa karikkeessa mitattiin korkeat Al- ja Fe-pitoisuudet, mikä selittynee maapölyllä. Harsuuntumisarvioinnin perusteella mäntyjen latvukset olivat hyvässä kunnossa, mutta ikääntyneiden kuusten latvukset luokiteltiin jo kohtalaisesti harsuuntuneiksi. MRK-alojen kuusten ja mäntyjen neulasten alkuainepitoisuuksissa ei pääsääntöisesti ollut havaittavissa oleellisia eroja eri pesukäsittelyjen välillä. Tämä osoittaa, ettei aineita ollut kertynyt neulasten pinnalle lukuun ottamatta muutamaa kuusialaa maa-ainesten murskauspaikan läheisyydessä. Niillä aloilla kuusen neulasten pinnan korkeat Al- ja Fe-pitoisuudet osoittivat selvästi pölypäästöjen vaikutuksen. Ihmistoiminnan aiheuttamia muutoksia ei havaittu Olkiluodon vanhojen metsien luonnonsuojelualueen tai sitä ympäröivän NATURA-alueen metsien tilassa.

Avainsanat: Harsuuntumisaste, karikesato, laskeuma, maavesi, metsikkösadanta, metsäekosysteemit, neulasanalyysi, puuston haihdunta.

CONTENTS

1 INTRODUCTION

Forest investigations carried out on Olkiluoto aim to monitor the state of the forest ecosystems, quantify Olkiluoto-specific processes taking place in the forests producing input data for the safety assessment (Hjerpe et al. 2010, Posiva 2010) of spent nuclear fuel disposal, and follow possible changes in the forest condition resulting from the intensive construction activities currently being carried out in the area, as well as the future construction of the spent nuclear fuel repository. In addition, the forest investigations provide data for a range of modelling purposes either in terms of input data or validation data.

The forest investigations form a part of the monitoring programme being carried out on Olkiluoto Island under the management of Posiva Oy (Posiva 2012). A summary of the current studies, observations and measurements is reported annually for each discipline: rock mechanics, hydrology, hydrogeochemistry, the environment and foreign materials. This report on forest monitoring at Olkiluoto in 2012 supplements preceding reporting. Results of forest monitoring during 2009-2011 have been reported by Aro et al. (2010, 2011 and 2012). Forest research conducted before 2009 has been reported partly in Posiva's memos, and some of those studies are included as appendices in this report.

In respect of monitoring possible environmental impacts of constructing a repository for spent nuclear fuel, and later on the continuation of the monitoring related to the operational safety of the repository, two potential pathways for loads going into forests should be considered. First, the network for monitoring atmospheric deposition should be positioned with consideration to the prevailing wind direction, i.e. north-west, north or north-east of the repository. Currently some MRK and FET sampling plots are located in that area, and their usability for monitoring purposes should be assured in the future. Secondly, in the case of the repository, the Liiklansuo watershed may be one of the most important areas to monitor possible environmental impacts which occur via soil water or surface runoff. Three forest intensive monitoring plots, FIP, have been established in that area.

This report has been prepared by several authors from the Finnish Forest Research Institute (Metla). Hannu Hökkä is responsible for tree stand transpiration, Antti-Jussi Lindroos for bulk deposition, stand throughfall and soil solution chemistry and Pasi Rautio for litterfall production and element return to the forest floor, as well as chemical composition of particulate matter on needle surfaces. Lasse Aro is responsible for the rest. In addition, he has been responsible for the compiling of different chapters, as well as for the final editing of the report.

2 MONITORING SYSTEM

2.1 Description of the forest monitoring network

The monitoring system consists of several overlapping levels (Figure 1). The first level is used for following changes in land use by interpreting aerial images. The second level is vegetation-type mapping, the purpose of which is to classify the vegetation and its distribution for use as a basis for the monitoring of primary plant succession caused by the post-glacial land uplift (about 6 mm/year, e.g. Haapanen et al. 2009) at the plant community level and the possible anthropogenic environmental impact (Haapanen 2009). Forest resources have also been mapped from the same vegetation polygons. The third monitoring level (FET, Forest ExTensive monitoring plots, Figure 2) is a grid of systematically located plots which are used to describe the biomass distribution of forests and to monitor growth and other changes in tree stands. A part of the FET plots has been selected for further studies (FET sub-set, i.e. FET sampling plots). In these plots the vegetation is inventoried and the soil, needles and vegetation are sampled at intervals of 5 to 10 years in order to identify soil properties, vegetation composition and nutrient concentrations of plants and trees (for more details, see Tamminen et al. 2007, Haapanen 2009). The last two levels (MRK and FIP, Figures 1 and 2) comprise plots where observations are mostly made monthly but in some cases even hourly (see Ch. 2.2). The intensity of the sampling efforts increases towards the sixth monitoring level (Figure 1).

Due to continuous changes in land use on Olkiluoto Island, it is not always possible to record the up-to-date extent of each monitoring network.

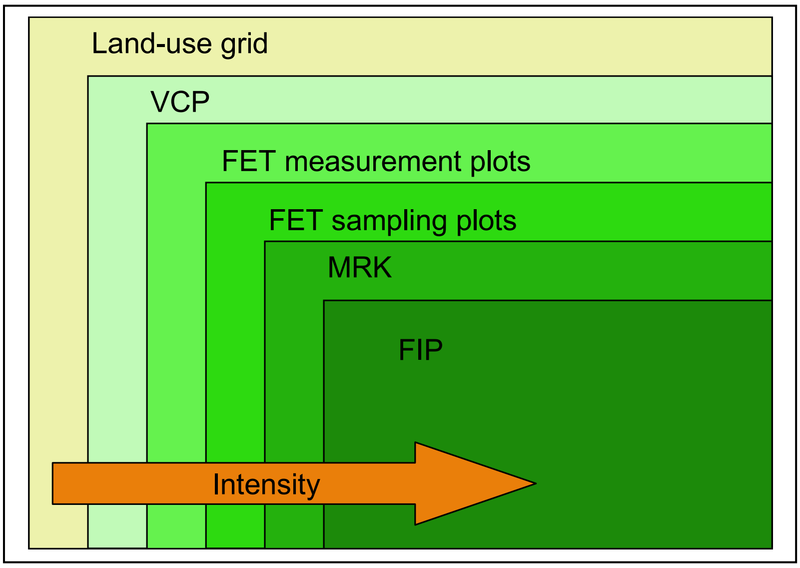


Figure 1. Forest monitoring levels. The outermost land-use grid consists of plots at 50 m intervals. These have been visually interpreted for land-use. VCP contains the vegetation polygons, from which the forest resources have also been inventoried. The numbers of currently monitored plots are 485 (FET), 94 (FET sampling plots) and 6 (MRK), of which 4 belong to the FIP grid as well. Grids have been modified (plots added/removed) according to increased knowledge of data needs and land-use changes on the island.

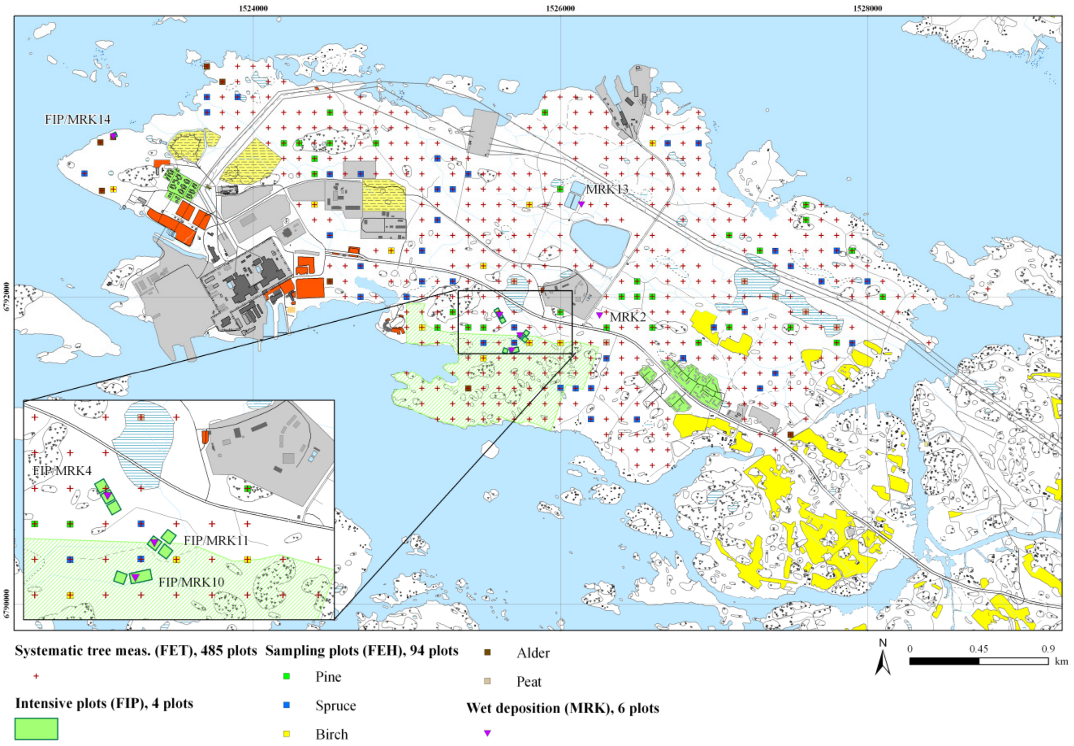


Figure 2. Forest monitoring locations in 2010. Map: Posiva.

2.2 Description of the MRK and FIP networks

2.2.1 Bulk deposition and stand throughfall plots (MRK)

The construction activities and rock crushing (i.e. an underground rock characterisation facility and an access to the spent fuel repository) on Olkiluoto Island are producing a potentially negative impact on forests, primarily in the form of stone dust. To monitor the effects on the forests, a bulk deposition and stand throughfall monitoring network with rainwater and snow collectors (Figure 3) was established in 2003. The annual precipitation and interception of the tree canopies are also recorded on these plots. Currently four of the monitoring plots are within FIP plots and two in open areas (Figure 3). Rainwater is collected every two weeks and snow every four weeks, and from these samples the deposition (including both dry and wet deposition) is analysed for the mean pH and the amounts of a range of anions, cations and other elements.

Figure 3. *Examples of monitoring plots in an open area (MRK13, left; picture taken 12.5.2009) and in a spruce forest (MRK8, right; 22.5.2006). (Photos: A. Ryynänen/Metla and J. Ilomäki/Metla).*

2.2.2 Forest intensive monitoring plots (FIP)

In order to gain a better understanding of the effects of different stress factors on the forests, as well as understanding and quantifying the different processes typical of forest ecosystems on Olkiluoto Island, an intensive monitoring system similar to the Level II ICP Forests programme in Finland (e.g. Raitio et al. 2001) was established on Olkiluoto Island. The aim of the intensive monitoring activities is to continuously follow changes taking place in the nutrient budgets and fluxes in the soil, tree stands and vegetation at both the stand and the catchment level to cover the seasonal, annual and long-term variation (Table 1).

Each FIP plot (excluding FIP14) consists of three square sub-plots (30 m x 30 m, total area 900 m^2) coded as OA1, OA2 and OA3. The corners of the sub-plots, as well as their centre points, have been marked in the field using numbered poles. An approximately 5 to10 m wide strip has been left between and around the sub-plots for possible future use in special studies, and for additional sampling. This area constitutes the fourth sub-plot (OA4). OA1 is reserved for tree growth measurements and OA3 for vegetation studies. Sampling methods that may have a detrimental long-term effect on the soil or stand, e.g. litter sampling, deposition and soil water collection, are concentrated on sub-plot OA2.

FIP14 consists of only one square sub-plot (OA2, total area 900 m^2) where litter sampling, deposition, soil water collection and micro-meteorological measurements are concentrated. Plot FET930231 (total area 300 m^2), which is used for tree growth measurements and vegetation studies (see Figure 2), is located beside the OA2 sub-plot.

Table 1. *Performed monitoring activities and their frequency on the FIP plots.*

	Performed activities				Normal Frequency
	FIP4	FIP10	FIP11	FIP14	
Establishment, start of equipment installation	2003	2003	2007	2009	
Location and measurement of trees	2004	2005	2008	2009	
Vegetation inventory (OA3)	2003, 2004, 2005, 2008, 2011	2003, 2004, 2005, 2008, 2011	2008, 2011	2010	Every 5 yrs
Soil condition	2007	2007	2007	2008	Every 10 yrs
Stand throughfall and precipitation measurements (MRK, OA2)	2003	2005	2007	2009	Continuous
Sap flow measurements	2007	2007	no	no	Continuous
Soil water sampling (OA2)	2003	2005	2007	2010	Continuous
Litterfall sampling (OA2)	2004	2005	2007	2009	Continuous
Foliage sampling (OA2)[1]	2003, 2004, 2005, 2006, 2007, 2009	2004, 2005, 2006, 2007, 2009	no	2009	Every 2 yrs
Micrometeorology (OA2)	2004	2005	2007	2009	Continuous
Stem diameter growth (OA2)	2004	2005	no	no	Continuous
Tree growth (OA1)	2009	2009			Every 5 yrs
Crown condition survey [2]	2006	2006	no	no	Biennial
Soil microbial community structure and activity	2006	2006			
Biomass and chemical composition of vegetation and humus layers	2008	2008	2008		
Fine root biomass	2008	2008	2008		
Fine root elongation and longevity	2008 – 2011	2008 – 2011	2008 – 2011		

[1] not sampled in 2011 because results in 2009 showed no significant changes compared to the previous sampling round

[2] annually 2006-2010, biennially 2010 –

Figure 4. *A view of the intensive monitoring plots FIP4 (top left; picture taken 20.4.2010), FIP10 (top right; 20.4.2010), FIP11 (bottom left; 25.8.2011) and FIP14 (bottom right; 11.8.2010). Photos: L. Aro/Metla.*

The first intensive monitoring plots were established in the small Liiklansuo catchment area, which represents the most important types of forest vegetation found on Olkiluoto Island. FIP4 was marked out in a 37-year-old Scots pine (*Pinus sylvestris*) stand (compartment no. 401.1, Rautio et al. 2004) and FIP10 in a 91-year-old Norway spruce (*Picea abies*) stand (compartment 366.1, Rautio et al. 2004) in August, 2003. The soil type on both plots was fine-textured till according to the compartment-wise inventory (Rautio et al. 2004). Both the Scots pine plot and the Norway spruce plot represent herb-rich heath forests (i.e. *Oxalis-Myrtillus* forest type, Table 3, Figure 4). The third intensive monitoring plot (FIP11) was established in a young birch dominated stand in the Liiklansuo catchment area during 2006–2007 (Figure 4). This birch dominated plot (FIP11) is located on a rocky site and the vegetation represented partly mesic heath forest vegetation (i.e. *Myrtillus* type) and partly herb-rich heath vegetation (i.e. *Oxalis-Myrtillus* type). The fourth FIP plot (FIP14, Figure 4) was established in an alder stand of a herb-rich type in 2009. The instrumentation of the FIP plots is presented in Table 2 and basic characteristics of the soil and vegetation in Table 3. The stem volume of the dominating tree species is shown in Figure 5. More details of tree stand characteristics during 2004-2009 were presented by Aro et al. (2012).

Table 2. *The instrumentation of the FIP plots with main installation information (i.e. the installation site in relation to the ground level and the date of installation).*

Description	FIP plot	Instrument	Quantity	Installation site	Date
Air temperature	4	FW-5k	3	2, 9 & 24 m	1.9.2004
	10	FW-5k	1	2 m	23.5.2005
	11	FW-5k	1	2 m	19.6.2007
	14	Vishay-10k	1	2 m	3.11.2009
Radiation	4	LI-190/200SZ	2	24 m	1.9.2004
Air pressure	4	PTB210	1	2 m	26.4.2005
Wind	4	Adcon	1	24 m	1.9.2004
Relative humidity	4	HMP45D	2	2 & 9 m	1.9.2004
	10	HMP45D	1	2 m	23.5.2005
	11	HMP45D	1	2 m	19.6.2007
	14	HMP45D	1	2 m	3.11.2009
Precipitation	4	RMY-52203	1	1 m	1.9.2004
	10	RMY-52203	1	1 m	23.5.2005
	11	RMY-52203	1	1 m	19.6.2007
Soil temperature	4	FW-5k	13	-10 … -90 cm	1.9.2004
	10	FW-5k	13	-10 … -90 cm	23.5.2005
	11	FW-5k	13	-10 … -90 cm	19.6.2007
	14	Vishay-10k	13	-10 … -90 cm	3.11.2009
Soil moisture	4	Theta Probe	2	-20 cm	1.9.2004
	10	Theta Probe	2	-20 cm	23.5.2005
	11	Theta Probe	2	-20 cm	19.6.2007
	14	Theta Probe	2	-20 cm	3.11.2009
Soil solution	4	Plate lysimeter	8	-5 cm	Sept. 2003
		Suction cup	12	-10, -20, -30 cm	Sept. 2003
	10	Plate lysimeter	12	-5 cm	May 2005
		Suction cup	24	-20, -30 cm	May 2005
	11	Plate lysimeter	8	-5 cm	13.12.2006
		Suction cup	12	-10, -20, -30 cm	13.12.2006
	14	Plate lysimeter	4	-5 cm	29.10.2009
Litterfall	4	Funnel type sampler	12	150 cm	June 2004
		Branch type	12	0 cm	7.5.2008
	10	Funnel type sampler	12	150 cm	12.5.2005
		Branch type	12	0 cm	7.5.2008
	11	Funnel type sampler	12	150 cm	25.4.2007
	14	Funnel type sampler	12	150 cm	15.5.2009
		Branch type	12	0 cm	30.6.2010
Stand throughfall	4	Snow sampler	5	180 cm	2.6.2003
		Rainwater collector	20	40–60 cm	2.6.2003
	10	Snow sampler	5	180 cm	23.5.2005
		Rainwater collector	20	40–60 cm	23.5.2005
	11	Snow sampler	5	180 cm	16.11.2007
		Rainwater collector	20	40–60 cm	May 2007
	14	Snow sampler	5	180 cm	17.9.2009
		Rainwater collector	20	40–60 cm	15.5.2009
Tree growth	4	Girth band	2	130 cm	1.9.2004
	10	Girth band	2	130 cm	23.5.2005

Table 3. *Basic characteristics of soil and vegetation of the FIP plots (Aro et al. 2012; more information on soil properties, see Appendix 1).*

FIP plot	Site type	Soil profiles	Humus thickness (cm)	Dominating tree species	The most abundant plant species in bottom and field layers
4	Herb-rich heath forest	Haplic Arenosol	4.4	Scots pine	Red-stemmed feather-moss, bracken
10	Herb-rich heath forest	Haplic Arenosol / Haplic Gleysol	9.6	Norway spruce	Red-stemmed feather-moss, bilberry
11	Mesic heath forest / Herb-rich heath forest	Haplic Gleysol / Histic Gleysol	7.5	Downy birch	Red-stemmed feather-moss, lingonberry
14	Herb-rich forest (grove)	Haplic Arenosol	5.7	Black alder	*Brachythecium oedipodium*, bracken [1]

[1] based on the vegetation survey of FET930231 (Aro et al. 2011)

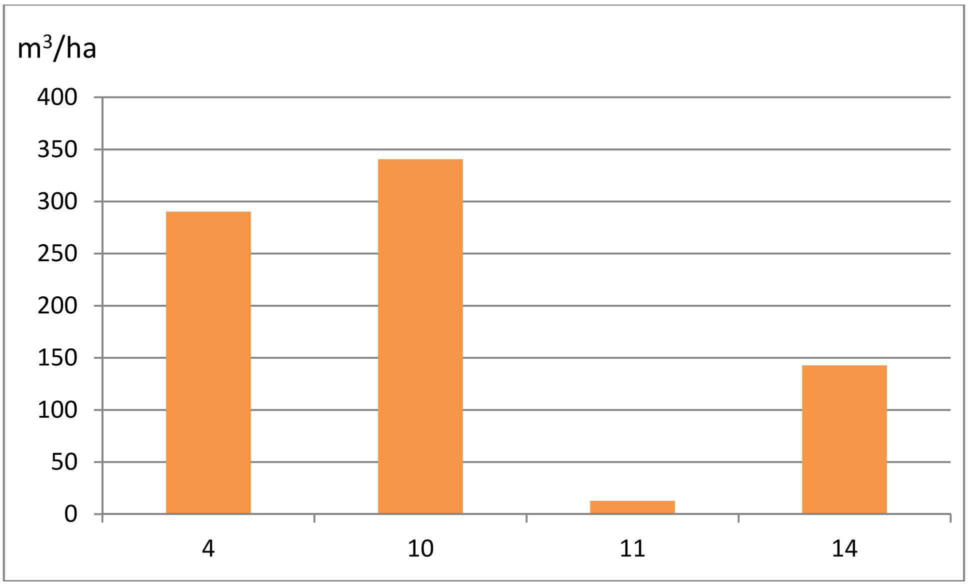


Figure 5. *Stem volume of the dominating tree species on the FIP plots: Scots pine on FIP4-OA1 (measured in 3/2009), Norway spruce on FIP10-OA1 (9/2009), downy birch on FIP11-OA1 (6/2008) and black alder on FIP14-OA2 (11/2009).*

3 MATERIAL AND METHODS

3.1 Bulk deposition and stand throughfall on MRK plots

Deposition loads on the forest and forest floor were monitored using a deposition monitoring network (MRK plots, Table 4). The monitoring was performed during 2012 on 6 plots, of which two were located in open areas (MRK2 and MRK13), one in the Scots pine stand (MRK4), one in the Norway spruce stand (MRK10), one in the young birch dominated stand (MRK11) and one plot in the alder dominated stand (MRK14).

The results for bulk deposition and stand throughfall during the period 3.1.2012-7.1.2013 are presented in this report (Ch. 4.1), and the deposition for this period is denoted in the following as the deposition for the year 2012. The results for 2012 are compared to the deposition load during the period 2004-2011 on Olkiluoto, as well as to the deposition load on two intensively monitored plots (one pine and one spruce) in Juupajoki, central Finland and two plots (one pine and one spruce) in Tammela, southern Finland (UN/ECE ICP Forests monitoring plots).

The samples were collected at predetermined intervals (at 2-week intervals during the snow free period, and at 4-week intervals during the winter) on Olkiluoto and mailed to Rovaniemi by the staff of Posiva Oy. This procedure was used in order to minimise contamination of the samples (while still in the collectors) through microbial growth during the warmer parts of the year. All the samples were stored in a cold room prior to making bulked samples in the laboratory. The chemical analyses (Table 5) were carried out by the laboratory staff of the Rovaniemi and Vantaa Units, Metla.

Table 4. *Basic characteristics of the establishment and deposition monitoring of the MRK plots. Type: TF=stand throughfall, BD=bulk deposition. V=total stem volume with bark (m^3/ha, all tree species included in March 2007; more details in POS-003852, Table 13, see also Figure 7).*

MRK plot	Established	Type	Tree species (dominating)	V (m^3/ha)	Monitoring period
1	6/2003	TF	Scots pine	134	6/2003 – 3/2008
2	6/2003	BD	open area	0	6/2003 – 12/2007, 4/2008 –
3	6/2003	TF	Scots pine	171	6/2003 – 3/2008
4	6/2003	TF	Scots pine	303[a]	6/2003 –
5	6/2003	TF	Norway spruce	176	8/2003 – 3/2008
6	6/2003	TF	Norway spruce	154	8/2003 – 3/2008
7	6/2003	BD	open area	0	6/2003 – 3/2008
8	6/2003	TF	Norway spruce	221	6/2003 – 3/2008
9	4/2004	BD	open area	0	4/2004 – 3/2008
10	5/2005	TF	Norway spruce	473[b]	5/2005 –
11	5/2007	TF	birch	17[c]	5/2007 –
12	10/2007	BD	open area	0	1/2008 – 3/2008
13	5/2009	BD	open area	0	5/2009 –
14	5/2009	TF	Black alder	147[d]	7/2009 –

[a] in May 2008
[b] in May 2008
[c] in June 2008
[d] in November 2009

The major problem in collecting deposition is the avoidance of contamination caused by bird droppings in the rainfall collection equipment. Bird droppings contain appreciable amounts of P which result in elevated phosphate concentrations in samples. The field workers had strict instructions to exclude samples from individual collectors where there was evidence of bird droppings.

There were no problems, in general, in the field work, transport of the samples to the laboratory or during the chemical analyses that can be considered to have had a significant effect on the results for 2012. However, storm events caused some problems to the collection and samples, but this disturbance was taken into account in the evaluation of the results as well as possible.

Table 5. *Performed analyses and their limits of quantification (LOQ) for water samples of bulk deposition and stand throughfall.*

Variable	Unit	LOQ
pH		
Alkalinity	mmol/l	
H+	mg/l	
Conductivity	µS/cm/25 °C	8
DOC	mg/l	0.6
Tot-N	mg/l	0.05
NH_4-N	mg/l	0.03
NO_3-N	mg/l	0.04
PO_4-P	mg/l	0.13
SO_4-S	mg/l	0.05
Al	mg/l	0.005
B	mg/l	0.004
Ca	mg/l	0.0004
Cd	mg/l	0.0007
Cl	mg/l	0.1
Cr	mg/l	0.001
Cu	mg/l	0.004
Fe	mg/l	0.002
K	mg/l	0.06
Mg	mg/l	0.001
Mn	mg/l	0.001
Na	mg/l	0.01
Ni	mg/l	0.002
P	mg/l	0.06
Pb	mg/l	0.005
Si	mg/l	0.006
Zn	mg/l	0.002
Ba	mg/l	0.0001
Nb	mg/l	0.002
Pd	mg/l	0.005
Sn	mg/l	0.004
Sr	mg/l	0.0001
Ta	mg/l	0.006
Te	mg/l	0.010
V	mg/l	0.001
W	mg/l	0.010

3.2 Soil solution on FIP plots

3.2.1 Method of sampling soil solution

The chemical composition of soil solution is monitored continuously during the snow-free period on FIP plots at Olkiluoto as a part of a comprehensive study on the functioning of forest ecosystems on the island. Changes in the chemical composition of rainfall (bulk precipitation) are followed as the water first passes down through the tree canopy (stand throughfall), and then down the soil profile in the form of soil solution (Figure 6). Soil solution is sampled at different depths down the soil profile, thus providing information about soil formation processes. In addition to determining the concentrations of individual ions, the amount of water passing down through the soil is also measured and modelled in order to be able to determine ion fluxes between the individual soil horizons in tree stands.

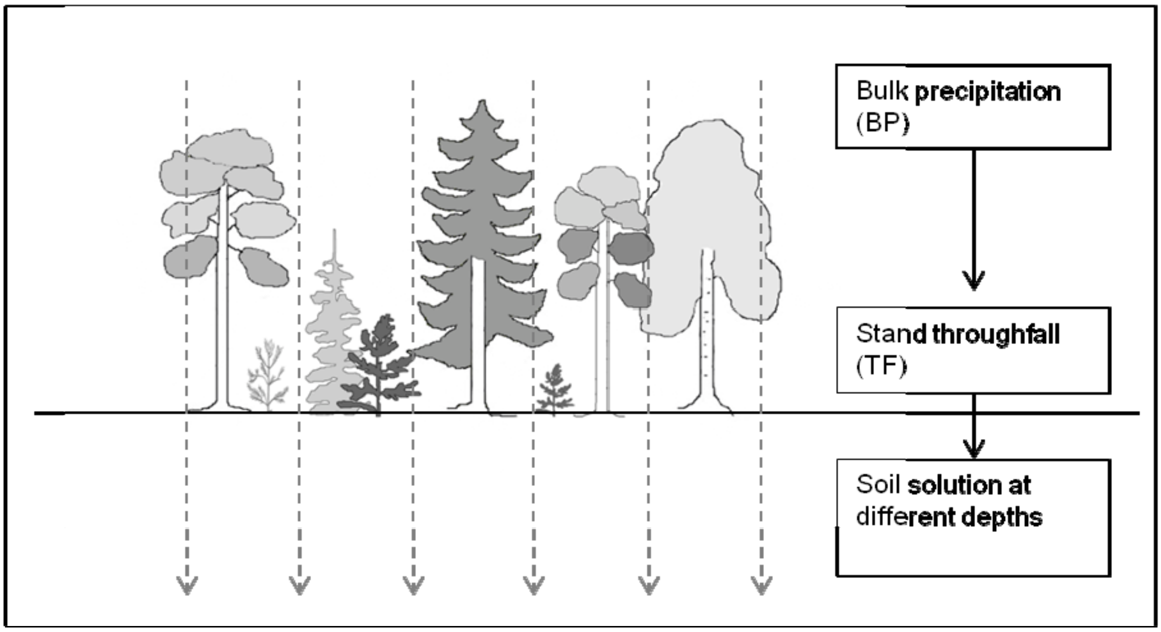


Figure 6. *A schematic presentation showing the path of water down through forest ecosystems, and the different components taken for chemical analysis (Drawing: A. Hamari/Metla).*

Two sampling techniques are used for sampling soil solution in the stands:

- Tension lysimetry (suction-cup lysimeters) installed at different depths, primarily in the mineral soil
- Zero-tension lysimetry (plate lysimeters) installed immediately below the organic layer

The two procedures differ considerably with respect to the soil solution fraction sampled, the effects of sampling on the site, as well as the extent to which they provide information about temporal and spatial variation in the properties of the soil solution. Of the two methods, zero-tension lysimetry is the only one which samples a clearly definable fraction of the soil water, i.e. free-flowing water that percolates down through the soil when the field capacity is exceeded. Even so, there are drawbacks to this method because zero-tension lysimeters, for technical reasons, do not necessarily collect all of the free-flowing water at the sampling point, and the volume of water collected/surface area of the collector is therefore not always equal to the water flux at the sampling point. Tension lysimetry samples a relatively broad fraction of the soil water. However, soil water samples are obtained by this technique only when the magnitude of the negative pressure (vacuum) applied exceeds that of the hydraulic forces holding the water in the soil. Tension lysimetry obviously also samples free-flowing water when it is present.

The sampling of soil solution started on FIP4 (Scots pine stand) on 18.5.2004, on FIP10 (Norway spruce stand) on 19.7.2005, on FIP11 (young mixed stand) on 1.6.2007, and on FIP14 (alder stand) on 16.6.2010.

The layout (location, depths and replications) of the lysimeters on the three plots is comparable to that used in establishing the intensive monitoring plots of the ICP Forests (UN/ECE) programme. Furthermore, the sampling procedure and the pre-treatment and analysis of the soil solution samples are carried out in accordance with the ICP Forests Sub-manual on Soil Solution Collection and Analysis.

The soil solution samples were collected at predetermined intervals on Olkiluoto and sent to Rovaniemi by the staff of Posiva Oy. The chemical analyses (Table 6) were carried out by the laboratory staff of the Rovaniemi and Vantaa Units, Metla.

3.2.2 Amounts of percolation water

Percolation water was collected during the snow-free periods in 2004-2012 on plot FIP4, in 2005-2012 on plot FIP10, in 2007-2012 on plot FIP11 and in 2010-2012 on FIP14 using plate lysimeters with a surface area of 0.1 m^2 (40 cm x 25 cm) located at a depth of 5 cm, i.e. immediately below the organic layer. On plot FIP4 there was a total of 8 plate lysimeters at 4 sampling points (2 replications/point). On plot FIP10 there was a total of 12 plate lysimeters and on plot FIP11 a total of 8 plate lysimeters, located systematically over the plot. On plot FIP14 there was a total of 4 plate lysimeters at one sampling point. The collection period of the percolation water starts in the spring after snowmelt when the ground is no longer frozen.

The amount of water percolating down to different depths in the soil is determined by a number of factors:

1) The amount of water falling on the forest floor as rain or snow. In a tree stand, this is the amount of stand throughfall (Figure 6).
2) Some of the water in stand throughfall is lost from the snow cover during the winter through evaporation directly from the snow surface. This can be especially high during spring when, even though the air temperature is below freezing point, solar radiation causes the sublimation of ice directly into water vapour that is released into the atmosphere.

3) Some of the water (as snow) falling on the forest floor is lost during snowmelt in the form of horizontal runoff out of the stand. This can be considerable if the ground immediately below the melting snow cover is still frozen, thus preventing the water from passing down into the soil
4) During the period extending from spring to autumn, a variable proportion of the water falling onto the forest floor is recycled back into the atmosphere though the uptake of water by the tree stand and ground vegetation (as evapo-transpiration). The plate lysimeters are located below the organic layer, which is the layer in the soil that contains the highest proportion of plant roots.
5) Some of the water (as rain) that collects on the surface of the ground vegetation during the snowfree period may evaporate directly into the atmosphere, especially during warm periods.
6) During the summer especially, the intensity (amount) of stand throughfall strongly affects the amount of percolation water; high precipitation events result in more percolation water owing to the proportionally smaller amount of water lost through evapo-transpiration.

In addition to the above natural factors, there are also technical problems during the snowmelt period; the capacity (volume) of the bottles used to collect the water samples may not always be sufficient to hold all the water running out of the plate lysimeters. Under such conditions, the amount of percolation water will be underestimated. On plot FIP10 there are also problems in the spring with an excessively high water table and inundation by high sea water; the plot is located only a few meters above sea level and water may pass into the collection bottles that is not derived from precipitation.

3.2.3 Chemical composition of the soil solution on FIP plots

Soil solution was collected in the Scots pine stand using 8 plate lysimeters at a depth of 5 cm, and suction cup lysimeters at depths of 10, 20 and 30 cm, in four observation clusters on the plot during the snow-free period. Soil solution was collected in the Norway spruce stand using 12 plate lysimeters systematically located at a depth of 5 cm on the plot during the snow-free period. The 24 suction cup lysimeters were located at depths of 20 and 30 cm (12 for each depth). In the young mixed stand, soil solution was collected using 8 plate lysimeters located at a depth of 5 cm, and 12 suction cup lysimeters at depths of 10, 20 and 30 cm (4 for each depth), systematically located on the plot during the snow-free period. Only 4 plate lysimeters were used to collect soil solution in the alder stand. The samples from each plate lysimeter were analysed separately, and the samples obtained with the suction cup lysimeters were bulked to give one sample per depth per monitoring plot per sampling occasion.

Table 6. *Performed analyses and their limits of quantification (LOQ) for soil solution.*

Variable	Unit	LOQ
pH		
Alkalinity	mmol/l	
Conductivity	µS/cm/25 °C	8
DOC	mg/l	0.6
Tot-N	mg/l	0.05
NH_4-N	mg/l	0.03
NO_3-N	mg/l	0.04
PO_4-P	mg/l	0.13
SO_4-S	mg/l	0.05
Al	mg/l	0.005
B	mg/l	0.004
Ca	mg/l	0.0004
Cd	mg/l	0.0007
Cl	mg/l	0.1
Cr	mg/l	0.001
Cu	mg/l	0.004
Fe	mg/l	0.002
K	mg/l	0.06
Mg	mg/l	0.001
Mn	mg/l	0.001
Na	mg/l	0.01
Ni	mg/l	0.002
P	mg/l	0.06
Pb	mg/l	0.005
S	mg/l	0.07
Si	mg/l	0.006
Zn	mg/l	0.002
Ba	mg/l	0.0001
Nb	mg/l	0.002
Pd	mg/l	0.005
Sn	mg/l	0.004
Sr	mg/l	0.0001
Ta	mg/l	0.006
Te	mg/l	0.010
V	mg/l	0.001
W	mg/l	0.010

3.3 Tree stand transpiration on the plots FIP4 and FIP10

The tree stand transpiration measurements on Olkiluoto Island were initiated on FIP4 and FIP10 in early May and early June 2007, respectively. The measurement system was enlarged with three new trees on both the plots in April 2010. The aim was to measure tree-level transpiration as a basis for calculating the stand transpiration rate and variability in the FIP areas. A measurement system by UP GmbH, based on the constant heat method, was installed. Water movement is measured with a pair of needle sensors (30-40 mm long, 2 mm in diameter), which are radially inserted into the sapwood of a tree at a ca. 1.5 m height with a vertical spacing of 10 to 15 cm (Granier 1985, Köstner et al. 1996). Both sensors have a thermocouple for recording temperature. The upper sensor is heated constantly with 0.2W direct power and the temperature difference between the needles is monitored. Temperature differences between the sensors have been related to the mass flow of water based on empirical calibration (Granier 1985) with several tree species. The maximum temperature difference is during the night, when sap flow is assumed to be 0. In the daytime, high flow reduces the difference because water flux transports the heat away from the upper needle. The measured flow density is extrapolated for the whole tree by multiplying by the tree sapwood area (Granier 1985). Since weather conditions (humidity, wind and radiation) determine the rate of transpiration, the meteorological data collected in the FIP4 weather station can be used in studying the variability of transpiration in relation to variations in local weather. The establishment of the system, calculation of the sapwood area and results for 2007 and 2008 are presented in Appendices 2 and 3.

Basically, some problems occurred in sap flow measurements especially during the winter season in 2009, 2010 and 2011. In particular some measuring observations were missing which resulted in unreal peaks in calculated transpiration. Therefore calculated values for tree transpiration can be considered reliable only for the period from the end of March to the beginning of December and consequently reliable for the period from April to November on a monthly basis during 2008-2011. In 2012 the sap flow measurements of the FIP4 plot were mostly reliable during 1.4.-27.9.2012 although calculation of the stand level transpiration was based on three trees instead of six trees in May, July and August. Due to missing data or unrealistic high peaks in signal data, it was not possible to report stand level transpiration on a monthly basis for January to March and November to December 2012.

In 2011, more severe problems occurred in the sap flow measurement systems of the FIP10 plot. Measurement systems had several breaks during January to April 2011. In May 2011 the operation of the systems recovered until mid-summer after which loggers produced data of bad quality, and finally another logger broke. Sap flow measurements were continued with one logger which, however, had several serious breaks during 2012 although the needle sensors of spruces 1-3 (FIP10-SF2) were replaced with new ones on 29.5.2012. Therefore we are not able to report the transpiration of the Norway spruce stand in 2011 and 2012.

***Table** 7. Maximum acceptable values of transpiration at single tree and tree stand levels.*

Level	Time unit	Max value	Unit
Tree stand	per hour	0.25 (min=0)	mm
	per day	2.5 (min=0)	mm
	per mounth	50 (min=0)	mm
Single tree	per hour	5	dm^3
	per day	45	dm^3

3.4 Litterfall production and element return to the forest floor on FIP plots

Litterfall was collected using 12 traps according to the methods defined by UN/ECE ICP Forests (Pitman et al. 2010) located systematically on FIP4 (pine), FIP10 (spruce), FIP11 (deciduous forest) and FIP14 (black alder) plots in 2011. The litterfall collectors were funnel-shaped traps with a collection area of 0.5 m^2 placed about 1.5 m above ground level (see Figure 4). Litterfall collection was started on the plots (FIP4, FIP10, FIP11 and FIP14) on 17.5.2011. Since the last collection date in 2010 was at the end of October (21.10.2010), the mass of the first collection in May 2011 represents the litterfall of the whole previous winter. Since the pretreatment of litter samples is laborious and time-consuming, the results of litterfall production and its chemical composition are available one year later than the other forest monitoring results.

In 2011 the collected litter was divided into eight different fractions:

1= dead pine needles (brown needles)
2= living pine needles (green needles)
3= spruce needles
4= leaves
5= remaining litter
6= small branches
7= branches
12= remaining litter in branch traps

Fractions 1-6 were collected using the funnel type litterfall traps used in the ICP Forests programme (Pitman et al. 2010). Branches (fraction 6) collected by this trap are rather small. To collect the whole spectrum of branch litter we used a new type of traps that are positioned on the ground (Figure 4). These new "branch traps", which consist of a nylon fabric stretched on a frame of approximately two centimetres in height, were developed in the Finnish Forest Research Institute specifically to collect branch litter that is missed by the funnel type litterfall traps used in the ICP Forests programme (Pitman et al. 2010), mainly to collect foliage litter. These branch traps are similar to the funnel traps in size (0.5 m^2). 12 branch traps were positioned close to each funnel trap. Branch traps were used on the plots FIP4, FIP10 and FIP14.

Litterfall production (dry mass in grams/m^2; 105°C) is reported for each of these fractions separately for each collection occasion. Element concentrations (aluminium, barium, boron, calcium, carbon, chromium, copper, iron, magnesium, manganese, nickel, nitrogen, phosphorus, potassium, sodium, strontium, sulphur, tin, vanadium and zinc) were determined if there was enough material in a given litter fraction to allow homogenization (grinding) and microwave digestion in acid (HNO_3/H_2O_2) preceding chemical analysis. Here we present concentrations of Al, Fe and N; concentrations of other elements can be found in the POTTI database. Concentrations of cadmium, lead, molybdenum, niobium, palladium, tantalum, tellurium and wolfram were in most cases below the limit of quantification.

3.5 Defoliation of trees on the plots FIP4 and FIP10

Visual assessment of the crown condition on intensive monitoring plots at Olkiluoto was carried out according to the guidelines of the UN/ECE crown condition sub-manual (Eichhorn et al. 2010).

3.6 Chemical composition of particulate matter deposited on needle surfaces

Chemical analyses on leaves and needles can be used to assess nutrient deficiencies and toxicity, as well as to monitor the nutrient balance of the trees. In addition, such samples can also be used for monitoring the effects and spread of air pollutants and for estimating the processes involved in the transport of nutrients from the soil to the needles/leaves. Spruce and pine needles were collected from the forested sample plots (MRK plots) during 2003-2007 in order to follow the foliar element concentrations. Special attention was paid to assessing the effect of particulate matter originating from the construction activities on the foliar concentrations by means of different washing procedures. Previous results were originally reported in Posiva's memos (see Table 13), but those results are also included in this report.

Element concentrations in pine and spruce needles were determined on samples collected during winter 2003/2004 (December 2003) on wet deposition plots (Figure 7) in Olkiluoto: MRK1, MRK3 and FIP4 (Scots pine plots) and MRK5, MRK6 and MRK8 (Norway spruce plots). On the same plots samples were collected during winter 2004/2005 (December-January) when also new spruce plot FIP10 was included in the monitoring programme. Sampling was repeated during winters 2005/2006 (January 2006), 2006/2007 (December 2006) and again during winter 2007/2008 (February 2008). Since winter 2007/2008 the sampling has been carried out biennially (the year means the moment when the current year needles were born). Needles born in 2009 were collected during March 2010.

The MRK plots were established close to the ONKALO construction site and the landfill site for crushed waste rock. Because the wet deposition plots were sited in the prevailing forest site types, the spruce plots are located around the landfill site and the pine plots around the ONKALO site. One sub-plot (OA2) in both of the FIP plots (4 and 10) is also used as an MRK plot. Therefore one of the spruce plots (FIP10) is located further away from the landfill sites than the other spruce plots (Figure 7). Among other selection criteria, the vicinity of the corresponding pine plot (FIP4) also influenced the location of this spruce plot. Of the pine plots, MRK1 and MRK3 are located in the vicinity of the ONKALO construction site (Figure 7) downwind of the prevailing wind direction, i.e. they presumably receive more dust than FIP4, which is located upwind from ONKALO. Of the spruce plots, MRK5 and MRK6 are located in the vicinity of the landfill site and rock crushing site, whereas MRK8 is located slightly further away (Figure 7).

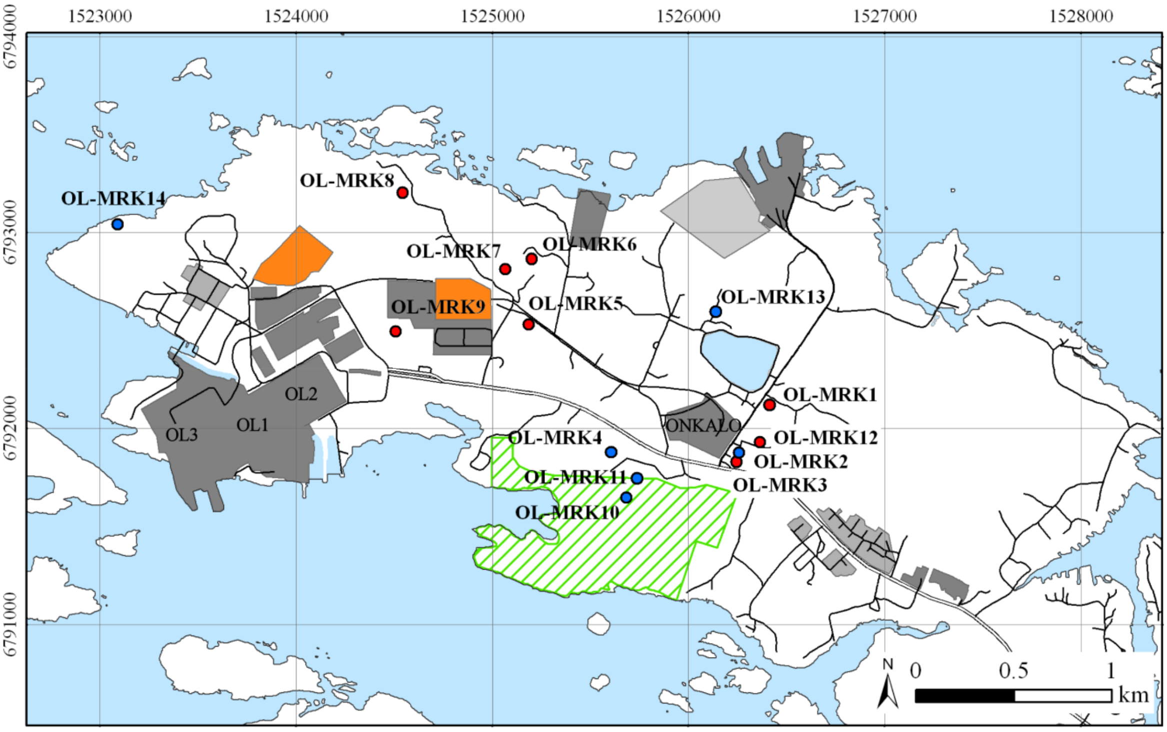


Figure 7. *Location of the wet deposition monitoring plots (MRK plots currently used in wet deposition monitoring are marked with blue dots) and of the ONKALO and rock piling and crushing areas (in orange). (Map: Posiva; see also Table 4).*

The samples were collected from the southern and western aspects in the upper third of the crown in accordance with the Pan-European Forest Condition Monitoring Programme (United Nations Economic Commission for Europe 2004). The samples were collected using an extendable branch cutter (18 m), each sample branch including at least two needle age classes (C = current-year, C+1 = previous-year needles). Samples were taken from ten trees on each MRK plot. The needle sampling trees were the same as those used in previous studies, apart from certain exceptions on the FIP plots (Table 8). The sample branches were stored in sealed plastic bags in a freezer (−20 ± 4°C) until pre-treatment in the laboratory of the Parkano Unit of the Finnish Forest Research Institute. Pre-treatment of the needle samples was performed separately for each sample tree. The C and C+1 branch sections with the needles still attached were first separated from each other.

An exception to the UN/ECE ICP Forests foliar manual (United Nations Economic Commission for Europe 2004) was that the pine needles were detached from the shoots before drying (according to the manual needles are detached after drying). This was done because the needles were to be washed with deionised water or chloroform after detachment from the shoots. The unwashed needles were therefore also treated in the same way in order to avoid systematic errors.

Table 8. *Tree numbers of the needle sampling pines and spruces on the FIP plots.*

Plot	Sampling Year	Tree no. 1	2	3	4	5	6	7	8	9	10
FIP4	2003	58	29	76	90	170	299	312	325	393	497
	2004 –	58	29	27	25	21	22	17	14	12	497
FIP10	2004	185	188	180	160	59	76	148	151	86	12
	2005	52	63	105	116	59	76	148	151	86	12
	2006 – *)	3052	3063	3105	3116	2059	2076	2148	2151	3086	2012

*) sampling trees are the same as in 2005, but the numbering was changed on 2.5.2006

As the spruce needles were washed while still attached to the shoots, there was no need to detach the needles before washing or drying. The accumulation of particulate material on the needle surfaces was quantified by i) washing with deionised water, ii) washing with chloroform, or iii) with no washing. Washing with water was performed by stirring needles (or shoots in the case of spruce) in approx. 400 ml of deionised water for two minutes. After washing, the needles were rinsed rapidly once more with deionised water to remove the water from the first washing that may have still contained detached particles. Chloroform washing was carried out by stirring the spruce shoots for half a minute in 130 ml of chloroform, after which the needles were rapidly rinsed with deionised water as described above. Chloroform washing of the pine needles was done by stirring the needles in 100 ml of chloroform for one minute, after which the needles were rinsed with deionised water as described above. A different washing time was chosen for spruce and pine needles because, according to the literature, elements are leached more readily from inside spruce needles than from pine needles (Turunen ym. 1995, Rautio & Huttunen 2003). We also tested this difference between spruce and pine needles in a pilot experiment, which confirmed the results reported in the literature.

The needles were oven-dried in paper bags (+60 °C, 24 h minimum, average duration 4 days), and the spruce needles then removed from the branch sections. The pine needles were already removed from the branch sections before drying. The needles were milled (Retcsh ZM 1 ultracentrifuge mill) to pass through a 1 mm sieve. The milled needle samples were stored in plastic bags at room temperature until analysis. The C and C+1 needles from each tree were analysed separately.

The carbon and nitrogen concentrations of the needle samples were determined on a CHN analyser (Leco CHN-2000) in the laboratory of the Parkano Unit. The element concentrations (Al, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, S, Sn, Sr, Ta, Te V, W and Zn) were determined by wet digestion (HNO_3/H_2O_2) and analysed by ICP-AES in the laboratory of the Vantaa Unit of the Finnish Forest Research Institute. Wet digestion was carried out in a microwave oven (CEM MarsXpress). The results were expressed on a dry matter basis (determined by drying at +105 °C).

The Mo, Nb, Pb, Ta, Te, V and W concentrations were below the limit of quantification for the analytical instrument and they have not been reported. Needle Cd, Cr, Pd and Sn concentrations were also frequently below the limit of quantification, and the results for Cd, Cr, Pd and Sn should therefore be considered as indicative only.

Table 9. *Performed analyses and their limits of quantification (LOQ) for needle analysis in 2012.*

Variable	Unit	LOQ
Al	mg/l	0.005
B	mg/l	0.004
Ba	mg/l	0.0001
C	%	1.0
Ca	mg/l	0.002
Cd	mg/l	0.0007
Cr	mg/l	0.002
Cu	mg/l	0.001
Fe	mg/l	0.002
K	mg/l	0.1
Mg	mg/l	0.001
Mn	mg/l	0.0004
N	%	0.06
Na	mg/l	0.06
Nb	mg/l	0.002
Ni	mg/l	0.002
P	mg/l	0.015
Pb	mg/l	0.01
Pd	mg/l	0.0055
S	mg/l	0.02
Sn	mg/l	0.004
Sr	mg/l	0.0001
Ta	mg/l	0.01
Te	mg/l	0.013
V	mg/l	0.003
W	mg/l	0.01
Zn	mg/l	0.001

3.7 Additional elemental analyses 2008 – 2011

The first samples of forests for additional elemental analyses were collected in 2008. Sampling was focused on the FIP plots and FET914254 sampling plot (Table 10) and it was carried out by adapting the procedures used in earlier inventories at Olkiluoto (e.g. Tamminen et al. 2007). Soil samples were collected from the organic layer and the 0-10 cm and 10-30 cm mineral soil layers. The plant samples included typical species of the understorey vegetation on each plot (e.g. *Deschampsia cespitosa, Dryopteris carthusiana, Oxalis acetosella, Vaccinium myrtillus, Vaccinium vitis-idaea*; see Appendix 4a). In addition, branch, needle and leaf samples were also collected from dominating trees. Pre-treatment of vegetation and soil samples has been presented by Tamminen et al. (2007). Soil samples were dried at 40ºC and sieved (< 2 mm) before analysis. The results are expressed on dry matter content at 105ºC.

Sample trees TR1 and TR2 were collected from the OL-KK14 soil pit before excavating and trees TR5 and TR6 from FET911275. KK14 is located in the Scots pine stand next to the intensive monitoring plot FIP4. Sampling and pre-treatment of sample trees have been presented in more detail by Aro et al. (2012). However, only wood and bark samples from breast height (1.3 m) were used for additional elemental analyses. Soil sampling from KK14 has been described by Lahdenperä (2009) and that of FET911275 by Tamminen et al. (2007). FIP4, FIP10 and KK14 represent heath forests, and FET911275 (site type changed after re-evaluation in 2011, see Aro et al. 2012) and FET914254 groves.

Needles born in 2009 were collected from MRK plots (representing heath forests) during March 2010 (see sampling and pre-treatment, Ch. 3.6 in this report). Unwashed fresh current year needles (c needles) were used for analyses of additional elements. A part of the fresh needles washed with deionised water or chloroform after detachment from the shoots were stored in a freezer. Three pooled samples consisting of two to four sample trees (Table 10) were combined for each MRK plot. Before analysis needles were washed with Milli-Q water (usually deionized before passing through the Milli-Q system) in order to remove the effect of deposition on the results. Soil samples (humus layer and mineral soil 0-30 cm) were collected with a shovel from MRK plots (MRK1, 3, 5 and 8) in September 2011 (PRJ-004303, see Table 13). Soil sub-samples (three per MRK plot, i.e. one sampling point per one needle tree repetition) were pooled by soil layer and by MRK plot. Soil samples were dried at 50ºC and homogenized before analysis. All soil analyses were carried out on non-sieved samples. Results are expressed on dry matter content at 105ºC.

Total element analyses of plant samples from FIP plots and FET914254 were done after digestion with HNO_3 in sealed Teflon containers in a microwave oven. (For I a sintering method for digestion was used.) Elements were analysed by ICP-SFMS. All analyses of soil samples from the same plots have been carried out after digestion with HNO_3. Se was analysed with AFS (atomic fluorescence spectrophotometer) and the rest of elements with ICP-SFMS.

Total element analyses of MRK needles were done after digestion with HNO_3/HF (trace). Analysis was carried out for 69 elements by ICP-SFMS with methane addition to achieve the best possible LOQs for Ag and Pd. The following elements were analysed quantitatively: Al, As, Ba, Be, Ca, Cd, Co, Cr, Cs, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, S, Se, Si, Sn, Sr, Ti, U, V and Zn. Also the halogens (Br, Cl and I) were analysed quantitatively (Appendix 4b).

The soil samples (dried at 40 ºC, < 2 mm fraction) from KK14 were analysed for other elements than I and Se after hydrofluoric acid – perchloric acid (total) digestion with ICP-MS/ICP-OES (Lahdenperä 2009). I and Se were analysed from fresh samples after HNO_3/H_2O_2 digestion with ICP-SFMS. The results are expressed on dry matter content at 105ºC (Appendix 4b).

In the analyses of bioavailable elements on MRK plots, 6.0 g (humus) or 3.0 g (mineral soil) of dried and homogenised material was weighed. The ratio of humus to NH_4Ac solution was 1:5, and that of mineral soil 1:10. The soil samples were leached in NH_4Ac (NH_4Ac-CH_4COO) solution buffered at pH 4.5 for 16h in an overhead shaker. After dilution, the leachates were analyzed for 69 elements by ICP-SFMS with methane addition to achieve the best possible LOQs for Ag and Pd. Separate analyses were made for Br, Cl and I with ICP-SFMS. The following elements were analysed quantitatively:

Halogens (Br, Cl and I), Al, As, Ba, Be, Ca, Cd, Co, Cr, Cs, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, S, Se, Si, Sn, Sr, Ti, U, V and Zn.

Total element analysis of humus samples from OL-MRK1, 3, 5 and 8 plots was done by HNO_3/HF (trace) digestion in a sealed Teflon container in a microwave oven for 15 minutes at 120 ºC using ICP-AES and ICP-SFMS. For mineral soil samples, total element analysis was done using a combination of two different methods for digestion, Lithium metaborate ($LiBO_2$) fusion and HNO_3/HF (trace). The total concentrations of As, Cd, Cl, Co, Cs, Cu, Hg, I, Pb, Pd, S, Se, Sn and Zn were analysed by HNO_3/HF (trace). The total concentrations of Al, Ba, Br, Si, Ca, Cr, Fe, K, Mg, Mn, Mo, Na, Nb, P, Sr, Ti, V, W and Zr were made by $LiBO_2$ dissolved in 25 ml 5% HNO_3. A 0.1 g sample was mixed with 0.4 g $LiBO_2$ and transferred to a graphite crucible and put into an oven at 1000 ºC for 45 minutes. After cooling the sample-pearl was dissolved in the dilute nitric acid overnight on a shaking table. Analysis was carried out ICP-SFMS with methane addition to achieve the best possible LOQs for Ag and Pd. (Lahdenperä 2014).

The chemical analyses were carried out in the ALS Laboratory Group in Luleå, Sweden, except for soil samples from KK14 which were analysed for other elements than I and Se at Labtium, Finland.

Table 10. *Position and tree species of the repeat samplings (original tree numbers have been presented for repeats 1-3 of pooled needle samples on MRK plots) and sample trees (TR) for additional analyses. For MRK plots coordinates equal to centre poles of the plots.*

Plot/site	Repeat	N coord.	E coord.	Tree species
FIP4	1	6791906.278	1525606.620	Scots pine
FIP4	2	6791899.430	1525616.029	Scots pine
FIP10	1	6791643.890	1525666.983	Norway spruce
FIP10	2	6791656.113	1525663.100	Norway spruce
FET914254	1	6791408.044	1525403.623	Black alder
FET914254	2	6791391.643	1525395.217	Black alder
FET911275	TR5	6791094.568	1527455.165	Black alder
FET911275	TR6	6791098.271	1527463.739	Black alder
KK14	TR1	6791928.774	1525624.274	Scots pine
KK14	TR2	6791925.364	1525627.150	Scots pine
MRK1	1 (3,13,116) 2 (24,37) 3 (129,148)	6792120.818	1526414.527	Scots pine
MRK3	1 (70,84,89) 2 (75,121) 3 (100,109)	6791827.805	1526245.303	Scots pine
MRK4	1 (12,14,17,497) 2 (21,22,25) 3 (27,29,58)	6791874.303	1525607.332	Scots pine
MRK5	1 (16,19,24,25) 2 (6,62,63) 3 (59,60,64)	6792532.325	1525185.619	Norway spruce
MRK6	1 (3,13,23) 2 (42,50,56,85) 3 (81,82,84)	6792866.473	1525202.623	Norway spruce
MRK8	1 (9,14,41) 2 (23,28,30,32) 3 (35,38,57)	6793205.531	1524543.452	Norway spruce
MRK10	1 (2151,2148,3086) 2 (2012,3052,3063) 3 (3105,3116, 2076,2059)	6791649.932	1525687.044	Norway spruce

3.8 Temperature sum and stand meteorology in the area

The length of the growing season and corresponding effective temperature sum (GDD, threshold +5°C, measuring height 2 m) on FIP plots (code for Olkiluoto weather stations, WOM) for 2012 were as follows:

FIP4 (WOM2)	4.5.-24.10.2012	1291 GDD
FIP10 (WOM3)	2.5.-24.10.2012	1284 GDD
FIP11 (WOM4)	8.5.-24.10.2012	1194 GDD
FIP14 (WOM5)	4.5.-24.10.2012	1206 GDD

Measurement of the stand meteorology suffered some problems during 2012 (Table 11). PAR and solar radiation sensors were also replaced on 28.11.2012. Other changes in the instrumentation are presented in Table 11. The revised data were sent as compressed files to Posiva and stored in the POTTI database. Original primary data have also been stored in the POTTI database (processing stage = MEAS, status = not in use).

Table 11. *Problems in the stand meteorological measurements, their date of occurrence and the correction method applied on the FIP plots.*

Plot	Parameter	Channel no.	Date	Correction method/ comment
FIP4	Soil temperature -30 cm	1	1.1.-31.12.2012	Values too high, data should not be used; new sensor installed to channel 22 on 3.5.2012 at 13:00
	Wind speed, 24 m (mean, min, max)	29, 45, 46	1.1. 2012 – 29.3.2012 12:00	Probably data of low quality, new sensor installed 29.3.2012
	Air temp in the crown at the height of 9 m (min)	33	12.1.2012 01:00 – 12:00	No data for correction
	All	1-48	25.3.2012 13:00 29.3.2012 13:00	Previous and following true values used to fill data gaps
	Relative air humidity 9m (min)	27	27.4.2012 01:00 – 12:00	No data for correction
FIP10	All	1–48	25.3.2012 13:00	Previous and following true values used to fill data gaps
FIP11	All	All	25.3.2012 13:00	Previous and following true values used to fill data gaps
	Soil temperature -40 cm	2 (logger A)	7.8.2012 01:00 – 12:00	Previous and following true values used to fill data gaps
	Soil temperature -60 cm	4 (logger A)	5.9.2012 14:00 – 00:00	Previous and following true values used to fill data gaps
FIP14	All	All (logger A) All (logger B) All (logger C)	25.3.2012 14:00 25.3.2012 14:00 25.3.2012 14:00	Previous and following true values used to fill data gaps

Table 12. *Weather conditions in the study area during 2003 – 2012. The information on the effective temperature sum and the precipitation sum for the growth period (normally April –October) was taken from Olkiluoto weather station 1 (WOM1, Haapanen 2013).*

Year	Temperature sum, GDD	Precipitation, mm
2003	1374	220
2004	1439	312
2005	1465	406
2006	1345	239
2007	1495	429
2008	1365	456
2011	1693	475
2012	1378	485

3.9 POTTI database and Kronodoc

Data from measurements and analyses have been stored in the POTTI database (Posiva’s research result database). Definitions for data in POTTI are presented in Appendix 5, and a list of data in the POTTI database in Appendix 6.

POTTI is a database built to store the official results from Posiva's research activities. The database is based on Oracle and it has a browser interface for both Posiva's internal use and users outside Posiva. The data in the database go through a review process.

In 2011 Posiva and Teollisuuden Voima Oyj (the company which owns and operates two nuclear power plant units, Olkiluoto 1 and Olkiluoto 2 at Olkiluoto) set up a GIS (Geographical Information System) database to use and share geographical information between these two companies on the Olkiluoto Island. The database is built on ESRI ArcGIS Server software and gives the companies better possibilities to plan land use on the island and also for Posiva to store spatial data.

In addition, instructions and manuals of sampling and forest monitoring, preliminary results and reports under preparation have been stored in the Kronodoc system. Kronodoc (BlueCielo ECM Solutions) is a secured documentation system used by Posiva to archive official documents and also to provide an environment for workgroups to share their materials and work with them. Posiva's Kronodoc is divided into different workspaces of which Posidoc (POS prefix) mainly stores administrative or otherwise official internal documents, and Projects (PRJ prefix) is a working space also open for users outside Posiva. Material related to this report available in Kronodoc is shown in Table 13.

Table 13. *Material related to forest monitoring on Olkiluoto island stored in Kronodoc.*

Description	Kronodoc no.
Results of forest monitoring on Olkiluoto Island in 2012	PRJ-006334
Results of forest monitoring on Olkiluoto Island in 2011	PRJ-005226
Results of forest monitoring on Olkiluoto Island in 2010	PRJ-003997
Results of forest monitoring on Olkiluoto Island in 2009	PRJ-003033
Stand meteorology (FIP plots, WOM2-WOM5)	PRJ-006090
Sampling of soil water on the FIP plots in 2011	PRJ-004267
Sampling of deposition on MRK and FIP plots in 2010	PRJ-003261
Sampling of deposition on MRK and FIP plots in 2011	PRJ-003708
Sampling of deposition on MRK and FIP plots (2012)	PRJ-005054
Results of deposition monitoring at MRK and FIP plots	PRJ-004074/POS-010859
Lindroos, A.-J., Derome, J. & Aro, L. 2008. Annual precipitation, interception by the tree canopies, and the mean pH and amounts of cations, anions and other elements in bulk deposition and stand throughfall on Olkiluoto during 2007, and a comparison with the results for 2004-2006. 13 p.	POS-003852
Sampling of litterfall in 2010	PRJ-003296
Sampling of litterfall in 2011	PRJ-004076
Sampling of litterfall in 2012	PRJ-005222
Results of litter nutrient analyses in FIP plots	PRJ-006085
Results of foliage washing analyses in MRK plots (2004-2009)	PRJ-006084
Tamminen, P. & Aro, L. 2008. Forest soil properties of the FIP plots on Olkiluoto in 2007. 11 p.	POS-005571
Results of soil solution chemistry from lysimeters elsewhere than at the FIP plots	PRJ-006173
Paljakkaan toimitetut Metlan arkistonäytteet (Archive samples stored in the Environmental Specimen Bank of the Finnish Forest Research Institute, Paljakka)	PRJ-005707
Olkiluodon hakkuut (Thinnings on Olkiluoto Island)	PRJ-002838
Ympäristötutkimuksen havaintopaikkakoodit ja numerointi	POS-000523
Seurantatutkimukset metsän intensiivihavaintoaloilla (toiminta kenttätutkimusten yhteydessä) (Monitoring studies on Forest intensive plots, field instructions)	POS-000659
Tietojen tarkastus ja hyväksyntä POTTI-järjestelmässä	POS-002807
Puuston runkohaihdunnan laskeminen (Estimating tree stand transpiration)	POS-003795
Hökkä, H. 2008. Tree stand transpiration in forest intensive monitoring plots (FIP4 and FIP10) on Olkiluoto Island – estimates of annual transpiration June 2007 – June 2008. 5 p.	POS-005147
Biomassakoepuiden otto ja esikäsittely (Sampling and pre-treatment of biomass sample trees)	POS-007889
Chemical analysis of sample trees	PRJ-004499
Aro, L., Ylinen, A. & Rautio, P. 2007. The effect of dust emissions on the needle element concentrations of Scots pine and Norway spruce on the wet deposition monitoring plots in Olkiluoto during 2005 and 2006. 22 p.	POS-003528
Pölypäästöjen seuranta MRK-verkoston neulasanalyysillä (Rautio, P., Aro, L. & Ylinen, A. 2008. The effect of dust emissions on the needle element concentrations of Scots pine and Norway spruce on the wet deposition monitoring plots in Olkiluoto during 2003-2007. 30 p.)	POS-005536
MRK-alojen maaperänäytteet 2011 (Soil sampling on MRK plots in 2011)	PRJ-004303
MRK-alojen neulasten ja maaperän siirtokertoimet (Transfer factors from soil to needles on the MRK plots)	PRJ-004957

4 RESULTS AND DISCUSSION

4.1 Bulk deposition and stand throughfall

The amount of precipitation in 2012 in open areas (bulk deposition, BD) and stand throughfall (TF) was higher than in all other years during the whole monitoring period (Figure 8). There were no clear increasing or decreasing trends in the pH of BD and TF during the period 2004-2012. The pH values were at a level slightly above the values measured at the ICP Forests monitoring plots (reference plots) located at Juupajoki and Tammela in central and southern Finland.

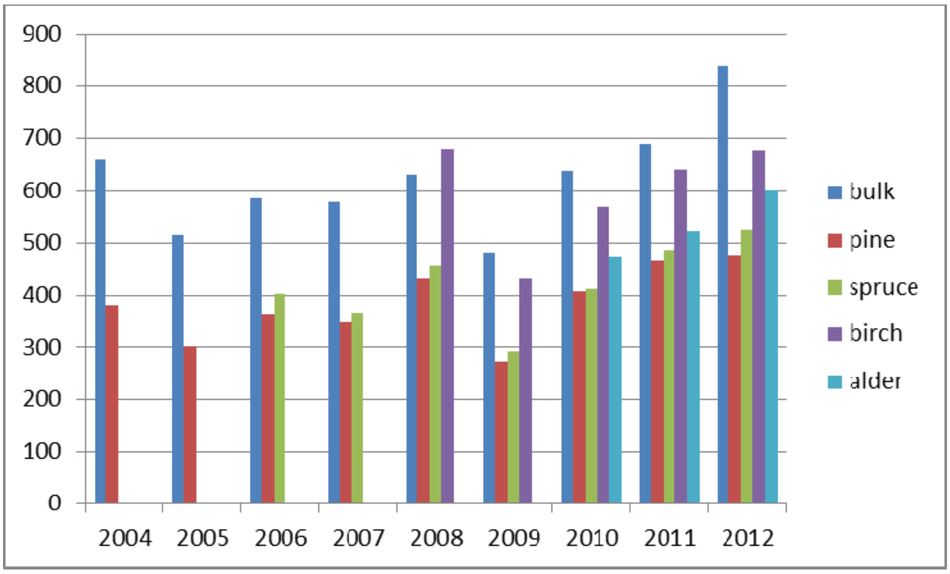


Figure 8. *Annual precipitation (mm) in open areas (bulk deposition) and stand throughfall in Scots pine (FIP4), Norway spruce (FIP10), birch dominated (FIP11) and black alder (FIP14) stands during 2004-2012.*

There was variation in the deposition of total nitrogen in BD and TF during 2004-2012. The values decreased in BD during 2012 compared to 2011 when it was the highest for the whole monitoring period. There was also variation in NO_3-N (Figure 9) deposition in BD and TF over the years, but the values were in general comparable to those measured at the Juupajoki and Tammela reference plots. However, the highest NO_3-N deposition so far in BD in Olkiluoto was measured in 2012. The NH_4-N (Figure 10) deposition increased clearly in 2011 compared to earlier years on both BD plots and one TF plot, MRK14. These values were also higher than those on the references plots in Juupajoki and Tammela. The highest annual N_{tot} and NH_4-N deposition in TF during 2004-2012 was measured on the new black alder plot in 2011. The increase in NH_4-N deposition was considered to probably be due to the construction activities in the area. However, in 2012 the NH_4-N deposition decreased on these plots to a level close to the general level during the whole monitoring period as well as close to the level on the reference plots. The deposition of nitrogen compounds in TF was generally lower than that in BD due to nitrogen uptake by the tree canopies (absorption into the needles and utilization by the mosses, lichens and microflora on the needle surfaces). Nitrogen retention in the tree canopies is a well-documented phenomenon in coniferous stands in Finland.

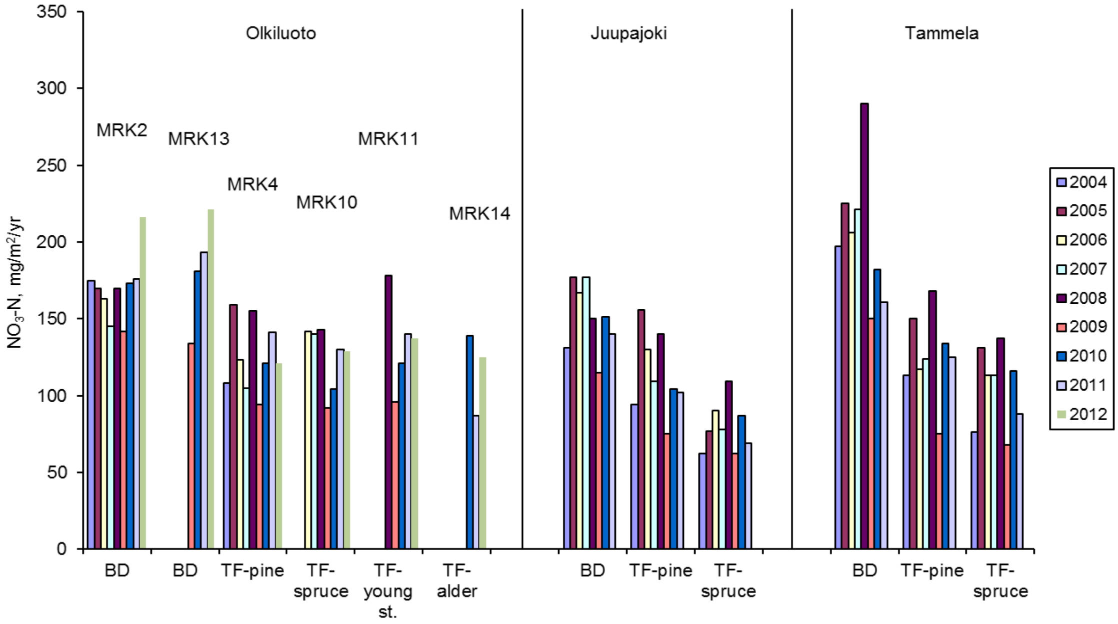


Figure 9. *The* NO_3*-N deposition in bulk deposition (BD, open area) and stand throughfall (TF, inside the stand) on Olkiluoto in 2004-2012. The sample plots and tree species are indicated in the Figure (young st. = young birch dominated stand). Reference values for ICP Forests plots at Juupajoki and Tammela are given for comparison.*

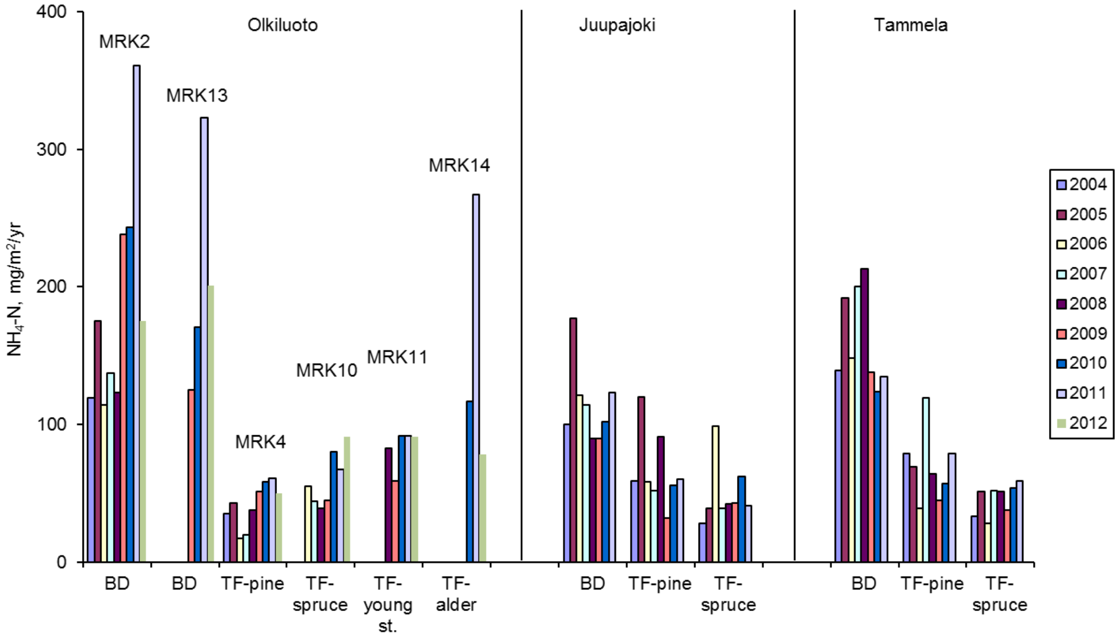


Figure 10. *The* NH_4*-N deposition in bulk deposition (BD, open area) and stand throughfall (TF, inside the stand) on Olkiluoto in 2004-2012. The sample plots and tree species are indicated in the Figure (young st. = young birch dominated stand). Reference values for ICP Forests plots at Juupajoki and Tammela are given for comparison.*

The sulphur (SO_4-S) deposition in BD on plot MRK2 was higher during 2009-2012 compared to that during 2004-2008. On plot MRK13 (BD, open area) the sulphur deposition was comparable to that on plot MRK2. The S deposition in an open area on Olkiluoto was higher during 2009-2012 than on the reference plots at Tammela and Juupajoki (Figure 11). The TF deposition at the Tammela spruce plot was clearly higher than in Olkiluoto or Juupajoki.

The deposition of base cations (Ca, Mg, K) in BD on plot MRK2 was somewhat higher or at a similar level compared to the situation on the reference plots at Tammela and Juupajoki. The Ca deposition was higher on plot MRK2 in 2009-2012 compared to 2004-2008. The relatively high deposition of Cl (with associated Na) at Olkiluoto is due to the proximity of the sea. This was especially the case on the new black alder plot MRK14 in 2011 and 2012. Storm events in the late autumn probably also affected these values somehow due to the fact that the sea is located close to the plots. The dissolved organic carbon (DOC) amounts in BD and TF were comparable to the values on the reference plots, indicating leaching of DOC from the tree canopies. The deposition of Al, Fe, Mn, Si, Cu, Zn and PO_4-P in BD and TF were relatively similar in 2012 compared to the values in earlier years.

The concentrations of all the measured BD and TF samples during 2012 were below or close to the limit of quantification for Cd, Cr, Ni, Pb, Nb, Pd, Sn, Ta, Te, V and W. Measureable concentrations could be determined generally in BD and TF samples in 2012 for Ba and Sr.

In general, the clearest changes in the deposition levels in 2012 were associated with the NH_4-N deposition that decreased compared to the situation in 2011. The NO_3-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004-2012.

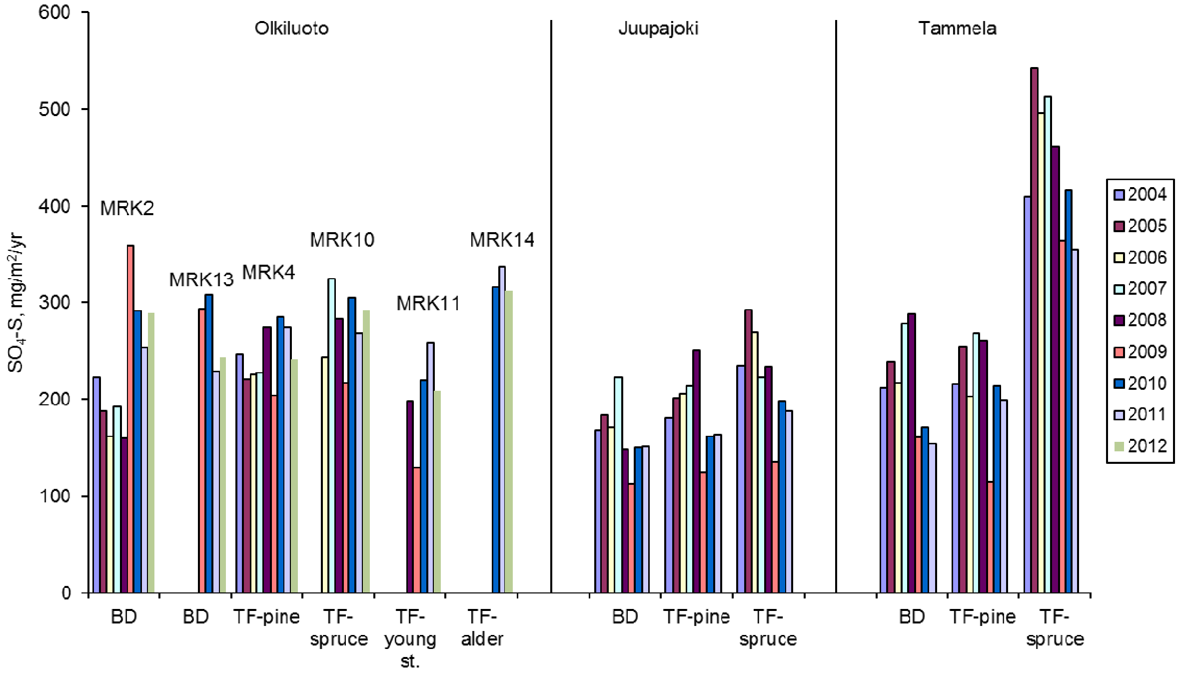


Figure 11. *The SO_4-S deposition in bulk deposition (BD, open area) and stand throughfall (TF, inside the stand) on Olkiluoto in 2004-2012. The sample plots and tree species are indicated in the Figure (young st. = young birch dominated stand). Reference values for ICP Forests plots at Juupajoki and Tammela are given for comparison.*

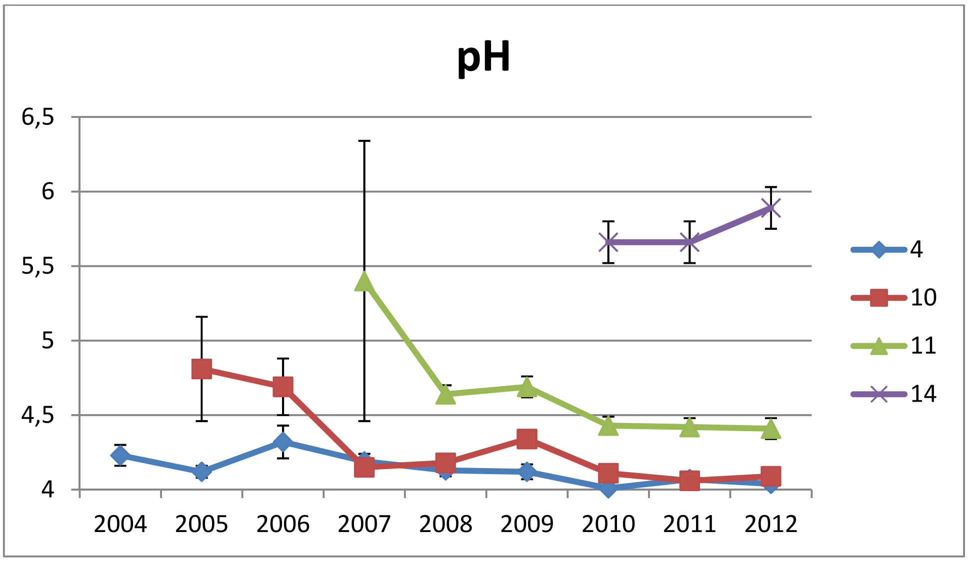
4.2 Soil solution

The proportion of percolation water passing down to a depth of 5 cm on plot FIP4 varied between 16 to 23% of the input to the forest floor (stand throughfall) during the snow-free period of 2004-2012. In 2012, the value was 20%. Corresponding values on the plots FIP10 (during 2005-2012) and FIP11 (during 2007-2012) were 1-28% (17% in 2012) and 1-17% (14% in 2012), respectively. The lowest values for the proportion of percolation water on FIP10 during 2005-2006 were explained by problems with the lysimeters which, however, are now functioning correctly. The proportion of percolation water passing down to a depth of 5 cm on plot FIP14 (black alder) was 22% of the input to the forest floor (stand throughfall) during 2010, 23% during 2011 and 29% during 2012, i.e. comparable to the other plots.

Overall, the pH of the soil solution clearly increased with increasing depth on FIP4. The pH of the soil solution at depths of 5-30 cm remained relatively constant throughout the 9-year monitoring period, without any strong increasing or decreasing trends. However, the pH at a depth of 5 cm has decreased slightly over the years (Figure 12, depth 5 cm). The pH values at a depth of 5 cm were fully comparable to a site of similar fertility at Tammela (years 2004-2010, Nieminen et al. 2013). There has been a slightly decreasing trend in the DOC concentration at a depth of 5 cm during the monitoring period 2004-2012 (Figure 12). Overall, the DOC concentration of the soil solution clearly decreased with increasing depth (Figure 13). The reason for this decrease is the fact that DOC is precipitated into the enrichment layer (B-horizon) of the forest soils under the conditions leading to podzolisation. The DOC concentration decreases also due to biological degradation processes. The decrease in DOC values with increasing depth is a very typical phenomenon in Finnish forest soils. The DOC concentrations at a 5 cm depth during all the nine years were not excessively high for forest soils rich in organic matter under a coniferous tree stand. At depths of 10, 20 and 30 cm the DOC concentrations decreased relatively strongly in 2005. The installation of the suction cup lysimeters in 2003 undoubtedly caused a short-term flush of DOC.

The pH of the soil solution at depths of 5, 20 and 30 cm on FIP10 during 2012 was comparable to a general level measured on this plot during the earlier years (2005-2011). However, the pH has decreased slightly over the years at a depth of 5 cm as was also the case for the plot FIP4 (Figure 12, depth 5 cm). The pH values at a depth of 5 cm were fully comparable to a site of similar fertility at Tammela (years 2005-2010, Nieminen et al. 2013). The DOC concentrations at all three depths were relatively high, but not excessively high for forest soils rich in organic matter under a coniferous tree stand. There has been a slightly decreasing general trend in the DOC concentration at a depth of 5 cm during the monitoring period 2004-2012 (Figure 12).

The pH of the soil solution is relatively high at all sampling depths on FIP11 (Figure 12). The DOC concentrations were relatively high at depths of 10-30 cm, but at a depth of 5 cm, the values have been lower compared to the situation on the plots FIP4 and 10 (Figure 12).



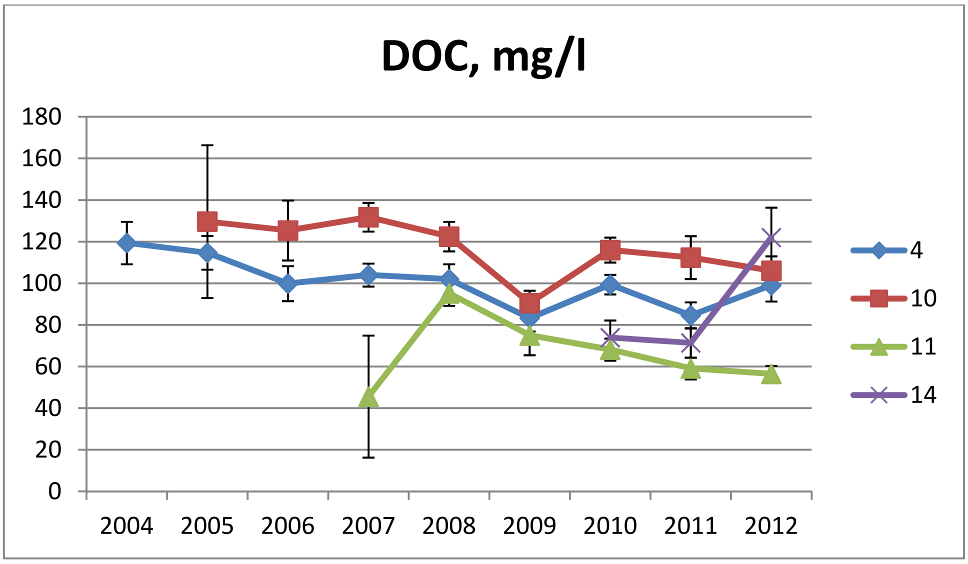


Figure 12. *Annual mean pH and dissolved organic carbon (DOC) concentration at a depth of 5 cm on plots FIP4 (pine stand), 10 (spruce stand), 11 (birch dominated stand) and 14 (alder stand) at Olkiluoto during the snow-free period in 2004 – 2012. The bars denote the standard error of the mean.*

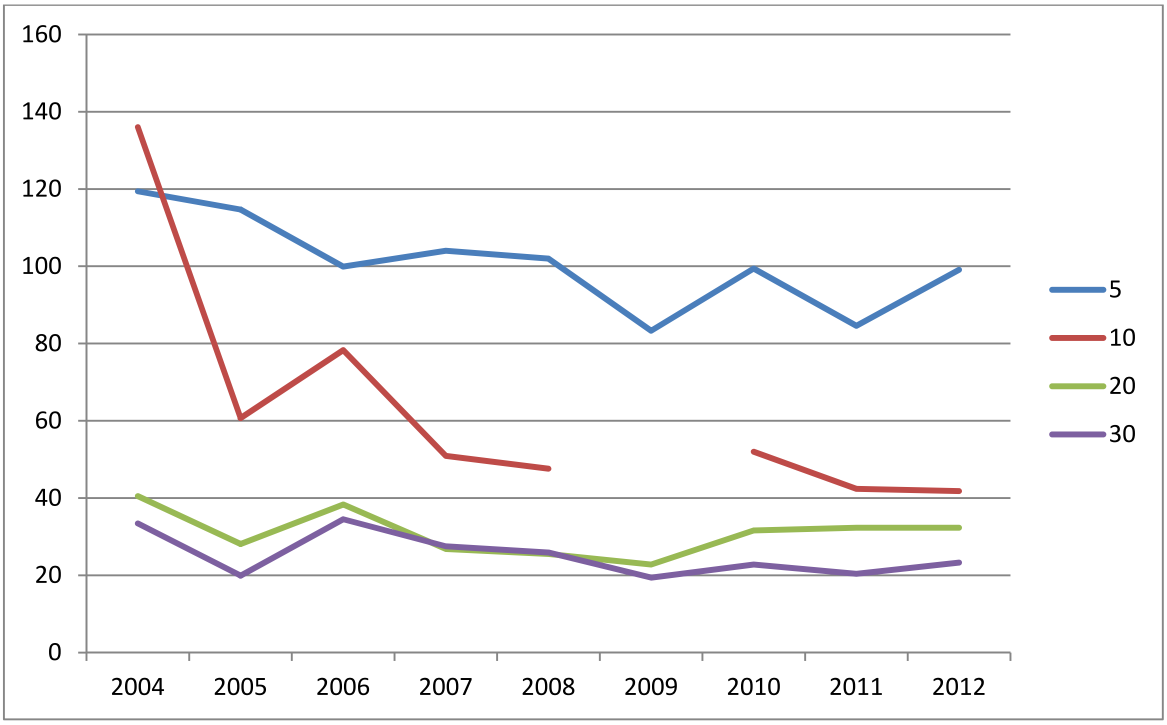


Figure 13. *Dissolved organic carbon (DOC, mg/l) concentration in the soil solution at depths of 5, 10, 20 and 30 cm on the plot FIP4 (Scots pine stand).*

Total nitrogen which, in addition to ammonium and nitrate, also includes organic dissolved nitrogen, obviously closely followed the pattern for the DOC concentrations on plots FIP4, 10 and 11. At all depths, ammonium and nitrate accounted for only about 10% of the total amount of nitrogen dissolved in the soil solution, i.e. most of the nitrogen in the soil solution is so-called dissolved organic nitrogen (DON). The NH_4-N, and especially the NO_3-N concentrations (Figure 14a), were extremely low at all depths in the mineral soil of the FIP plots throughout the monitoring period. The low concentrations are primarily due to the fact that nitrogen is the main factor limiting tree growth in coniferous stands in Finland; the available nitrogen (NH_4 and NO_3) mineralized from the organic layer is rapidly taken up by the roots of the trees and ground vegetation. The low NO_3-N concentrations in the soil solution mean low nitrate leaching from the forest soils indicating that the soils are far from the so-called nitrogen saturation point. High nitrate leaching could weaken the ground water quality. It has been proposed that nitrate leaching would be elevated if the NO_3-N concentration exceeded 1 mg/l in the soil solution. The nitrate concentrations were far below this limit in Olkiluoto also in 2012. The nitrogen situation was totally different on the new black alder plot, FIP14, where nitrate concentrations were high in the soil solution in 2010 and even in 2011-2012, although the concentration has clearly decreased (Figure 14a).

Sulphate concentrations at a 5 cm depth on FIP4 were at the same level in all 9 years as those at the reference site (Nieminen et al. 2013). Sulphate concentrations were also approximately the same or slightly higher on FIP10 than those for the corresponding reference site at a 5 cm depth (Nieminen et al. 2013). There was a clear overall increase in sulphate concentrations with increasing depth on FIP4 and 10. Similar trends in sulphate concentration have been reported at all the ICP Forests Level II plots in

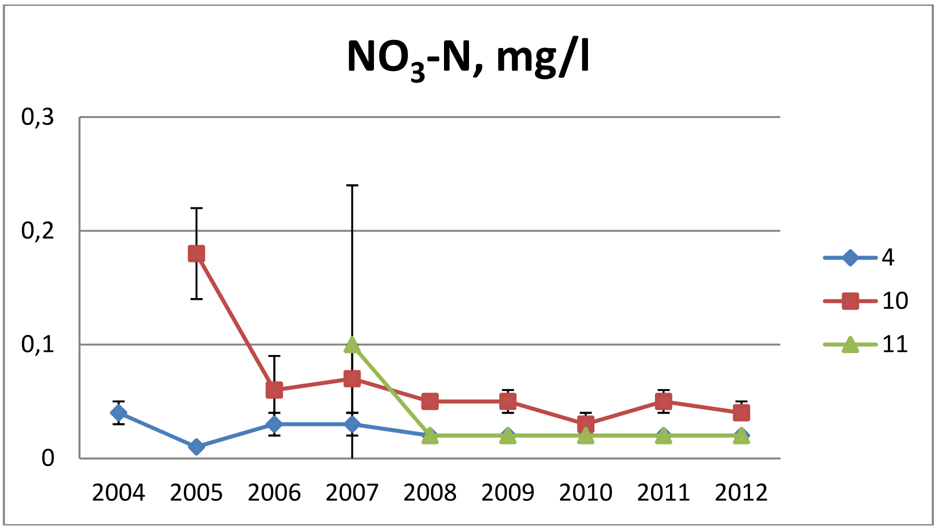
Finland (Derome et al. 2007). No clear trends have been found in the SO_4-S concentrations during 2004-2012 on the FIP plots 4, 10 and 11 at a depth of 5 cm (Figure 14b).

Chloride concentrations were extremely high at all depths on all FIP plots throughout the monitoring period; it is clear that there is a considerable input of NaCl in deposition derived from the sea. Phosphate concentrations were in general very low. Phosphate concentrations are very low in the soil solution at most forested sites in Finland (Derome et al. 2007).

The concentrations of the three important plant nutrients (Ca, Mg, K) on FIP4, 10 and 11 were comparable in 2012 to the values measured in earlier years at all depths. The soil on the plots at Olkiluoto is very young, and the weathering processes in the mineral soil will be relatively strong and release abundant amounts of these three nutrients. The high concentrations of Na at all depths are due to both the input from the sea and the weathering of minerals.

On all of the plots and at all depths, the concentrations of total Al in 2012 were relatively similar to those in earlier years. The concentrations of Al^{3+} were lower than the widely accepted toxicity level of 2 mg/l on all the plots. The Fe, Mn and Si concentrations at all depths were comparable in 2012 to the values measured in earlier years.

The concentrations of heavy metals (Cd, Cr, Ni, Pb) at all depths at Olkiluoto during 2004-2012 continued in many cases to be close to or below the limit of quantification (LOQ for Cd = 0.001 mg/l, for Cr = 0.001 mg/l, for Ni = 0.010 mg/l, for Pb = 0.015 mg/l). In 2012, the concentrations of Ba, Nb, Pd, Sn, Sr, Ta, Te, V and W were also determined from the soil solution samples. The concentrations were generally below the respective limits of quantification for all parameters except Ba, Sr and V.



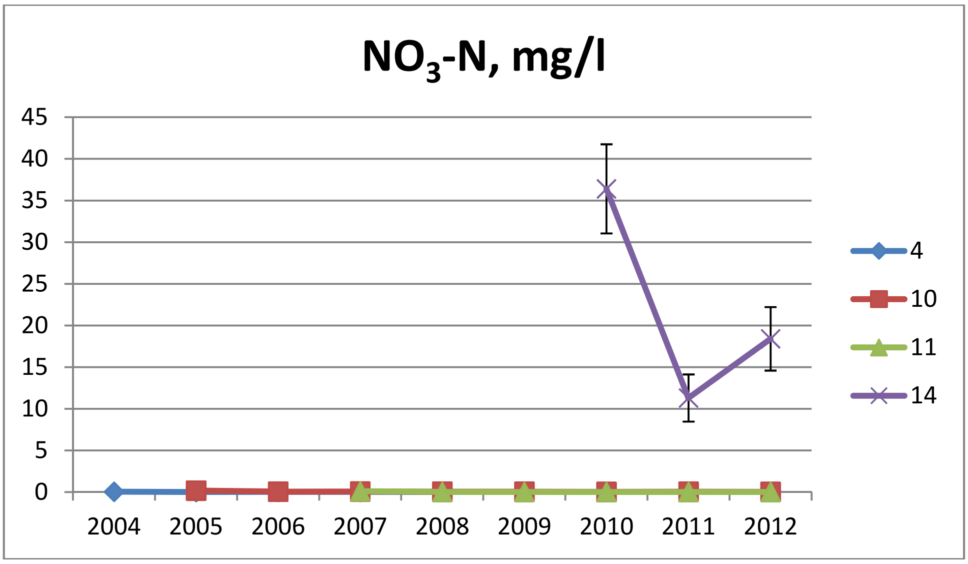


Figure 14a. *Annual mean nitrate (NO_3-N) concentrations at a depth of 5 cm on plots FIP4 (pine stand, NO_3-N below the respective limit of quantification 2008-2012), 10 (spruce stand), 11 (birch dominated stand, NO_3-N below the respective limit of quantification 2008-2012) and 14 (alder stand) at Olkiluoto during the snowfree period in 2004-2012. The bars denote the standard error of the mean. NO_3-N concentrations are presented in two different scales due to the high values of NO_3-N at FIP14.*

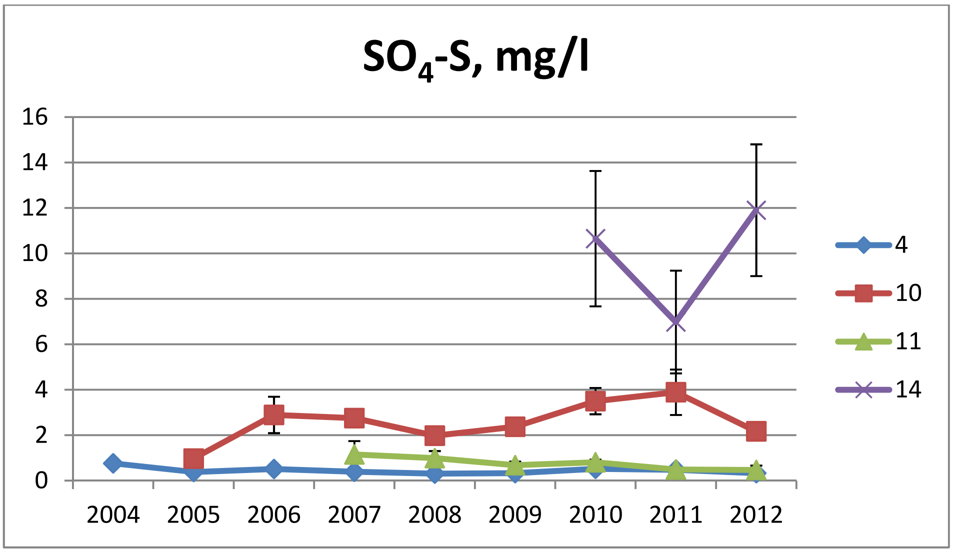


Figure 14b. *Annual mean sulphate (SO_4-S) concentrations at a depth of 5 cm on plots FIP4 (pine stand), 10 (spruce stand), 11 (birch dominated stand) and 14 (alder stand) at Olkiluoto during the snowfree period in 2004-2012. The bars denote the standard error of the mean.*

4.3 Tree stand transpiration

The monthly stand level transpiration of the Scots pine (FIP4) dominated stand is presented in Figure 15. In 2012 the monthly level of transpiration on the plot FIP4 was lower than during previous years (2008-2011, Figure 16). High values (4.6 – 12.7 mm/month) in winter months (January – March and November – December 2012) are due to errors in data and thus not reported in the POTTI database.

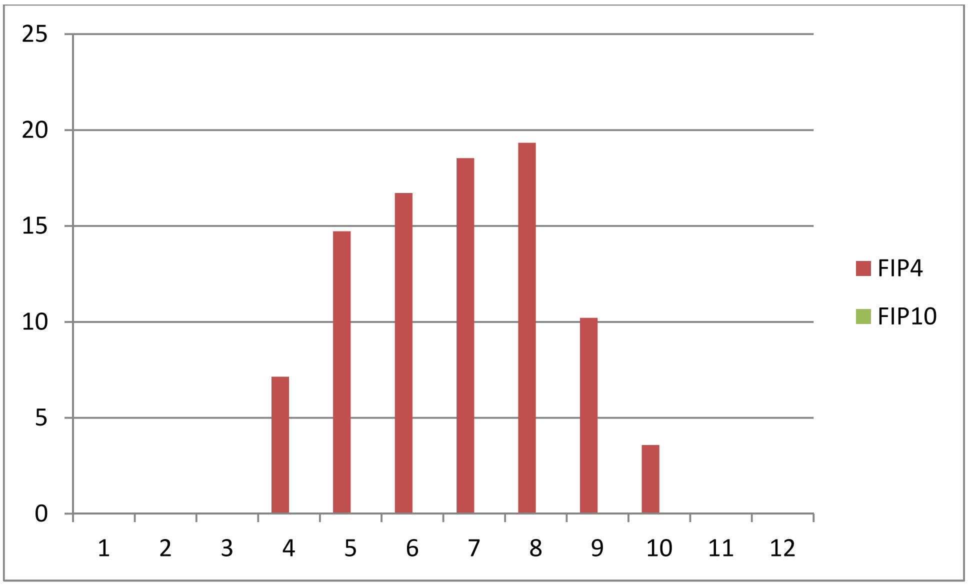


Figure 15. *Monthly stand level transpiration (mm) on the FIP4 (Scots pine stand) sample plot in 2012. Data for the Norway spruce stand (FIP10) is missing due to measurement problems during 2012.*

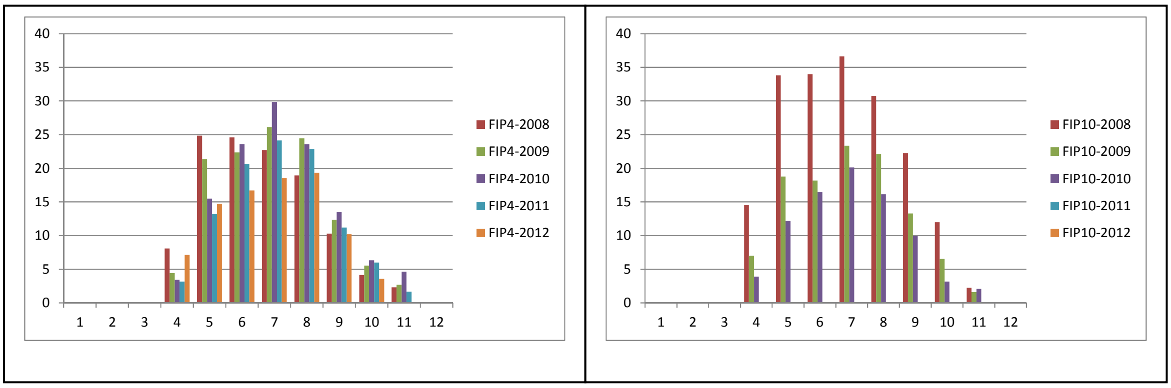


Figure 16. *Monthly stand level transpiration (mm) on the FIP4 (left) and FIP10 (right) sample plots during 2008-2012. Results are only reliable for the period of April-October/November (FIP4 2008-2012 and FIP10 2008-2010).*

4.4 Litterfall production and element return to the forest floor

Annual total litterfall production in coniferous plots (FIP4 and 10) was in general more or less on the same level in 2011 (Figures 17a and 17b) as during the previous collection period (2010, Aro et al. 2012). On the birch dominated plot (FIP11) leaf litter was somewhat larger during the present collection period than in 2010 (Figure 17c). However, this difference between years is natural annual variation caused by e.g. weather factors. Annual total litterfall production without large branches during 2004-2011 is presented in Figure 18.

As a reference Ukonmaanaho et al. (2008) reported annual litterfall production (without large branches, i.e. fraction 7 here) of 226 g_{dw}/m^2 for Scots pine and 350 g_{dw}/m^2 for Norway spruce in 13 Finnish ICP Forests plots (mainly in southern Finland) during 1996-2003. The corresponding values for the FIP plots were 379.9 g_{dw}/m^2 (Scots pine stand), 317.4 (Norway spruce stand), 157.5 (birch-dominated stand) and 349 (alder stand) during 2011.

The most notable differences in element concentrations between the plots are those of Al and N concentrations (Tables 14 and 15). Al is commonly higher in living pine needles than in spruce needles and this can also be seen in the Al concentration (Table 14) in litterfall on the pine plot (FIP4) compared to the spruce plot (FIP10). High Al (Table 14) and Fe (Table 16) concentrations in fraction 5 (remaining litter) are most likely due to soil dust. The highest N concentrations were generally detected in fraction 4 (leaves) or 5 (remaining litter). The remaining litter can include e.g. seeds and flowers (i.e. living biological material) or insect faeces that are naturally high in N. Hence the remaining litter can in some cases have an equal or even higher N concentration than alder leaves (Table 15, FIP14) which are known to have a high N concentration even after senescence. On the birch dominated plot (FIP11) the highest N concentrations in leaves occurred during summer (i.e. non-senescent leaves) but also senescent leaves (i.e. those collected during autumn) contained more N than green pine needles (Table 15).

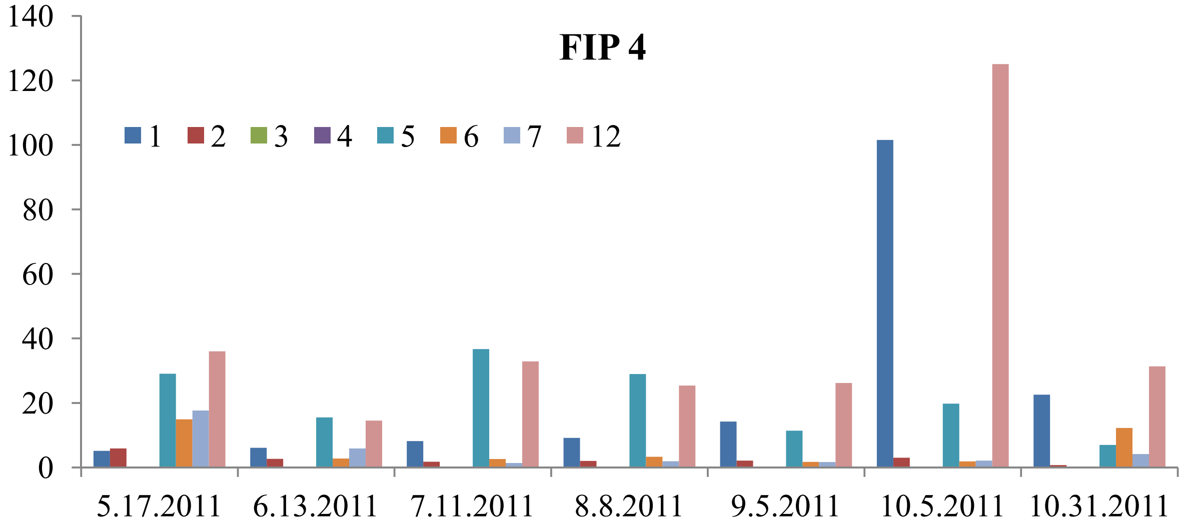


Figure 17a. *Mass (g_{dw}/m^2) of different fractions of litterfall on different collection dates during 2011 on the Scots pine dominated plot. Fraction legends refer to: 1= dead pine needles, 2= living (green) pine needles, 3= spruce needles, 4= leaves, 5= remaining litter, 6= small branches, 7= branches from branch traps and 12= remaining litter in branch traps.*

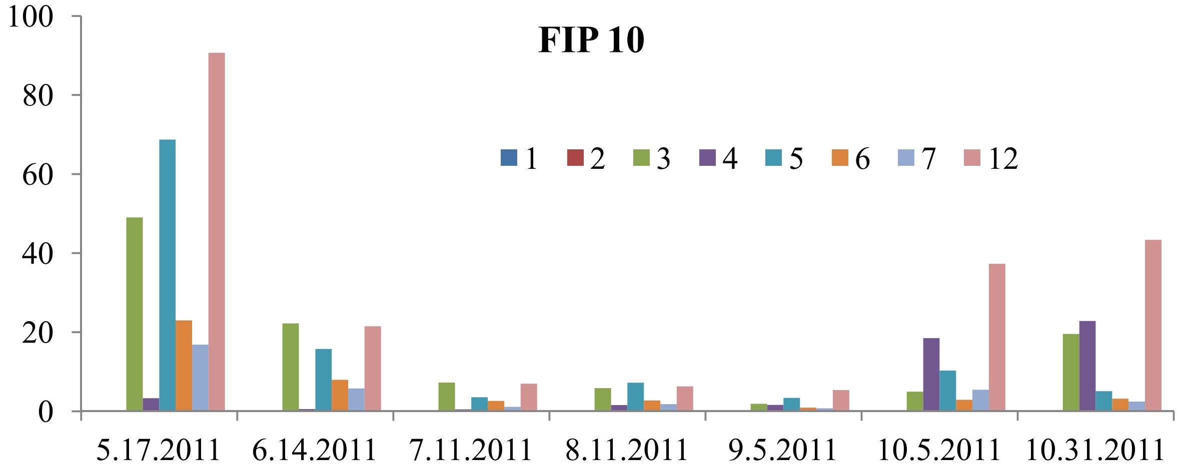


Figure 17b. *Mass (g_{dw}/m^2) of different fractions of litterfall on different collection dates during 2011 on the Norway spruce dominated plot. Fraction legends, see Figure 17a.*

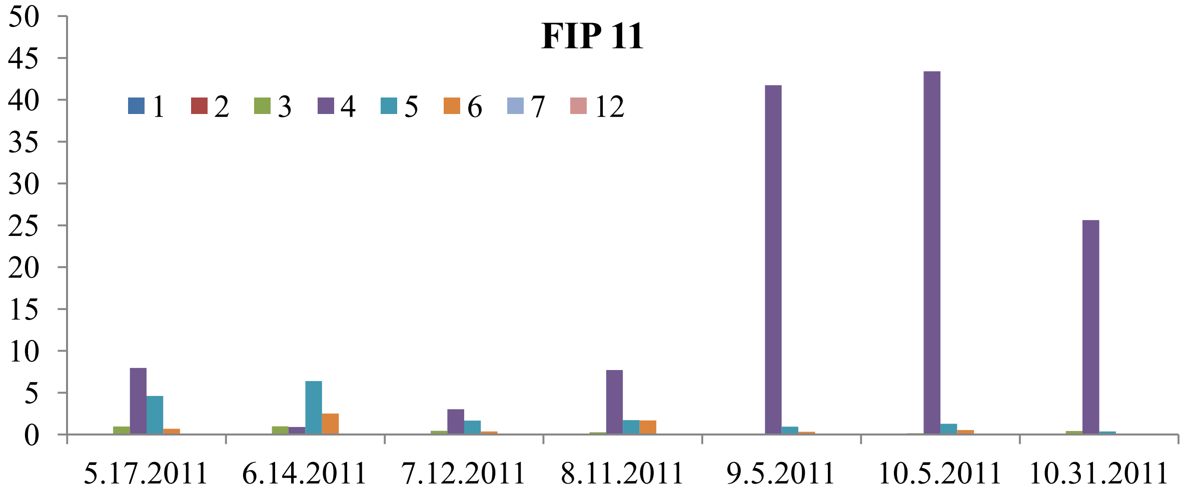


Figure 17c. *Mass (g_{dw}/m^2) of different fractions of litterfall on different collection dates during 2011 on the birch dominated plot. Fraction legends, see Figure 17a.*

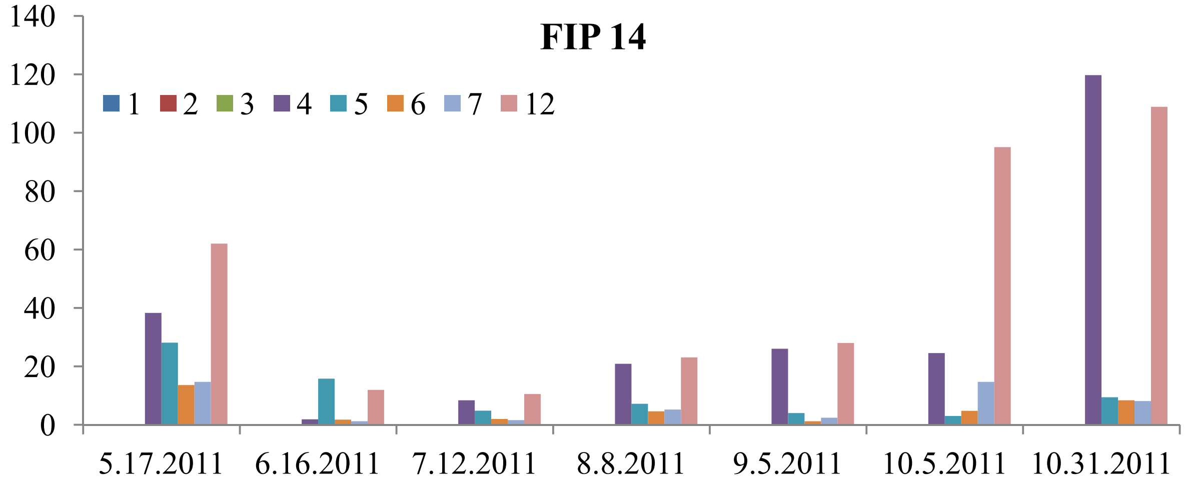


Figure 17d. *Mass (g_{dw}/m^2) of different fractions of litterfall on different collection dates during 2011 on the alder dominated plot. Fraction legends, see Figure 17a.*

Table 14. *Aluminium concentration (mg/kg$_{dw}$) in the seven fractions of litterfall on the FIP plots during 2011. The annual total is given if there has not been enough material for chemical analysis in individual collection periods.*

		Litter fraction[1]						
Plot	Date	1	2	3	4	5	6	7
FIP4	17.5.2011	675	488			1850	656	461
	13.6.2011	339	319			544	467	389
	11.7.2011	338	313			328	454	453
	8.8.2011	323	195			278	391	504
	5.9.2011	291	228			475	439	369
	5.10.2011	304	332			429	450	447
	31.10.2011	328	261			589	261	444
	Annual total			164				
FIP10	17.5.2011			101	582	424	273	323
	14.6.2011			66	129	322	150	181
	11.7.2011			55	179	1200	132	124
	11.8.2011			50	146	768	137	186
	5.9.2011			46	82	696	300	299
	5.10.2011			95	233	212	223	147
	31.10.2011			49	58	317	191	203
FIP11	17.5.2011				1330	1620		
	14.6.2011				125	242		
	12.7.2011				80	530		
	11.8.2011				99	398		
	5.9.2011				49	229		
	5.10.2011				95	317		
	31.10.2011				49	198		
	Annual total			136			47	
FIP14	17.5.2011				271	157	51	48
	16.6.2011				266	240	51	40
	12.7.2011				125	268	35	28
	8.8.2011				130	269	39	38
	5.9.2011				73	189	22	38
	5.10.2011				131	185	40	23
	31.10.2011				45	100	56	56
	Annual total			56				

1) Litter fractions: 1= pine brown needles, 2= pine green needles, 3= spruce needles, 4= leaves, 5= remaining litter, 6= small branches, 7= branches from "branch traps"

Table 15. *Nitrogen concentration (%) in the seven fractions of litterfall on the FIP plots during 2011. The annual total is given if there hasn't been enough material for chemical analysis in individual collection periods.*

Plot	Date	Litter fraction[1] 1	2	3	4	5	6	7
FIP4	17.5.2011	0.95	1.57			0.89	0.79	0.64
	13.6.2011	1.36	1.41			0.94	0.90	0.65
	11.7.2011	1.05	1.44			0.73	0.78	0.58
	8.8.2011	0.83	1.64			0.60	1.02	0.58
	5.9.2011	0.71	1.47			0.68	0.92	0.55
	5.10.2011	0.69	1.09			0.68	0.91	0.69
	31.10.2011	0.71	1.39			0.93	0.57	0.82
	Annual total			1.05				
FIP10	17.5.2011			0.96	1.32	0.82	1.00	0.98
	14.6.2011			1.05	3.78	1.05	0.98	0.89
	11.7.2011			1.11	2.45	1.82	0.88	0.72
	11.8.2011			0.94	1.64	1.39	0.87	0.92
	5.9.2011			0.94	1.08	1.54	0.96	0.83
	5.10.2011			0.97	1.39	0.94	1.02	0.83
	31.10.2011			0.64	0.88	1.08	0.85	0.93
FIP11	17.5.2011				1.52	0.79		
	14.6.2011				2.55	1.59		
	12.7.2011				1.79	2.63		
	11.8.2011				1.42	2.35		
	5.9.2011				1.38	2.08		
	5.10.2011				1.53	1.94		
	31.10.2011				1.16	2.11		
	Annual total			1.17			0.75	
FIP14	17.5.2011				2.98	2.46	1.57	1.40
	16.6.2011				3.08	2.53	2.07	2.13
	12.7.2011				2.94	3.06	1.87	1.53
	8.8.2011				2.72	2.84	1.67	1.48
	5.9.2011				2.53	2.57	1.75	1.54
	5.10.2011				3.10	3.10	1.72	1.47
	31.10.2011				2.33	2.51	1.47	1.31
	Annual total			1.07				

1) Litter fractions: 1= pine brown needles, 2= pine green needles, 3= spruce needles, 4= leaves, 5= remaining litter, 6= small branches, 7= branches from "branch traps"

Table 16. *Iron concentration (mg/kg$_{dw}$) in the seven fractions of litterfall on the FIP plots during 2011. The annual total is given if there hasn't been enough material for chemical analysis in individual collection periods.*

		Litter fraction[1]						
Plot	Date	1	2	3	4	5	6	7
FIP4	17.5.2011	736	398			2470	775	445
	13.6.2011	143	124			625	464	347
	11.7.2011	145	149			304	410	360
	8.8.2011	128	73			230	382	472
	5.9.2011	112	88			441	501	314
	5.10.2011	117	105			344	425	433
	31.10.2011	117	58			607	239	433
	Annual total			131				
FIP10	17.5.2011			141	999	720	427	496
	14.6.2011			85	251	467	225	274
	11.7.2011			69	348	1550	202	195
	11.8.2011			58	283	1200	197	297
	5.9.2011			57	164	924	490	485
	5.10.2011			96	257	242	296	221
	31.10.2011			53	139	480	293	304
FIP11	17.5.2011				2210	2850		
	14.6.2011				248	404		
	12.7.2011				170	881		
	11.8.2011				203	646		
	5.9.2011				119	367		
	5.10.2011				157	504		
	31.10.2011				117	247		
	Annual total			216			78	
FIP14	17.5.2011				545	291	109	95
	16.6.2011				537	417	110	88
	12.7.2011				266	465	92	72
	8.8.2011				287	491	99	82
	5.9.2011				179	338	73	91
	5.10.2011				216	247	86	65
	31.10.2011				113	190	100	103
	Annual total			94				

[1] Litter fractions: 1= pine brown needles, 2= pine green needles, 3= spruce needles, 4= leaves, 5= remaining litter, 6= small branches, 7= branches from "branch traps"

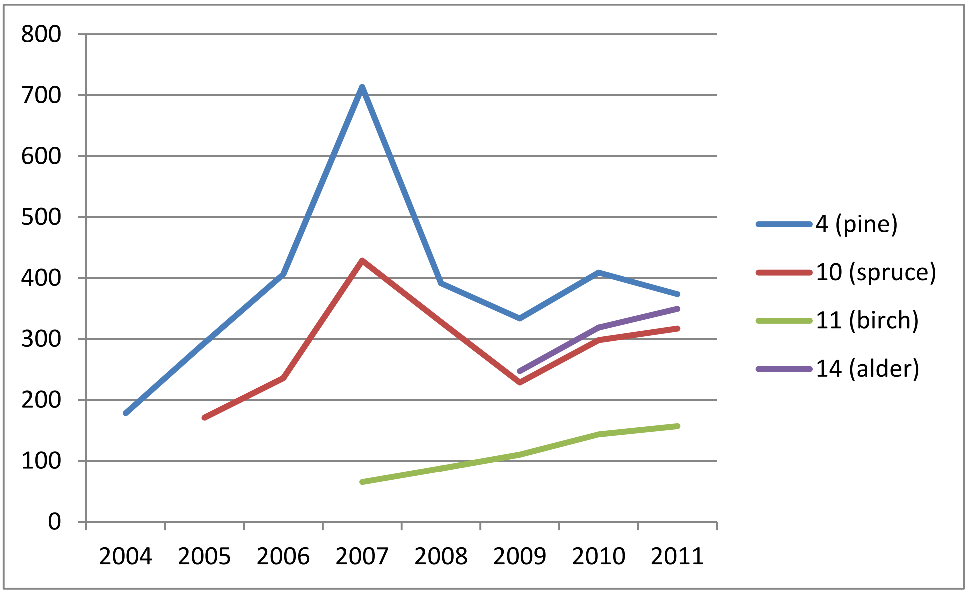


Figure 18. *Annual total litterfall production* (g_{dw}/m^2) *without large branches on the FIP plots during 2004-2011. All branches excluded in 2004-2005.*

4.5 Defoliation

The degree of defoliation of Scots pine and Norway spruce was determined on the FIP plots during 3.–6.9.2012. The average defoliation level of the pines was 3.9% (±0.9, sd) and of the spruces 26.3% (±1.9). The pines were classified as non-defoliated indicating good crown condition of the trees. However, the spruces were classified as moderately defoliated (defoliation degree >25%, Table 17). Previously (2006-2009) the spruces were classified as slightly defoliated. The defoliation degree level of Scots pine was correlated strongly with the results for the ICP Level II plots in Tammela (Nevalainen & Lindgren 2013). The increase in defoliation of the pine in 2007 was due to severe infection by Peridermium stem rust on one pine on FIP4-OA2 (tree nr. 344; the degree of defoliation increased from 15% to 85% during 2006 – 2007). In 2008, tree 344 was already dead and it was replaced with tree nr. 334.

Table 17. *Number of assessed trees (Nr.) and defoliation degree (DEF, %) of the trees on the FIP plots by sub-plot during 2006-2012.*

Plot	Sub-plot	Species	Nr.	DEF 2006	2007	2008	2009	2010	2012
4	1	Scots pine	20	3.2	3.4	5.2	4.5	3.5	3.8
	2	Scots pine	20	3.2	7.7	4.9	5.7	4.9	5.3
	3	Scots pine	20	4.2	2.9	3.7	3.3	4.0	3.1
	4	Scots pine	20	4.5	3.3	3.8	4.9	5.2	3.5
	Mean			3.7	4.3	4.4	4.6	4.4	3.9
	SD			0.7	2.2	0.8	1.0	0.8	0.9
10	1	Norway spruce	20	15.8	19.8	17.5	21.0	23.8	23.8
	2	Norway spruce	20	18.8	18.8	19.3	26.0	27.5	28.0
	3	Norway spruce	20	15.5	20.8	18.5	23.3	27.3	26.0
	4	Norway spruce	20	21.3	17.8	18.3	26.3	28.8	27.3
	Mean			17.8	19.3	18.4	24.1	26.8	26.3
	SD			2.7	1.3	0.7	2.5	2.1	1.9

4.6 Chemical composition of particulate matter on needle surfaces

4.6.1 General trends

There were no substantial differences in the concentrations of most of the analysed elements between the different washing procedures, which clearly indicates that the elements had not accumulated on the needle surface in particulate material. The aluminium and iron concentrations, which are present in relatively high concentrations in many soil minerals, were higher in the unwashed needles than in the needles washed with deionised water or chloroform. The results for aluminium and iron are therefore discussed in more detail in this report. The results for sulphur and nitrogen are also presented because they are elements commonly investigated in bioindicator surveys.

4.6.2 Spruce plots

The aluminium (Al) concentrations were highest on the spruce plots (MRK5, MRK6) located closest to the landfill site and also downwind of the site (Figure 19). The Al concentrations increased on these plots from 2003 to 2005 but remained rather stable after that (Figure 19). In both C and C+1 needles the Al concentrations were still higher in 2009 in MRK5 and MRK6 than on the farthest spruce plot FIP10 (Figure 19). Crushing rock material at the landfill site explains this trend rather well. However, the Al concentrations on the MRK8 plot decreased during 2004-2006. This may be due to the fact that the blasting and excavation of the OL3 base was finished before the needles were sampled in January 2006. A slight increase was observed again in 2007 but the concentrations remained below the top values of 2004-2005. The Al concentrations on the FIP10 plot remained relatively stable during 2004-2009.

The different washing procedures had a significant effect on the Al concentrations in the needles on MRK5, 6 and 8 in 2005-2009 (Figure 19). The Al concentrations were significantly lower in the C or C+1 needles (or both) washed with chloroform than in unwashed needles in 2005-2009 (Figure 19). This indicated that a considerable proportion of the Al in the needles was in actual fact present on the needle surfaces in the form of particulate matter. At the same time, however, the Al concentrations and the variation in the Al concentrations between the plots remained at approximately the same level in the inner parts of the needles (i.e. washed with chloroform) during 2003-2009. Washing with water affected the needle Al concentrations especially on MRK5 in 2005, which indicated high stone dust levels during that year. In general, however, washing with water had no statistically significant effect on the needle Al concentration, i.e. the 95% confidence intervals of the unwashed needles and needles washed with water generally overlap (Figure 19).

The iron (Fe) concentrations in unwashed C and C+1 needles increased on MRK5 and MRK6 from year 2004 to 2005 but decreased in 2006, to rise again in 2007-2009 (Figure 20). This pattern also took place in the C+1 needles on MRK8. These differences were due to surface accumulation because the inside concentrations ($CHCl_3$ washed needles) remained at approximately the same level throughout the study. The highest Fe concentrations were detected in the unwashed needles of MRK5 and MRK6 in 2005. This suggests that the source of Fe in the needle surface is most likely the same as for Al. On the plot furthest from the landfill sites (FIP10) the Fe concentrations remained approximately at the same level in all the washing treatments during 2004-2009 (Figure 20).

Nitrogen (N) concentrations were not affected by the washing treatments (Figure 21). This is due to the fact that, under normal conditions, nitrogen is the main factor limiting tree growth in boreal coniferous forests; the trees require more nitrogen than is available in the soil, and they therefore also effectively utilize nitrogen deposition on the needle surface through foliar uptake. This is also seen in the deposition measurements (see chapter 4.1). In open places the N deposition is higher than inside the forest (throughfall) which indicates that trees retain the N. This pattern is seen also in Al measurements but as revealed here, a major part of Al adheres to needle surfaces and can be removed by chloroform unlike N. A slight decrease in the N concentrations between 2007 and 2009 was observed, but the concentrations were at approximately the same level as in the Forest Focus/ICP Forest plots in southern Finland (Merilä 2013).

As was the case for the N concentrations, the sulphur (S) concentrations were not affected by the washing procedures. There was a slight trend of increasing S concentrations over the monitoring period (from 2003 to 2004-2005) on some of the plots (Figure 22). The S concentrations are many times higher in the vicinity of large population centres and industrial plants. The S concentrations on almost all of the plots at Olkiluoto were, however, under 1000 mg/kg_{dw} (from 2006 onwards on average in all plots), which can be considered as a low value in international comparisons (Rautio & Fürst 2013). By 2007 the differences between plots in S concentrations levelled out and, especially in C needles, there were practically no differences between the plots (Figure 22).

Because the dust does not contain significant amounts of toxic elements (e.g. heavy metals), but primarily elements common in the soil, dust deposition in the forests on Olkiluoto Island probably does not pose any long-term threats to the forest ecosystems. Dust accumulating on the needle surfaces might lower the photosynthesising capacity of the trees (stomatal functioning might be disturbed and a thick layer of dust might decrease the amount of light available for photosynthesis) which, in turn, might be reflected in tree growth and vitality. However, this most probably only applies to the trees growing very close to the sources of dust (road verges, the ONKALO construction site, the landfill site for crushed waste rock), and therefore the overall effects of dust deposition on the forest ecosystems will, in the long term, be only minimal.

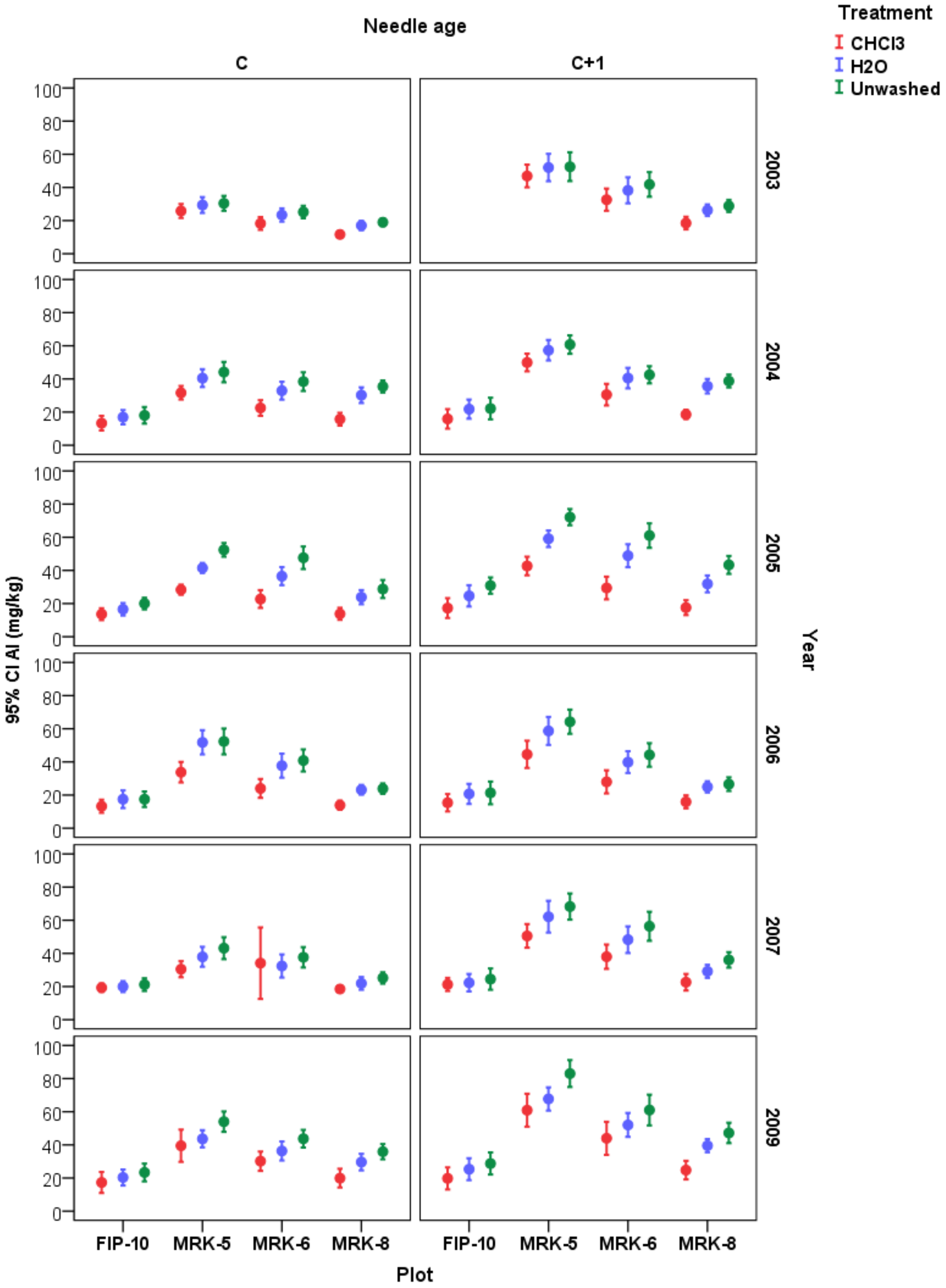


Figure 19. *Aluminium (Al) concentrations in unwashed spruce needles and in needles washed with deionised water (H_2O) or chloroform ($CHCl_3$) (mg/kg$_{dw}$). The figure shows the mean values and ± 95% confidence intervals in current-year (C) and previous-year (C+1) needles. The FIP10 plot was established in summer 2004 and hence the spruce needles were collected for the first time at the end of 2004.*

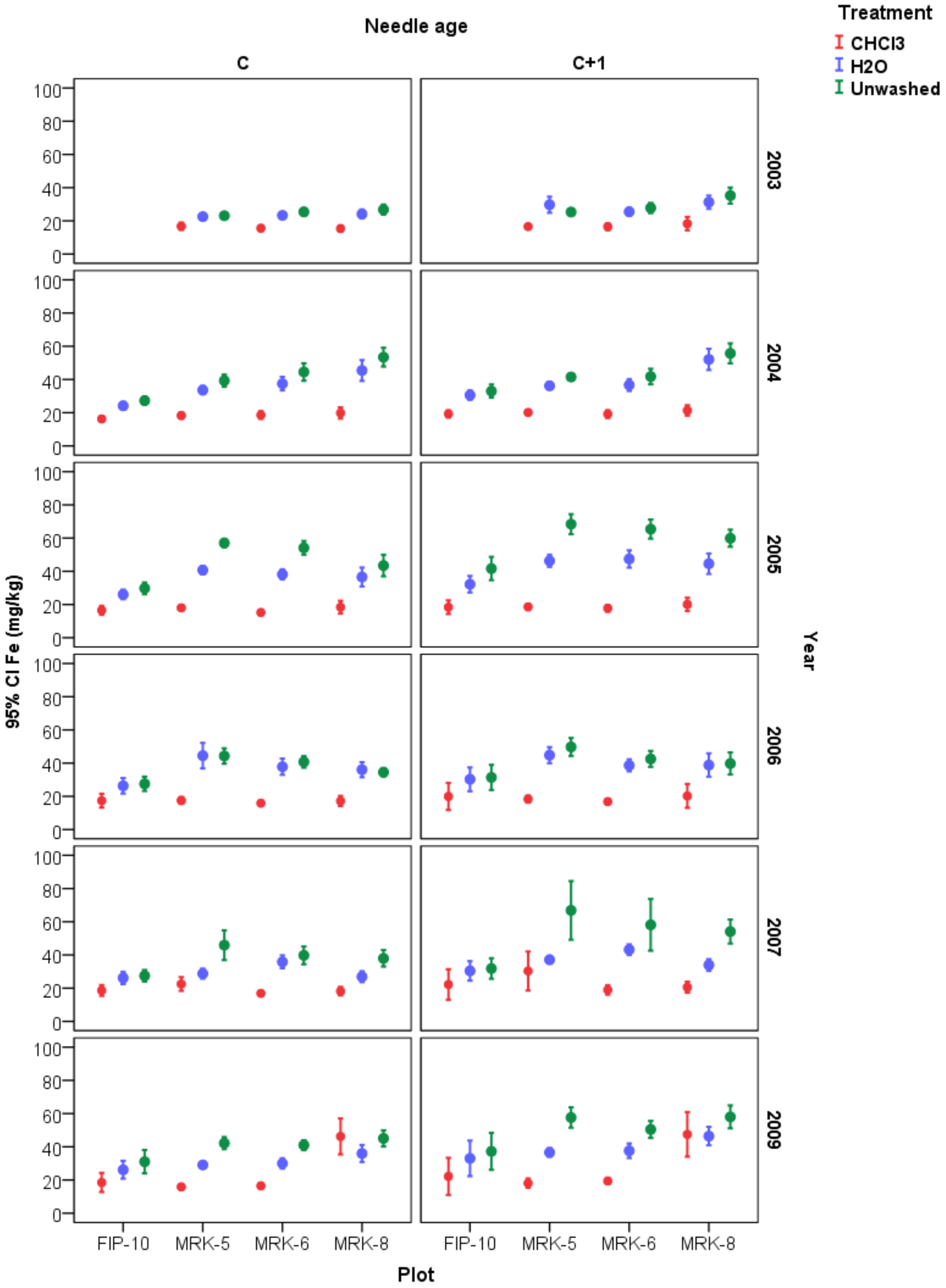


Figure 20. *Iron (Fe) concentrations in spruce needles (mg/kg$_{dw}$).*

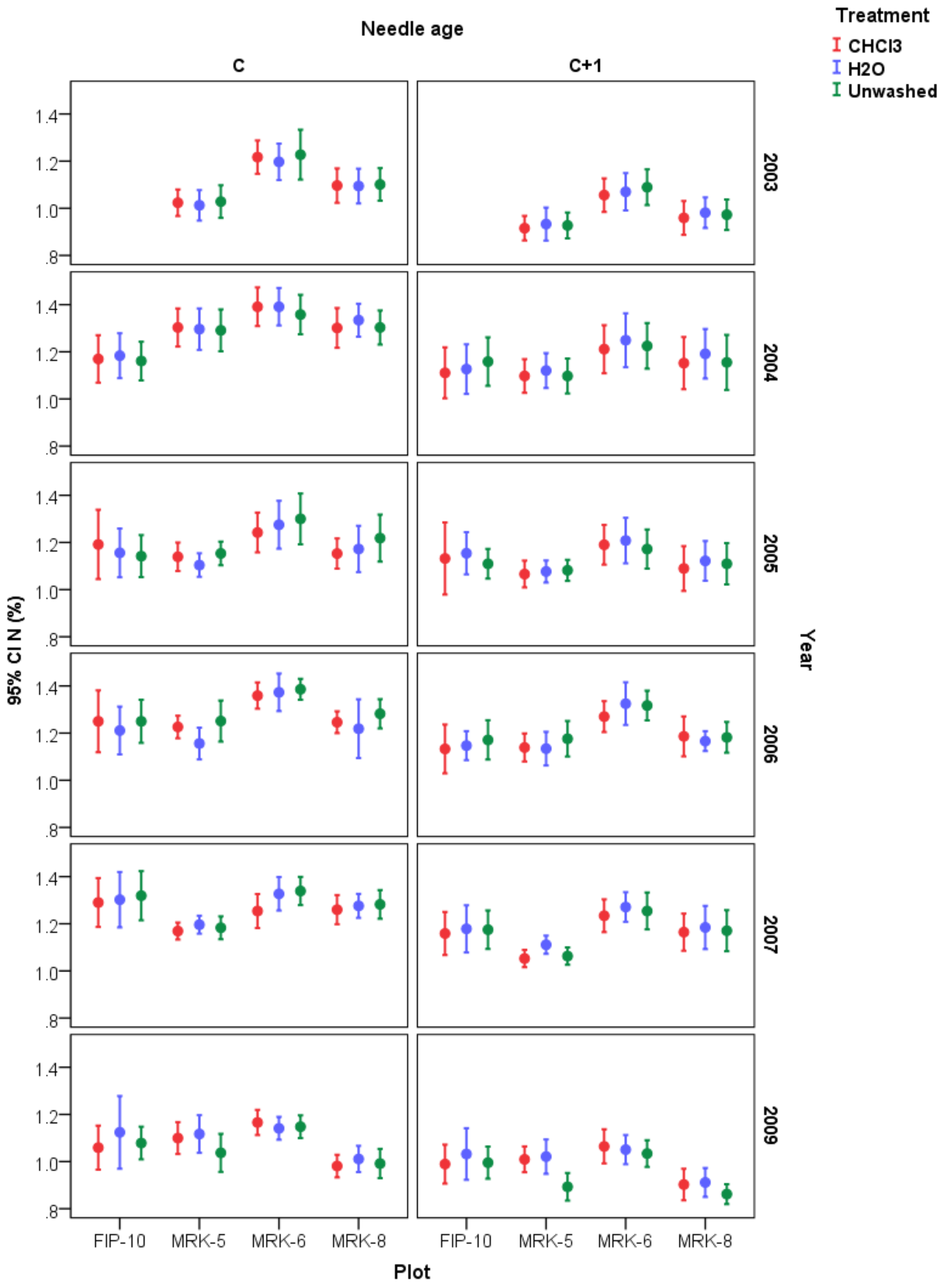


Figure 21. *Nitrogen (N) concentrations in spruce needles (%).*

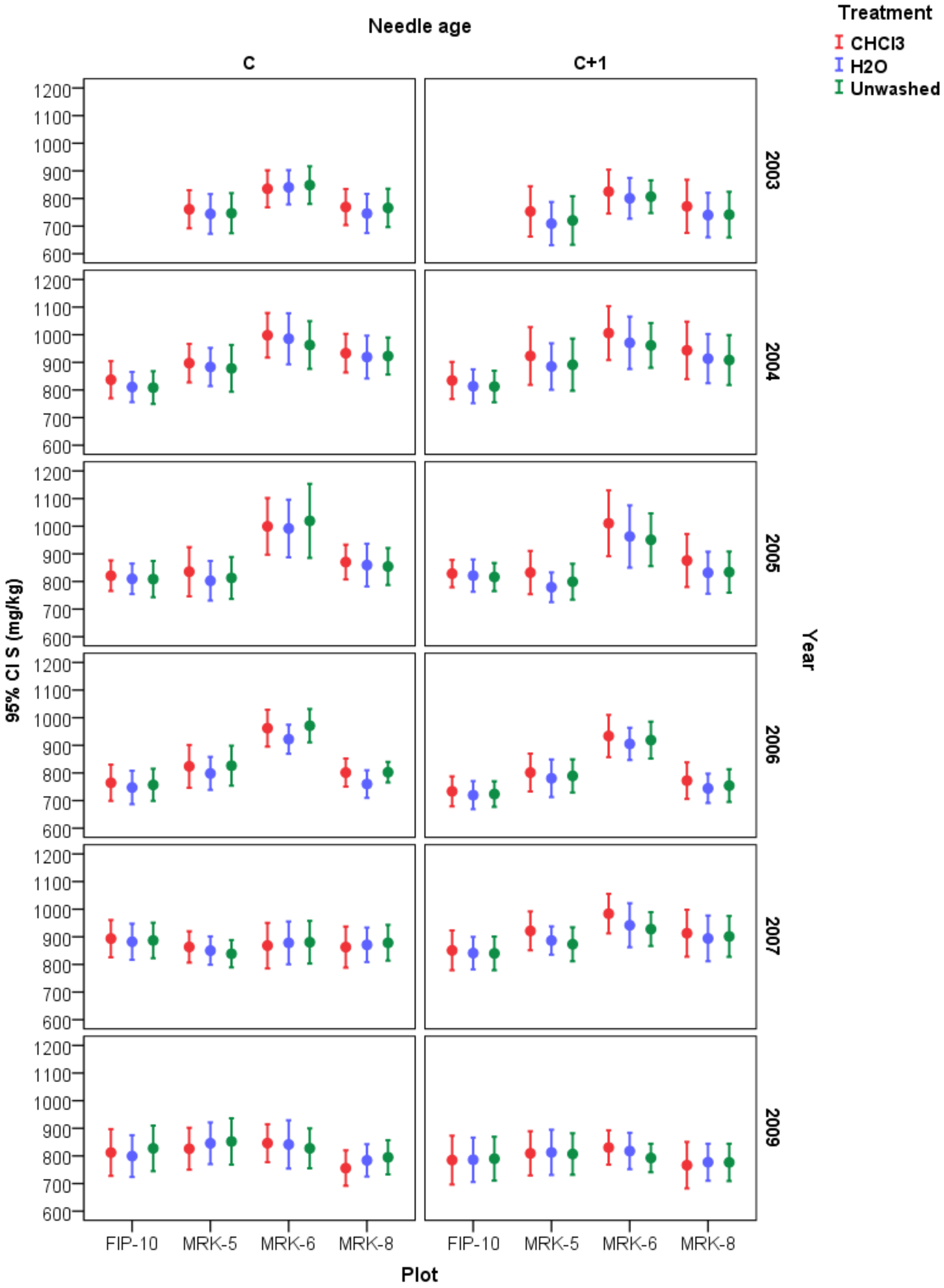


Figure 22. *Sulphur (S) concentrations in spruce needles (mg/kg$_{dw}$).*

4.6.3 Pine plots

There were no differences between the washing treatments in the case of Al, but the Fe concentrations showed similar behaviour to the spruce. The Al concentrations increased somewhat from the beginning of the monitoring period (2003) up until 2005, but by 2006 they had returned to the 2003 level and even below (Figure 23). However, when using pine needles for Al monitoring caution is required due to large internal Al concentrations. When comparing the Al concentrations in pines (Figure 23) to Al in spruce needles (Figure 19) up to 10-fold differences can be seen. When the proportion of Al in the surface of the spruce needles is at highest (around 30 mg/kg_{dw}, and in most cases 10 mg/kg_{dw} or less (Figure 19)), it can be assumed that if the proportion of Al in the pine needles surface is at the same level, detecting this on the basis of the present results would not be possible (cf. Figure 23: the variation between trees on the same plot can be over 200 mg/kg_{dw}).

The Fe concentrations in C+1 needles (i.e. the needles exposed longer to dust deposition) in 2005 followed the increasing trend that was observed already in 2004 (Figure 24). This increase was clearly due to deposition on the needle surfaces, because the increase in the chloroform-washed needles was much smaller than in 2003. By 2006 the levels had decreased to close to the levels in 2003 (Figure 24). In 2007 and 2009, however, Fe concentrations in unwashed needles and in needles washed with water showed quite large variation within plots (i.e. between trees on the same plot, Figure 24), which suggests that some trees received larger deposition than earlier but that the deposition was not uniform throughout the plot.

There were no significant differences in needle N and S concentrations between the washing procedures or the sampling plots (Figures 25 and 26). A slight increase was observed in the N concentrations in the pine needles during 2003-2006 but in 2007 this trend was reversed (Figure 25). The increase was most probably due to the increase in traffic in the area during construction work. The N concentrations were, however, at approximately the same level as on the Forest Focus /ICP Forests plots in Southern Finland (Merilä 2013). The slight increase in the S concentrations that began in 2004 and continued in 2005 ceased and even declined by 2006 (Figure 26). In 2007 an increase in S concentrations was observed, especially on plot MRK1 (Figure 26), to decrease again in 2009. Generally speaking the concentrations in C needles remained under 1100 mg/kg_{dw} which can be considered as a low level in international comparisons (Rautio & Fürst 2013). Both N and S were at the same level in the unwashed and washed needles. This suggests that N and S in deposition are taken up by the needles, which is a normal pattern in areas where the deposition does not exceed the levels that the vegetation is able to utilize. Overall, as in the case of the spruce plots, the composition and amount of dust deposition on the pine plots will most probably not cause any long-term effects to the forest ecosystems.

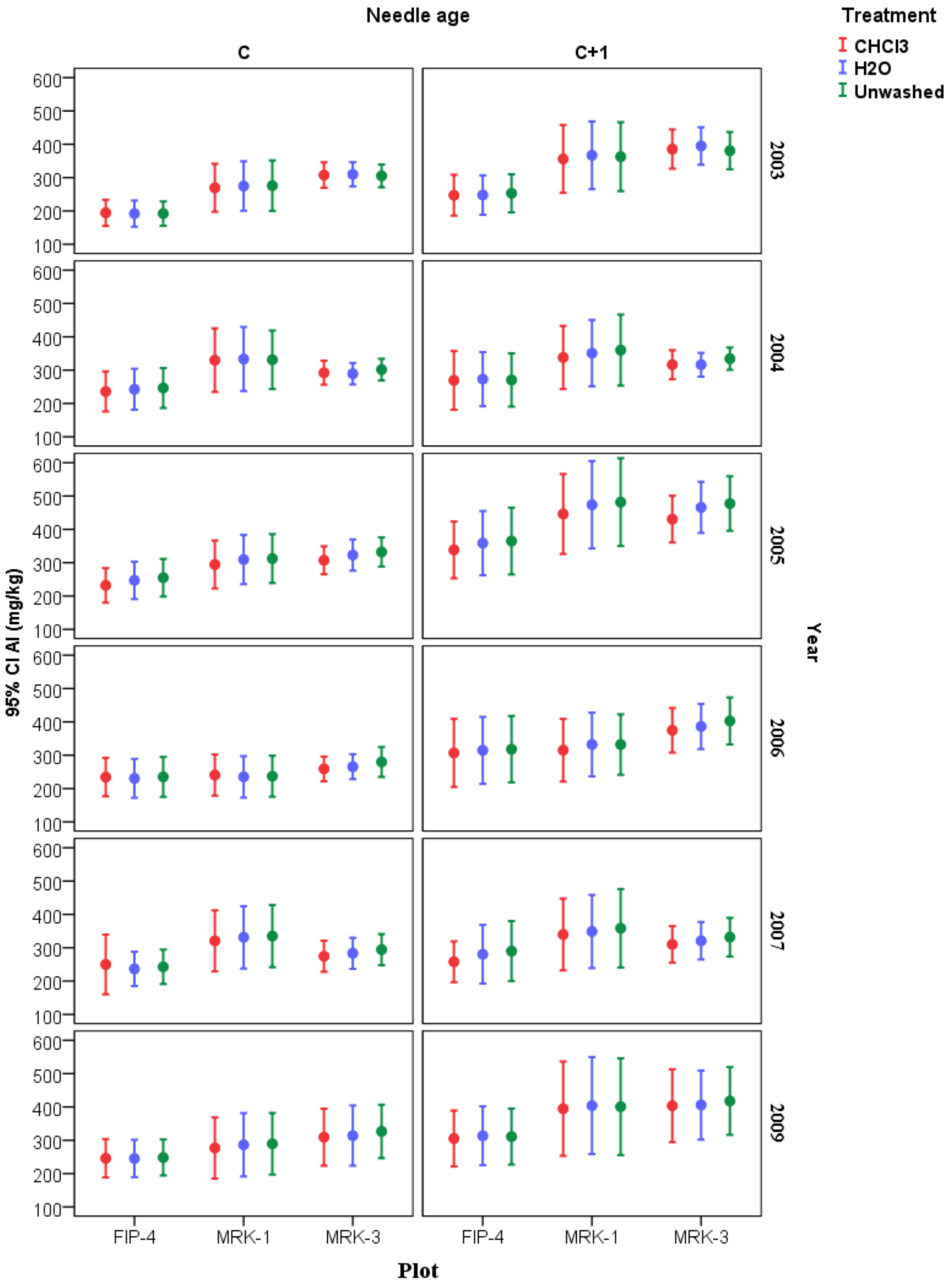


Figure 23. *Aluminium (Al) concentration in pine needles (mg/kg$_{dw}$).*

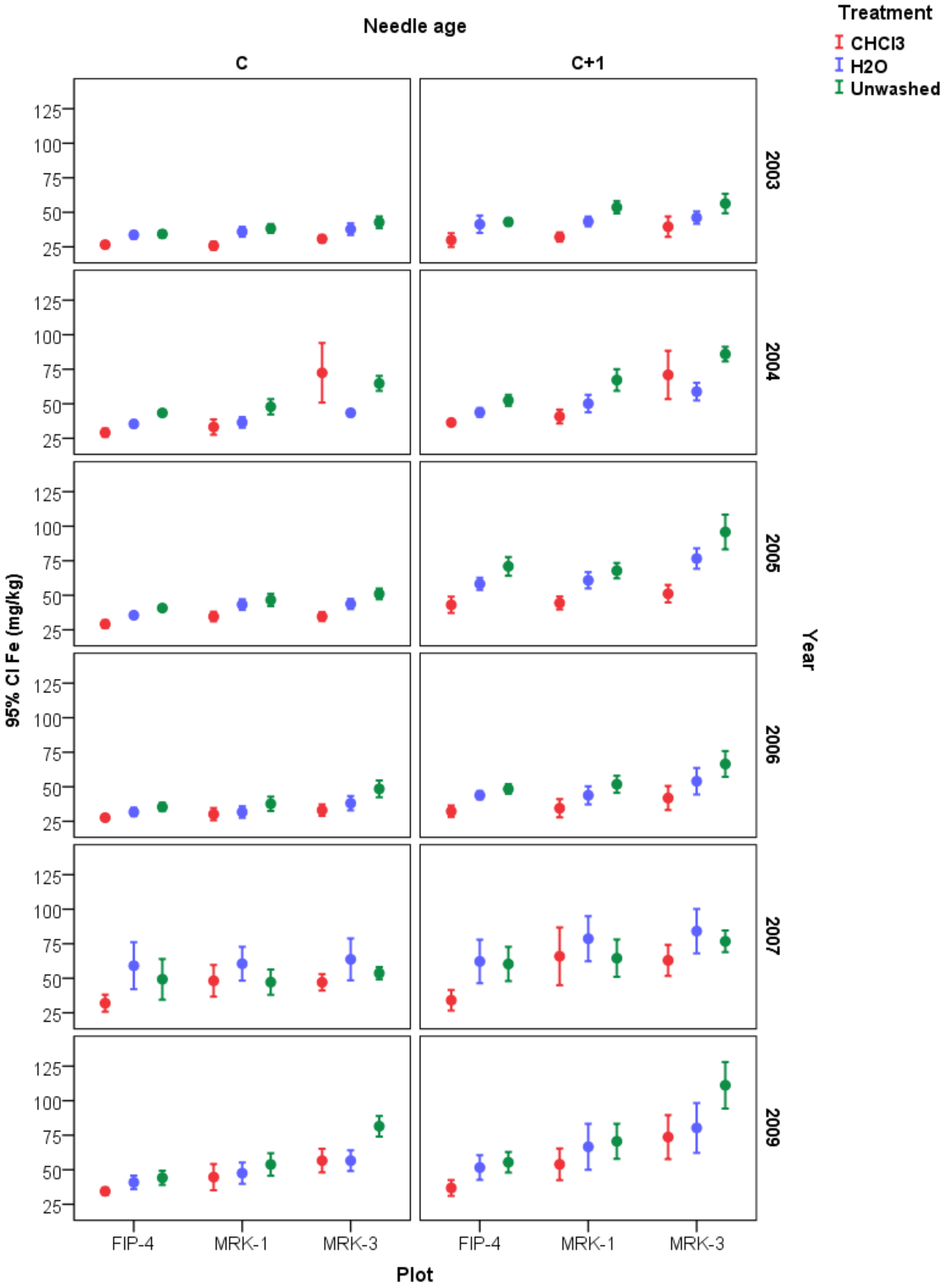


Figure 24. *Iron (Fe) concentration in pine needles (mg/kg$_{dw}$).*

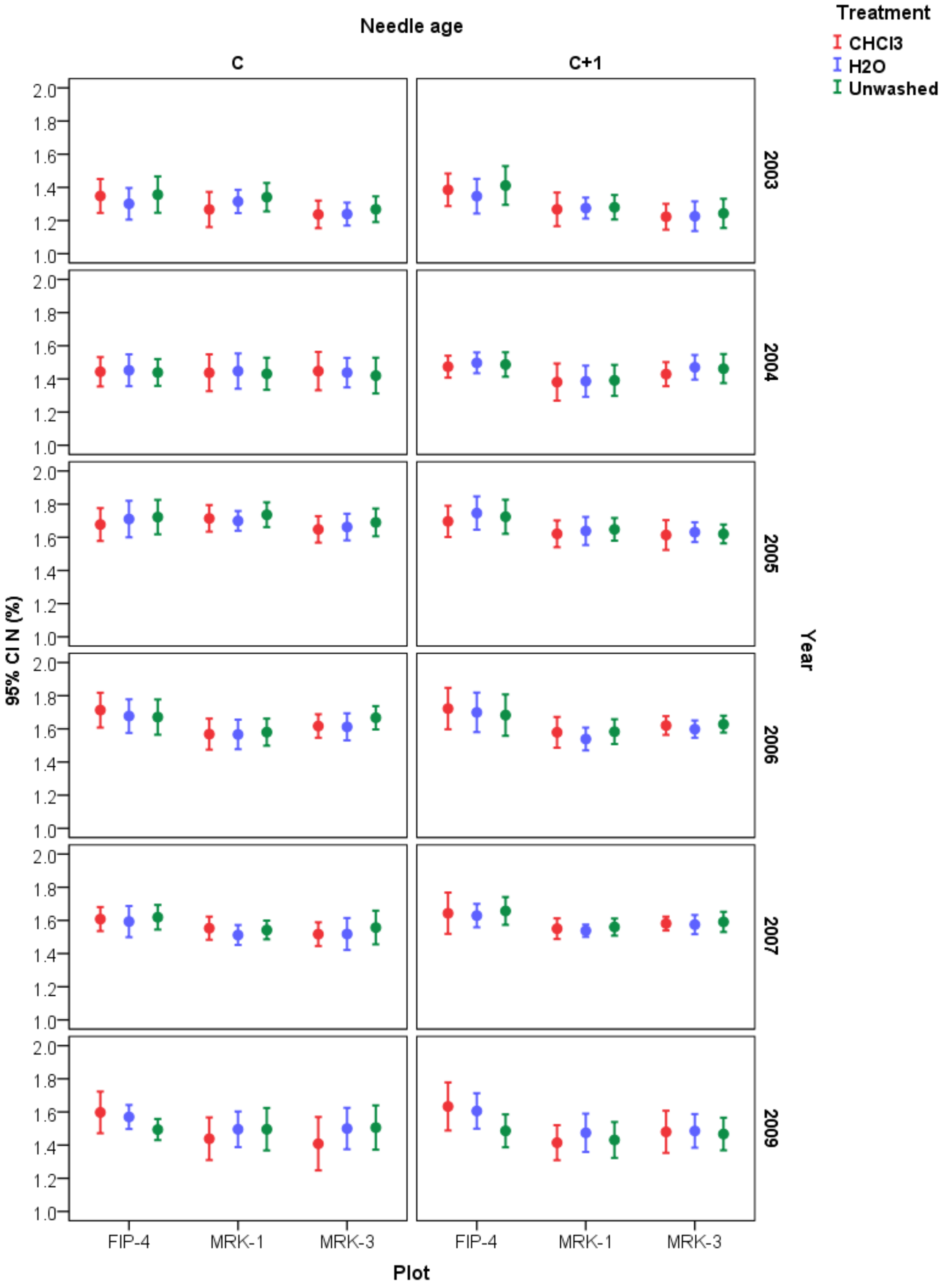


Figure 25. *Nitrogen (N) concentration in pine needles (%).*

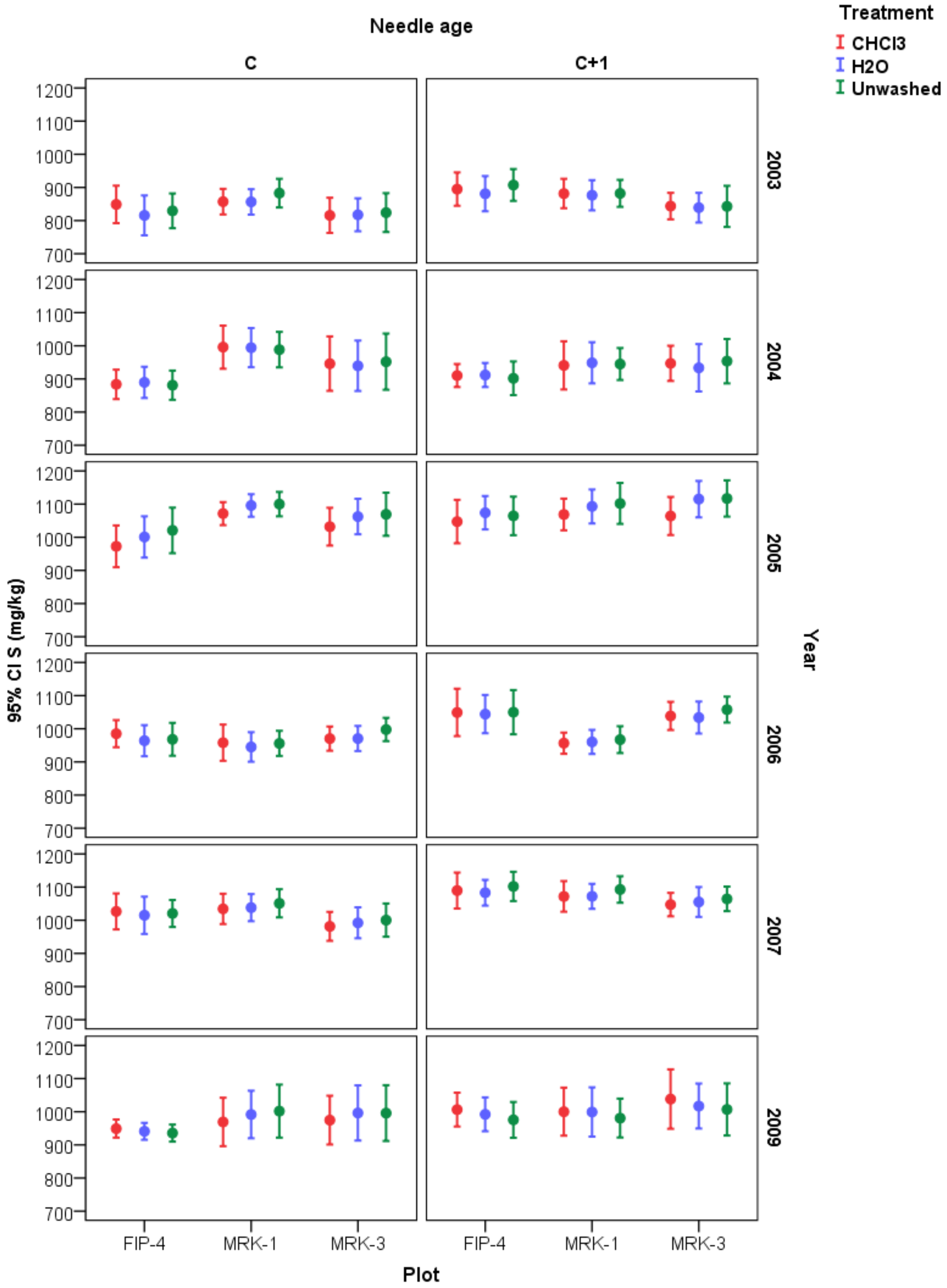


Figure 26. *Sulphur (S) concentration in pine needles (mg/kg$_{dw}$).*

5 CONCLUDING REMARKS

The forest investigations form a part of the monitoring programme being carried out on Olkiluoto Island under the management of Posiva Oy. This report focused on activities performed on bulk deposition and forest intensive monitoring plots (MRK and FIP plots) in 2012, excluding litterfall production, results of which cover the previous year, 2011. All the data have been stored in the POTTI database (Posiva research result database) and only the main findings are presented in this report.

There were no essential changes in monitoring networks during 2012. It would be beneficial to forest monitoring and biosphere description in the future if new MRK plots (or even FIP plots) could be established on a rocky forest and on a mire, e.g. in the vicinity of the ONKALO site at Olkiluoto or in a neighbouring area of Olkiluoto Island.

In general, the clearest changes in the deposition levels in 2012 were associated with the NH_4-N deposition that decreased compared to the situation in 2011. The NO_3-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004-2012. The increase in NO_3-N in bulk deposition was probably due to the construction activities in the area (e.g. rock detonations).

The major problem in collecting deposition is the avoidance of contamination caused by bird droppings in the rainfall collection equipment. So far, contaminated samples from individual collectors have been excluded if there has been evidence of bird droppings. However, these contaminated samples might be valuable in determining elemental cycles in relation to birds. Thus, the question of whether those samples could be collected and analysed separately, instead of destroying them, should be considered.

The soil solution quality in 2012 was also quite comparable to that in earlier years. The NH_4-N and NO_3-N concentrations were low at all depths in the mineral soil of the FIP plots 4, 10 and 11. This indicates that available nitrogen mineralized from the organic layer is rapidly taken up by the roots of the trees and ground vegetation on these plots. However, nitrate concentrations were high in the soil solution on FIP14. There appeared to be a clear overall increase in sulphate concentrations with increasing depth on FIP4 and FIP10. Chloride concentrations in the soil solution were extremely high at all depths on all FIP plots throughout the monitoring period; it is clear that there is a considerable input of NaCl in the deposition derived from the sea. The concentrations of heavy metals (Cd, Cr, Ni, Pb) in the soil solution at all depths at Olkiluoto during 2004-2012 continued in many cases to be close to or below the limit of quantification.

The biogeochemical studies in Olkiluoto including element concentrations and fluxes in deposition, stand throughfall and soil solution would benefit from the information of element fluxes related to mineral weathering in the forest soil. Estimation of weathering fluxes would complete the picture of input and output flows of nutrients and elements through the forest ecosystems. This would be especially important when considering key elements in biosphere assessment, such as Sr.

In 2012 the monthly level of transpiration in the Scots pine dominated stand was in general lower than during previous years (2007-2010). For the Norway spruce dominated stand, it was not possible to calculate monthly transpiration due to the numerous problems in the sap flow measurements.

In general, annual total litterfall production was more or less at the same level in coniferous plots in 2011 as during the previous collection period 2010. Total annual litterfall production (without larger branches) was 380 g_{dw}/m^2 (Scots pine stand), 317 (Norway spruce stand), 158 (young birch-dominated stand) and 349 (alder stand). The most notable differences between the plots were detected in Al and N concentrations. The Al concentration was higher in living pine needles than in spruce needles. High Al and Fe concentrations were found in the remaining litter, and were most likely due to soil dust.

Spruce and pine needles were collected annually from the same MRK plots during 2003 to 2007 and again in 2009 in order to follow changes in the foliar element concentrations. Special attention was paid to assessing the effects of particulate matter originating from the construction activities on the foliar concentrations by means of different washing procedures. The foliar concentrations of most of the studied elements were not affected by the different washing procedures, which clearly indicated that most of the elements had not accumulated on the needle surfaces. However, on the spruce plots close to the soil and rock landfill site the effect of elements originating from soil material was clearly visible. The concentrations of Al, which is an element common in many minerals, were higher in the spruce needle samples collected in plots close to the construction activities in 2004-2009 than in 2003, i.e. after the construction activities started, thus clearly reflecting the effect of construction activities on the foliar concentrations. There was no distinct increase in the Al concentrations of the chloroform-washed needles from 2003, which indicated that the increase in the Al concentrations were due to material deposited on the needle surfaces. The large difference in the foliar Al concentration between spruce and pine was normal, and is due to plant-specific differences in the root uptake of Al. The difference between the unwashed and chloroform-washed needles in the foliar Fe concentrations was even clearer than in the case of Al; there were practically no differences between the plots in the Fe concentration of chloroform-washed needles, but the Fe concentrations in the unwashed needles clearly increased from 2003 to 2005, decreased temporarily in 2006, to rise again in 2007. The highest Fe concentrations occurred on the same sample plots as the highest Al concentrations, i.e. on the plots that were closest to the landfill site for crushed waste rock. On the pine plots close to the ONKALO excavation area, the effect of these activities was not as clear as on the spruce plots. However, the highest Fe concentrations occurred in samples collected in 2004 and 2005 on the plot closest to the ONKALO area and, correspondingly with the spruce needles, the concentrations decreased in the samples collected in 2006. In 2009 a slight increase was again observed but this trend can be considered as natural variation. The concentrations of N and S were at approximately similar levels to those measured in spruce and pine foliage elsewhere in Southern Finland.

In conclusion, the composition and amount of dust deposited on tree foliage on the studied plots will most probably not cause any long-term effects to the forest ecosystems on Olkiluoto Island. Because the concentration of the main elements derived from rock dust (Al and Fe) have decreased from their highest levels and remained quite stable in the last two sampling years it is recommended that from now on the foliage sampling and analysis could be carried out biennially if notable changes in the construction activity on Olkiluoto do not take place.

No harmful effects of human activities on the forest condition were observed in the Nature conservation area.

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APPENDICES

Appendix 1a. Tamminen, P. & Aro, L. 2008. Forest soil properties of the FIP plots on Olkiluoto in 2007. Posiva Oy, Memo POS-005571, 11 p.

Appendix 1b. Corrections to the Memo POS-005571 after re-checking the data and calculations. Changed values of the organic layer have been marked in italics.

Appendix 2. Hökkä, H. 2008. Tree stand transpiration in forest intensive monitoring plots (FIP) on Olkiluoto Island – Measurement system and tentative results from summer 2007. Posiva Oy, Memo POS-003795, 15 p.

Appendix 3. Hökkä, H. 2008. Tree stand transpiration in forest intensive monitoring plots (FIP4 and FIP10) on Olkiluoto Island – estimates of annual transpiration June 2007 – June 2008. Posiva Oy, Memo POS-005147. 5 p.

Appendix 4a. Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008. Repeats 1A and 1B mean that the same sample was analysed twice after two separate HNO_3/HF digestions.

Appendix 4b. Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011. Repeats 1A and 1B mean that the same sample was analysed twice after two separate HNO_3/HF digestions.

Appendix 5. Data definition in the POTTI database.

APPENDIX 1A

Forest soil properties of the FIP plots on Olkiluoto in 2007

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Background

The functioning of forest ecosystems on Olkiluoto island is studied in Forest Intensive monitoring Plots (FIP). Three plots have now been established in the Liiklansuo catchment area: FIP4 (Scots pine forest), FIP10 (Norway spruce forest) and FIP11 (young Norway spruce/birch forest). FIP4 and FIP10 represent *Oxalis-Myrtillus*/grove-like mineral soil forest site types. The birch dominated plot is located on a rocky site and the vegetation represented partly mesic heath forests vegetation (i.e. *Myrtillus* type) and partly herb-rich heath vegetation (i.e. *Oxalis-Myrtillus* type). Each FIP plot consists of three 30 x 30 m sub-plots (OA1-3). A 5- 10 m wide zone between and around the sub-plots constitutes OA-4. The establishment and basic characteristics of the current plots have been reported in a memo by Finnish Forest Research Institute (Aro 2006). The general layout and monitoring activities of the plots are in accordance to the Forest Focus/ICP Forests, level II system (e.g. Derome et al. 2007). Some amendments have been done in order to serve the data needs of ecological modelling, e.g., monitoring of tree evapotranspiration was started in 2007 and forest soil properties of these plots were studied in 2007. This memo reports the results of the soil survey.

Soil sampling and pre-treatment of the samples

Soil samples were taken in May 2007 from three FIP plots as follows. Three composite samples were collected from the organic layer and from the 0-10, 10-30 and 30-60 cm mineral soil layers. For the organic layer and 0-10 and 10-30 cm mineral soil layers, five sub-samples were taken along three sides of the OA-2 sub-plot in such a way that each composite sample consisted of 15 sub-samples. Each composite sample represented the whole plot. In addition, three composite peat samples were taken from one side of the OA-2 sub-plot on FIP11 in such a way that each composite peat sample consisted of five sub-samples (Appendix 1). The samples from the 30-60 cm layer were taken in two (FIP11) or three (FIP4 and FIP10) soil pits, one on each side of the plot (Appendix 1). Sub-samples from the organic layer (n = 15) were taken with a cylinder (d = 60 mm), and sub-samples from the mineral soil layers (n = 15, for the layer 30-60 cm n = 3) with a spade because of the stoniness. The volumetric proportion of stones in the mineral soil 0...30 cm layer was estimated by the "rod" method (Viro 1952, Viro 1958, Tamminen 1991). The soil profile was described in three pits on each FIP plot and the soil type was classified according to the WRB soil classification system (IUSS_working_group_WRB 2006). Samples for defining the soil classification were taken from the two uppermost horizons. The deepest soil pits were photographed with a digital camera.

Peat samples were taken using a stainless steel peat sampler after any green (living) vegetation had been removed. The removed vegetation was taken as a separate sample for future studies. The sampler had a surface area of 27 mm x 63 mm (1701 mm2) and a length of about 60 cm. The actual length of each sub-sample was measured. The length of the peat samples was 5 or 10 cm. The total thickness of the peat layer at each sampling point was determined to an accuracy of 1 cm using a 1 m metal measuring rod. Before cutting the individual peat layers, each peat profile was photographed with a digital camera.

Soil samples from the mineral soil sites were sent directly for drying, sieving and grinding at the Salla office of the Rovaniemi Research Unit of the Finnish Forest Research Institute. The samples were first air-dried at 40 $_{o}$C. The organic soil samples were then ground in a mill with a 2 mm bottom sieve, and the mineral soil samples passed through a 2 mm sieve in order to separate the < 2 mm fraction from the gravel (2 to 20 mm) fraction. The peat samples were stored in a freezer until analysis. The peat type was determined, and the samples then weighed before and after drying, and finally ground in a mill to pass through a 2 mm bottom sieve before analysis (Tamminen et al. 2007). All the analyses were performed on the < 2 mm fraction.

Soil analyses

The analyses were performed on air-dry samples. The moisture and organic matter content were determined on a Leco TGA oven. pH was measured in a 0.01 M $CaCl_2$ suspension (1:2.5, v:v). The exchangeable cation concentrations were determined by extraction with 0.1 M $BaCl_2$. A batch of c. 3.75 g of organic sample or c. 15 g of mineral soil sample was extracted with 150 ml of $BaCl_2$. The samples were shaken in a rotating rack for 2 hours and then filtered. A 50 ml portion of the filtrate was titrated to pH 7 with 0.05 M NaOH in order to determine the exchangeable acidity. The total element concentrations in the organic samples were determined by wet digestion ($H_2O_2 + HNO_3$) in a microwave oven. Element concentrations in the $BaCl_2$ extraction and the total digestion solution were measured by inductively coupled plasma atomic emission spectrometry (ICP/AES). Total carbon and nitrogen concentrations were determined on a Leco CHN-1000 analyser (upland sites) or on a Leco CHN-2000 analyser (peatland site).

The particle size distribution in the 10-30 cm mineral soil layer was determined on a Coulter LS230 laser diffraction analyser in the laboratory of the Department of Forest Ecology, University of Helsinki.

Calculations and statistical treatment

Cation exchange capacity was calculated as the sum of the concentrations (in equivalent values) of base cations and exchangeable acidity (EA):

(1) CEC (mmol/kg) = $Ca^{2+}+K^{+}+Mg^{2+}+Na^{+}+EA$.

Base saturation was calculated as the proportion of sites occupied by base cations out of the CEC:

(2) BS (%) = $100*(Ca^{2+}+K^{+}+Mg^{2+}+Na^{+})/CEC$.

The amounts of elements (kg/ha) were also estimated. The mass of the organic layer was calculated according to the formula (3)

(3) M (kg/ha) =100000*m/(n*A),

where m = the dry mass of the organic sample (g), n = the number of sub-samples (15 or 8) and A = 28.27 cm^2. The masses were also calculated for the mineral soil layers. Bulk density BD_{2mm} of the soil layers was predicted using a regression equation (4):

(4) $BD_2 = 0.7668 - 0.08523 \cdot \sqrt{OM} - 0.01217 \cdot gravel + 0.1852 \cdot depth + 0.4318 \cdot BD_{Lab}$

where OM = proportion of organic matter in the layer (%), gravel = proportion of the 2-20 mm fraction (%), depth = mean depth of the layer (0.05, 0.2 and 0.45 m) and BD_{Lab} = laboratory density of the < 2 mm fraction (g/cm^3) (Tamminen and Starr 1994). The relevant soil volume (containing the < 20 mm soil fraction) was $V_{20} = V_{gross} - stone\%*V_{gross}/100$. The gross soil volumes were 1000, 2000 and 3000 m^3 for the 0-10, 10-30 and 30-60 cm layers, respectively. The mass of the < 2 mm soil fraction (kg/ha) was

(5) $M_{2mm} = 1000 \cdot BD_2 \cdot V_{20}$.

Mean values and standard errors of the means were computed for every plot using the values of all the composite samples. The sampling error, i.e. the coefficient of variation of the three composite samples, was estimated for the concentrations only.

Physical soil properties

The soil on the FIP4 plot was podzolized to some extent. All three soil profiles were classified as Haplic Arenosols, resembling Haplic Podzols. Two profiles on plot FIP10 were classified as Haplic Arenosols (≈ Haplic Podzols) and one profile as Haplic Gleysols. On plot FIP11 two profiles were classified as Haplic Gleysols and one as Histic Gleysols. The soils on Olkiluoto Island are too young to meet the criteria for Podzols in the WRB classification system. However, all the coarse or medium coarse soils on Olkiluoto will gradually develop into Podzols.

Similarly to the FEH inventory plots surveyed earlier (Tamminen et al. 2007), the FIP intensive monitoring plots were also stony (Table 1). The soil on the FIP plots contained plenty of rock fragments, i.e. there was also gravel in addition to stones.

Table 1. *Volumetric proportion (%) of stones (d > 20 mm) in the 0-30 cm mineral soil layer and the gravimetric proportion (%) of the gravel fraction by soil layer.*

		Plot		
		4	10	11
Stones, %		55	34	62
Gravel, %	0-10 cm	18	9	17
	10-30 cm	15	6	4
	30-60 cm	17	7	0

According to the particle size analysis, the surface soil layers tended to be coarser than the deeper layers (Table 2). Plot FIP11 had finer textured soil than the other plots, which represented normal till soils in southern Finland.

The organic layer type was mainly mor, except for plot FIP10 where mull-like peat was predominant (Table 3). The mor layer was moderately thick, but the peat layers on plot FIP11 were relatively thin, 15 – 30 cm, and consisted of well humified Lignum-*Carex* peat.

Table 2. *Particle size (µm) distribution in the 10-60 cm soil layer by plot. Percentage of the median particle size class in bold.*

Plot	Layer cm	Cumulative percentage ≤2	≤6	≤20	≤63	≤200	≤632	Soil texture class
4	10-30	0.5	1.7	4.0	9.7	24.0	**58.9**	sand
4	30-60	4.4	9.7	21.9	**52.7**	93.3	99.2	sandy loam
10	10-30	2.0	5.1	10.4	21.4	38.3	**71.3**	loamy sand
10	30-60	1.0	2.1	4.8	16.3	**62.7**	96.1	loamy sand
11	10-30	11.9	27.2	40.6	44.8	49.3	**65.6**	sandy loam
11	30-60	32.1	**73.5**	96.9	100.0	100.0	100.0	silty clay loam

Table 3. *Mean thickness (cm) of the organic layer by organic layer type.*

Plot	Organic layer type Mor $\bar{x}$	Mor n	Moder $\bar{x}$	Moder n	Peat $\bar{x}$	Peat n	Mull-like peat $\bar{x}$	Mull-like peat n	Total $\bar{x}$	Total n
4	4.4	44	6.0	1					4.4	45
10	7.5	15					10.7	30	9.6	45
11	6.7	17	9.2	6			12.0	1	7.5	24[1)]
11					19.1	15				15[2)]

[1)] 3*8 = 24 sub-samples from the upland site; [2)] 3*5 = 15 sub-samples from the peatland site

Soil acidity and exchangeable base cations

The soil was relatively acidic on the FIP plots (Table 4), but the acidity was within the same range as on the FEH plots (cf. Tamminen et al. 2007).

Table 4. *Mean and standard error of the mean of pH and exchangeable acidity by soil layer and by plot (n = 3).*

Plot	Layer	pH$_{CaCl2}$ $\bar{x}$	pH$_{CaCl2}$ $s_{\bar{x}}$	pH$_{water}$ $\bar{x}$	pH$_{water}$ $s_{\bar{x}}$	Exch. acid. $\bar{x}$	Exch. acid. $s_{\bar{x}}$
4	Organic	3.50	0.04	4.13	0.04	67.3	6.0
	0-10 cm	3.70	0.10	4.32	0.10	20.6	2.1
	10-30 cm	3.83	0.05	4.44	0.05	17.7	1.4
	30-60 cm	4.27	0.11	4.87	0.10	7.9	1.8
10	Organic	3.48	0.01	4.10	0.01	122.0	5.0
	0-10 cm	3.78	0.03	4,40	0.03	18.8	1.0
	10-30 cm	4.52	0.04	5.12	0.04	4.5	0.1
	30-60 cm	4.63	0.62	5.22	0.61	7.9	6.7
11	Organic	3.69	0.03	4.31	0.03	68.2	2.7
	0-10 cm	4.13	0.05	4.74	0.05	9.7	1.5
	10-30 cm	4.97	0.05	5.55	0.04	2.5	0.2
	30-60 cm	5.51	0.21	6.08	0.20	1.0	0.2
	Peat 0-10 cm	3.85	0.06	4.38	0.05	46.4	4.2
	Peat 10-20[1)]	4.94		5.39		11.3	

[1)] n = 1

The exchangeable cation concentrations in the organic and mineral soil layers were in the same range as in the FEH plots (Tamminen et al. 2007). On plot FIP11 there was exceptionally high variation in the 10-30 and 30-60 cm layers, probably due to the variable soil texture. According to the base cation concentrations and base saturation, plot FIP11 was the most fertile (Table 5). The Ca and Mg concentrations in the peat were 2-7-fold compared to the results for the FEH plots (Tamminen et al. 2007). Consequently, the CEC in peat was also higher.

The amounts of base cations were relatively low compared to those on the FEH plots (cf. Table 6 and Tamminen et al. 2007). The largest amount of base cations was on plot FIP11, especially in the deeper soil layers (Table 6), as was clearly evident from the concentrations given in Table 5.

Table 5. *Mean and standard error of the mean of the exchangeable base cation concentrations (mmol(+)/kg) by soil layer and by plot (n = 3).*

Plot	Layer	Ca		K		Mg		Na		CEC		BS	
	(cm)	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
4	Organic	166	5.7	18.7	0.7	32.8	1.4	2.3	0.3	287	23	76.7	1.0
	0-10	6.6	0.9	0.68	0.04	1.9	0.1	0.13	0.05	29.9	3.2	31.0	0.5
	10-30	5.5	0.2	0.55	0.03	1.7	0.2	0.09	0.02	25.5	2.5	30.4	1.1
	30-60	2.9	0.2	0.44	0.06	1.2	0.1	0.16	0.06	12.6	1.7	38.9	5.8
10	Organic	237	6.5	17.9	0.7	64.6	2.6	5.0	0.2	446	13	72.7	0.6
	0-10	10.2	0.6	0.69	0.10	3.6	0.2	0.38	0.04	33.7	1.9	44.2	0.1
	10-30	12.3	0.7	0.77	0.04	4.3	0.2	0.45	0.08	22.3	0.9	79.7	1.2
	30-60	11.1	0.2	1.20	0.40	4.6	1.0	0.32	0.03	25.1	4.7	70.5	22.3
11	Organic	336	18	15.8	0.4	61.1	2.5	1.7	0.1	483	20	85.8	0.9
	0-10	18.8	0.3	0.82	0.03	5.4	0.2	0.27	0.03	35.0	1.9	72.5	2.5
	10-30	49.2	5.7	2.03	0.18	14.7	1.6	0.82	0.09	69.3	7.5	96.2	0.6
	30-60	53.8	25.6	2.31	1.02	15.8	7.7	0.96	0.41	73.9	34.5	98.0	1.2
	Peat $_{0-10}$	526	13	18.3	1.5	82.0	1.1	2.0	0.19	674	10.4	93.1	0.7
	Peat $_{10-20}$ 1)	1632		5.19		132		3.8		1784		99.4	

1) n = 1

Table 6. *Amounts of exchangeable base cations (kg/ha) by soil layer and by plot (n = 3).*

Plot	Layer	Ca	K	Mg	Na
4	Organic	193	42	23	3.1
	0-10	61	12	11	1.4
	10-30	112	22	21	2.1
	30-60	94	27	23	6.3
10	Organic	624	92	103	15.3
	0-10	143	19	31	6.1
	10-30	402	49	84	16.7
	30-60	536	114	137	18.3
11	Organic	903	83	99	5.2
	0-10	147	12	26	2.4
	10-30	843	68	153	16.0
	30-60	1442	121	258	29.6
	Peat $_{0\text{-}10}$	2005	136	190	8.8
	Peat $_{10\text{-}20}$ 1)	7423	46	363	20

1) n = 1

Total concentrations of carbon, nitrogen and other elements in the organic layer

Based on the C/N ratio, all the FIP sites appeared to be as fertile as the average conifer sites in southern Finland (Table 7). Plots FIP10 and FIP11 had a statistically significantly lower C/N ratio, indicating higher productivity than on plot FIP4. Nitrogen concentrations in the mineral soil were, however, relatively low on every plot. A low C/N ratio in the organic layer usually means high nitrogen concentration in both the organic and the surface mineral soil layers.

Table 7. *Mean and standard error of the mean of the carbon and nitrogen concentrations (%) and the C/N ratio by soil layer and by plot (n = 3).*

Plot	Layer	C		N		C/N	
	(cm)	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
4	Organic	38.0	2.5	1.31	0.06	29.0	0.7
	0-10	0.92	0.20	0.05	0.007	16.8	1.6
	10-30	0.67	0.12	0.04	0.006	15.0	0.6
	30-60	0.31	0.04	0.03	0.001	10.1	1.1
10	Organic	44.3	1.2	1.91	0.04	23.2	0.2
	0-10	1.35	0.10	0.09	0.006	14.9	0.2
	10-30	0.43	0.07	0.04	0.004	10.1	0.6
	30-60	0.19	0.004	0.03	0.003	6.7	0.6
11	Organic	41.3	0.8	1.88	0.05	22.0	0.2
	0-10	0.71	0.08	0.06	0.004	12.3	1.0
	10-30	0.55	0.05	0.07	0.003	8.3	0.2
	30-60	0.45	0.13	0.06	0.018	7.2	0.1
	Peat $_{0\text{-}10}$	50.6	0.57	1.95	0.02	26.0	0.6
	Peat $_{10\text{-}20}$ 1)	47.3		2.02		23.4	

1) n = 1

The amounts of organic matter, carbon and nitrogen ranged within the values obtained on the FEH plots on Olkiluoto Island (Table 8; Tamminen et al. 2007). The most striking difference between the FIP plots was the small amount of total nitrogen in the organic layer of plot FIP4, which was only 30 % of the amount on the other FIP plots.

Total element concentrations in the organic layer were mostly within the range of the FEH plots (Table 9, Tamminen et al. 2007). However, the Ca concentration in the peat was clearly higher and the S concentration lower than on the peatland sites in the FEH forest soil survey (Tamminen et al. 2007).

The amounts of elements in the organic layer were clearly dependent on the total mass of the organic layer. The amounts of elements, excluding Mn, were clearly lowest on plot FIP4 due to both the lowest concentrations and the smallest organic layer mass on this plot (Tables 8-10). Accordingly, the amount of Ca in the 10-20-cm peat layer was many times higher than that reported in the FEH survey (Tamminen et al. 2007).

Table 8. *Amounts of organic matter, carbon and nitrogen (kg/ha) by soil layer and by plot (n = 3).*

Plot	Layer	OM	C	N
4	Organic	39830	22150	763
	0-10	9380	4220	246
	10-30	17680	6850	452
	30-60	17430	4800	481
10	Organic	106380	58220	2510
	0-10	19030	9490	635
	10-30	18440	7000	689
	30-60	18380	4830	733
11	Organic	96550	55210	2510
	0-10	6980	2760	227
	10-30	18050	4750	569
	30-60	26060	5970	828
	Peat $_{0-10}$	190409	96314	3706
	Peat $_{10-20}$ 1)	226988	107365	4585

1) n = 1

Table 9. *Mean and standard error of mean of total element concentrations (mg/kg) in the organic layer by plot (n = 3).*

Element	Plot								
	4		10		11		11		11
	humus		humus		humus		peat $_{0\text{-}10}$		peat $_{10\text{-}20}$ $^{1)}$
	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$
Al	3560	212	4506	103	5813	187	1937	82	7550
B	6.1	0.4	6.3	0.2	5.9	0.2	7.7	0.3	18.6
Ca	3777	39	5330	191	7457	335	12633	521	45100
Cd	0.52	0.002	0.48	0.018	0.65	0.068	0.71	0.005	1.2
Cr	18.5	1.4	11.4	0.4	16.9	1.8	3.2	0.4	10.7
Cu	16.5	0.6	34.4	1.3	38.7	7.8	27.0	1.6	89.2
Fe	3276	126	6867	312	5743	208	2867	211	6530
K	1500	79	1100	36	1613	35	908	82	650
Mg	915	27	1033	12	1303	64	1077	33	1910
Mn	562	78	82	5	177	15	210	32	50
Na	103	9	165	4	108	3	105	6	193
Ni	12.3	0.2	14.9	0.5	16.9	0.9	9.4	0.2	27.5
P	873	43	1001	11	987	18	938	46	906
Pb	37.3	1.7	32.2	0.5	40.1	2.4	28.8	0.2	22.3
S	1330	79	2337	92	1897	19	2577	92	6870
Zn	82.0	1.3	40.9	1.3	55.2	3.0	66.8	1.6	17.8

$^{1)}$ n = 1

Table 10. *Total amounts of elements (kg/ha) in the organic layer by plot (n = 3).*

Element	Plot 4	10	11 $_{\text{humus}}$	11 $_{\text{peat 0-10}}$	11 $_{\text{peat 10-20}}$ [1)]
B	0.35	0.83	0.78	1.47	4.2
Ca	220	701	998	2403	10237
Cd	0.03	0.06	0.09	0.13	0.27
Cr	1.1	1.5	2.3	0.6	2.4
Cu	1.0	4.5	5.2	5.2	20.2
K	87	144	216	173	148
Mg	53	136	175	205	434
Mn	33	11	24	40	11
Na	6	22	14	20	44
Ni	0.7	2.0	2.3	1.8	6.2
P	51	131	132	178	206
Pb	2.2	4.2	5.4	5.5	5.1
S	77	307	254	490	1559
Zn	4.8	5.4	7.4	12.7	4.0

1) n = 1

Sampling error and the smallest observable change in element concentrations

The sampling error was estimated as the coefficient of variation, and the smallest observable change (d) was estimated according to formula (6).

(6) $d \geq t \cdot \frac{100 \cdot s_1}{\bar{x}_1}\sqrt{\frac{2}{3}}$, where $t =_{0.05, f=2} = 4.30$, $\bar{x}_1$ is the mean of three composite samples at the first sampling time, s_1 is the corresponding standard deviation, and the term $\frac{100 \cdot s_1}{\bar{x}_1}$ is the coefficient of variation. If the variances of the variable in question are equal at the first and second sampling time, then the smallest observable change can be estimated with formula (6).

It is obvious that it is almost impossible to find any changes in a single plot (Tables 11 and 12). The changes that can be confirmed have to be large, c. 50 to 100 %. On the other hand, when the high variation of most of the soil properties is taken into consideration, then only relatively large changes are really significant for most soil variables.

Table 11. *Sampling error and the smallest observable change at the probability of 95 % for exchangeable acidity (EA), cation exchange capacity (CEC) and base saturation (BS) by soil layer and by plot.*

		Sampling error, %			Smallest obs. change, %		
Plot	Layer	EA	CEC	BS	EA	CEC	BS
4	Organic	15.6	8.2	2.3	55	29	8
	0-10 cm	18.0	18.7	2.8	63	66	10
10	Organic	7.1	5.2	1.5	25	18	5
	0-10 cm	9.4	9.7	0.5	33	34	2
11	Organic	6.9	7.1	1.8	24	25	6
	0-10 cm	26.0	9.5	6.1	91	33	21

Table 12. *Sampling error and the smallest observable change at the probability of 95 % for total nitrogen, C/N ratio and some heavy metal concentrations in the organic layer by plot.*

	Sampling error, %			Smallest obs. change, %		
Variable	4	10	11	4	10	11
N	7.3	3.3	4.6	26	11	16
C/N	4.1	1.5	2.0	14	5	7
Cd	0.6	6.5	18.5	2	23	65
Cr	13.1	6.7	18.1	46	23	63
Cu	6.1	6.8	34.9	21	24	122
Ni	2.6	6.0	9.5	9	21	33
Pb	8.0	2.7	10.5	28	9	37

Conclusions

The intensively monitored sample plots, i.e. the FIP plots, correspond relatively well to the extensively monitored FEH plots, even though the FIP plots are located close to each other. This means that the results were within the range measured on FEH plots. The variation in soil variables on the FIP plots is so high that it will be possible to detect only very large changes on individual plots. However, the main aim of this study was to provide data about forest soil properties on the FIP plots for ongoing projects dealing with element fluxes, e.g. the Olkiluoto Biosphere Description 2009 report. Furthermore, this study aimed to harmonize the sampling system used in the different monitoring networks on Olkiluoto. As a result, FIP plots can now be included in the next forest soil survey that will be repeated on the more extensively studied FET plots (i.e. FEH plots) in the future.

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Appendix 1. *Coordinates (KKJ-1) of the deep soil pits for soil profile description (SP) and peat sampling sites (PS) on the FIP plots.*

FIP plot	Sample pit	Y	X
4	SP1	6791897.000	1525593.000
4	SP2	6791869.000	1525596.000
4	SP3	6791861.000	1525609.000
10	SP1	6791634.000	1525683.000
10	SP2	6791651.000	1525704.000
10	SP3	6791662.000	1525695.000
11	SP1	6791758.000	1525725.000
11	SP2	6791765.000	1525741.000
11	PS1	6791728.638	1525743.567
11	PS2	6791730.902	1525746.192
11	PS3	6791743.059	1525751.145
11	PS4	6791745.327	1525751.724
11	PS5	6791746.817	1525753.859

APPENDIX 1B

Table 6. *Amounts of exchangeable base cations (kg/ha) by soil layer and by plot (n = 3).*

Plot	Layer	Ca	K	Mg	Na
4	Organic	*185*	*40*	*22*	*3.0*
	0-10	61	12	11	1.4
	10-30	112	22	21	2.1
	30-60	94	27	23	6.3
10	Organic	*611*	*90*	*101*	*15.0*
	0-10	143	19	31	6.1
	10-30	402	49	84	16.7
	30-60	536	114	137	18.3
11	Organic	*869*	*80*	*96*	*5.0*
	0-10	147	12	26	2.4
	10-30	843	68	153	16.0
	30-60	1442	121	258	29.6
	Peat $_{0-10}$	2005	136	190	8.8
	Peat $_{10-20}$ 1)	7423	46	363	20

1) n = 1

Table 8. *Amounts of organic matter, carbon and nitrogen (kg/ha) by soil layer and by plot (n = 3).*

Plot	Layer	OM	C	N
4	Organic	*37980*	*21120*	*728*
	0-10	9380	4220	246
	10-30	17680	6850	452
	30-60	17430	4800	481
10	Organic	*104290*	*57080*	*2460*
	0-10	19030	9490	635
	10-30	18440	7000	689
	30-60	18380	4830	733
11	Organic	*92950*	*53150*	*2421*
	0-10	6980	2760	227
	10-30	18050	4750	569
	30-60	26060	5970	828
	Peat $_{0-10}$	190409	96314	3706
	Peat $_{10-20}$ 1)	226988	107365	4585

1) n = 1

Table 10. *Total amounts of elements (kg/ha) in the organic layer by plot (n = 3).*

Element	Plot 4	10	11 humus	11 peat 0-10	11 peat 10-20 1)
B	*0.34*	*0.81*	*0.75*	1.47	4.2
Ca	*210*	*687*	*961*	2403	10237
Cd	0.03	0.06	*0.08*	0.13	0.27
Cr	*1.0*	*1.4*	*2.2*	0.6	2.4
Cu	*0.9*	*4.4*	*5.0*	5.2	20.2
K	*83*	*141*	*208*	173	148
Mg	*51*	*133*	*168*	205	434
Mn	*31*	*10*	*23*	40	11
Na	6	*21*	14	20	44
Ni	0.7	*1.9*	*2.2*	1.8	6.2
P	*48*	*129*	*127*	178	206
Pb	2.1	4.1	5.2	5.5	5.1
S	*74*	*301*	*244*	490	1559
Zn	*4.6*	*5.3*	*7.1*	12.7	4.0

1) n = 1

APPENDIX 2

Tree stand transpiration in forest intensive monitoring plots (FIP) on Olkiluoto Island – Measurement system and tentative results from summer 2007

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1. BACKGROUND

Forest vegetation has an important role in the water cycle between soil and atmosphere because it transfers the precipitated water back to atmosphere through evapotranspiration. In Finnish conditions the proportion of evapotranspiration (ET) of precipitation varies between 50-60% (Vakkilainen 1986). In boreal forests, tree stand transpiration contributes to the majority of the total evapotranspiration but there is high variation depending on the stand leaf area index (LAI). However, the maximum forest ET may not change much as LAI decreases, because the proportion of understory will increase accordingly (Kelliher et al. 1993). Transpiration is the so-called 'active' component of forest ET, in which trees uptake water from different soil layers and transfer it into the air. However, transpiration is almost entirely controlled by the weather conditions: only lack of water in the soil can make the trees to limit transpiration by closing their stomata. The weather conditions influence transpiration in multiple ways:

- radiation provides the necessary energy
- water pressure deficit in the air is the prerequisite for the atmospheric demand needed to move water molecules from the plant to the air
- wind mixes the air and transfers water vapour away from the tree canopy and enables more water to move the air next to stomata
- as an example, high rate of transpiration occurs on a warm, dry, windy day, while on a rainy, cool day transpiration is generally low.

The tree stand transpiration measurements on Olkiluoto island were initiated in two FIP areas, in which measurement systems were installed in early May (FIP4) and early June (FIP10) 2007. The aim was to measure tree-level transpiration as a basis to calculate stand transpiration rate and variability in the FIP areas. This information was considered necessary for the environmental monitoring program. The measurement systems collect transpiration data that are stored in data loggers. Since weather conditions determine the rate of transpiration, the meteorological data collected in FIP4 weather station are needed in the analysis.

This report describes the measurement methods, the system installation, and some tentative results on tree and stand transpiration in 2007. The measurement system is new and there was a problem with one sensor in the FIP4 plot. Due to this the results are based only two trees on FIP4, which is not enough. The tree dimensions in the plots are lacking 2-3 years growth and thus cannot be used for up-scaling the sap-flow measurements in a more reliable way than what has been made in this report.

2. THE STUDY SITES

FIP4 is a 41-year-old Scots pine (*Pinus sylvestris*) stand and FIP10 is a 94-year-old Norway spruce (*Picea abies*) stand. A more detailed description of the sites is given in Aro (2006). The soil type was fine-textured till according to the inventory by forest compartments (Rautio et al. 2004). Both the Scots pine plot and the Norway spruce plot represent herb-rich heath forests (i.e. *Oxalis-Myrtillus* forest type, Salemaa & Korpela 2005).

On FIP4, transpiration measurements are made in the western corner of sub-plot OA2. On FIP10, transpiration measurements are made on sub-plot OA2, but one tree grows on sub-plot OA1. Stand characteristics (FIP4 measured in June 2004, FIP10 measured in June 2005) are given in Table 1.

Table 1. *Stand characteristics of the FIP sites at the time of plot establishment (2004 and 2005).*

Site	Species	Stems, ha^{-1}	Basal area $m^2\ ha^{-1}$	D_{gM} cm	H_{dom} m	Volume $m^3\ ha^{-1}$
FIP4 OA2	Scots pine	956	32	21	18.4	268
FIP10 OA2	Norway spruce	711	34	32	28.0	386
	Pubescent birch	167	7	24	25	74

3. METHODS

3.1. The principle

ET can be estimated by several methods, including, e.g., physical formulas based on climatic parameters, water balance method, lysimeters, and eddy covariance technique. All methods are not applicable in all situations. Direct measurements of tree transpiration can only be made by measuring the water flux in the trees. For this, there are also different techniques available, all monitoring the water movement in the sapwood of trees.

The method used in Olkiluoto is called the constant heat method and was originally developed by Granier (1985). It has been widely applied in different conditions and tree species since that. It is relatively inexpensive, successfully compared to other methods in several studies (e.g., Granier et al. 1996, Köstner et al. 1996) and thus rather reliable. Water movement is measured with a pair of needle sensors (30-40 mm long, 2 mm in diameter), which are radially inserted into the sapwood of a tree at ca. 1.5 m height with a vertical spacing of 10-15 cm (Granier 1985, Köstner et al. 1996, Fig. 1). Both sensors have a thermocouple for recording temperature. The upper sensor is heated constantly with a 0.2W direct current and the temperature difference between the needles is monitored (Fig. 1). Temperature differences between the sensors have been related to the mass flow of water based on empirical calibration with several tree species.

The maximum temperature difference is during the night, when sap flow is assumed to be 0. At daytime high flow lowers the difference because water flux transports the heat away from the upper needle. The measured flow density is extrapolated for the whole tree by multiplying with the tree sapwood area (swa) (Granier 1985):

$$T_{tree} = 0.119 \cdot \left(\frac{(dT_{\max} - dT)}{dT} \right)^{1.231} \cdot swa \qquad (1)$$

where 0.119 (kg m^{-2} s^{-1}) and 1.231 are empirical constants based on calibration.

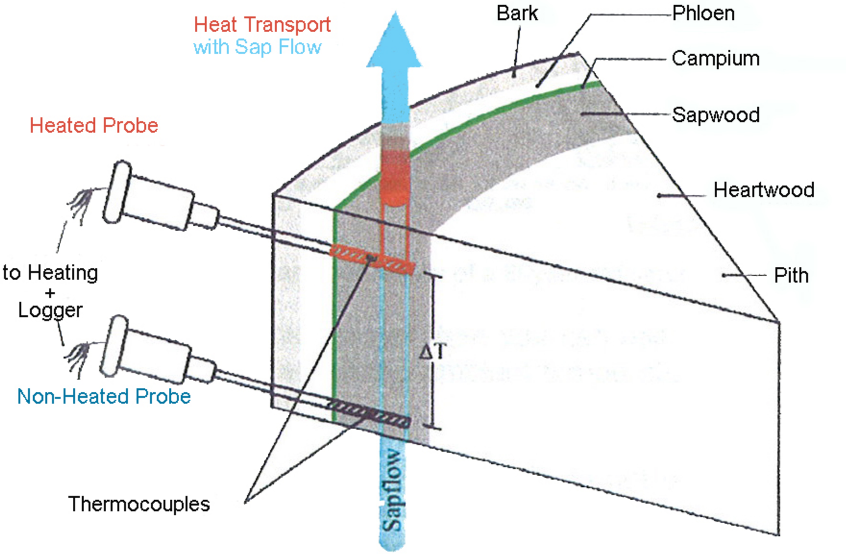

Fig. 1. A scheme of a pair of needles, i.e., a sap flow sensor (UP Sap Flow-system User Manual).

3.2. The sap flow measurement system and tree measurements

Different manufacturers serve rather similar applications of the measurement principle with variable price. The German supplier UP GmbH offers a ready-to-go package including a constant current source for heating the needle, a data logger, and sensors for three trees with a reasonable price. The system has been used earlier in studies published in peer-reviewed journals (e.g., Wullschleger et al. 2001) and was thus chosen to be used here, too. Easiness of installation, reliability, and price were the main criteria in the decision-making.

Since the dominant trees are known to contribute to the majority of stand transpiration, three dominant sample trees were selected for transpiration measurements. A battery-powered driller was used to make two holes at breast height on the northern side of the tree for aluminium tubes that were inserted into the sapwood of the sample trees. The needle sensors were put into the tubes, sealed with silicon grease and covered with aluminium radiation shields (Fig. 2). Sample tree diameters were measured with 1 mm accuracy at the time of system set up (8th May 2007).

The data-logger - current source device was connected to the electrical supply, which action started the heating and measurements. Windows program PROSALOG was used to set up the logger. For monitoring the sap flow, temperature differences were recorded at 10 min intervals. For data collection, a specific cable was used to connect the logger to a laptop.

For determining the sapwood areas, five additional sample trees representing the range of tree diameters were selected and cored from two directions (90° angle) with an increment borer. The border of sapwood and heartwood was marked in the core samples in the field. Over-bark diameters and bark thickness were also measured from these sample trees. The thickness of sapwood was measured from the sample cores in the laboratory with 1 mm accuracy using a ruler. Based on these measurements, the sapwood area of the sample trees was determined.

For FIP10, the monitoring system was set up on June 6th 2007. The above mentioned measurements were performed also in FIP10.

3.3. Calculation of sap flow

The PROSA program was used to transform the measured temperature differences (in mV) into sap flow velocity and actual sap flow (application of Equation 1). However, there was an apparent bias in the estimated transpiration for one spruce sample tree (Spruce 1), which could not be removed. Due to this, a SAS program (SAS Institute Inc. 1999) was made to calculate the transpiration estimates for all data directly using equation 1. The calculation presumed that the sapwood areas of the sample trees are known.

Based on additional sample tree measurements, a regression model was constructed for sapwood area as a function of tree diameter. Using this regression, the sapwood areas of the transpiration trees were predicted and used in the SAS program for calculating sap flow. The measured diameters and predicted sapwood areas for the sample trees are presented in Table 2.

Table 2. *Measured diameters and predicted sapwood areas of sample trees on the FIP plots.*

FIP plot	Sample tree	Diameter, cm	Sapwood area, cm^2
4	Pine 1 (tree no. 344)	19.5	116.7
4	Pine 2 (351)	22.5	170.8
4	Pine 3 (341)	20.1	125.8
10	Spruce 1 (1185)	33.3	181.5
10	Spruce 2 (1188)	26.8	114.4
10	Spruce 3 (1205)	44.5	336.7

4. RESULTS ON TREE AND STAND TRANSPIRATION

The figures given in this report have been verified against other studies and based on that fact the magnitude and variation of the transpiration estimates appeared to be reasonable (cf. Cermak et al. 1995, Köstner et al. 1996, Lagergren & Lindroth 2002, Wang. et al. 2005, Table 3).

After starting the measurements, the FIP4 sap flow data were collected for evaluation for the first time on June 6th. It turned out that one sap flow tree showed no flow signal. It was tried to solve this problem during the next visits to the FIP areas by checking the needles, changing the location of the needles in the tree, and finally by ordering additional pair of sensors and replacing the original sensor pair. However, no flow was observed when the data were screened last time on October 19 following all these actions. Due to this, the results on FIP4 are given for two trees only. It is likely that the problem is in the current source, which will be checked during the winter. On FIP10, all sample trees are used in the calculation.

Generally, the cool and rainy summer 2007 was not favourable for high rates of transpiration. Based on sap flow recordings, transpiration started to decrease at late September and virtually ended on October 20. However, there were occasional days after that when trees showed transpiration, the latest being on November 5. After that no clear signals were noticed.

The results on transpiration are given here in four different ways as examples for a one-week period July 1 - July 7 (highest mean temperature occurred on July 5): 1) individual tree transpiration rates (l/h) and day-to-day variation, 2) total daily tree-level transpiration (in litres), 3) estimates of daily total stand level transpiration in both stands, and 4) correlations of stand transpiration and weather parameters in the FIP4. Annual transpiration estimates were not calculated because of the 7-8-month monitoring period. However, the daily sap flow rates (l/d) of both stands and the corresponding daily mean temperature (^{o}C) and humidity (%) from June 8 to October 16 are shown in Fig. 7.

Table 3. *Rates of tree and stand transpiration observed in different studies.*

Publication	**Region**	**Species**	**Transpiration, l/tree/d**	**Stand transpiration mm/d**
Granier, A. 1987. Tree phys. 3: 309-320	France	Douglas-fir	8 – 22	1 – 3
Cienciela et al. 1992. Trees 6: 121-127	Sweden, Halmstad	Spruce	10 – 50	–
Cermak et al. 1995. J. Hydrol. 168: 17-27	Sweden, Uppsala	Pine – spruce mixed	Pine: 15 Spruce: 27	0.6 – 0.7 (pine and spruce combined)
Köstner et al. 1996. Theor. Appl. Climat. 53: 105-113	Germany, Rhone valley	Scots pine	4.4 – 24	1.1 – 6.0
Cienciela et al. 1997. Agr. For. Meteor. 86: 157-167	Sweden, Uppsala	Pine – spruce mixed	–	Pine: 0 – 1.7 Spruce: 0.1 – 2.8
Moren et al. 2000. Trees 14: 384-397	Sweden, Uppsala	Spruce – pine mixed	2 – 75	–
Kellomäki, S. & Wang, K.-Y. 2000. Ann. Bot. 85: 263-278	Finland Ilomantsi	Pine, small	0.17 – 2.9	–
Lagergren & Lindroth 2002. Agr. For. Meteor. 112: 67-85	Sweden, Uppsala	Pine – spruce mixed	5 – 40	0.3 – 2.0
Wang. et al. 2005. J. Exp. Bot. 56: 155-156	Finland Ilomantsi	Pine, small	0.5 – 3.77	–

1) In both locations the larger trees showed higher rate of transpiration, i.e., they transported more water than the smaller trees (Fig. 3). Otherwise the day-to-day and within-day variability in the flow rate was similar among the trees. Transpiration started between 5 and 7 o'clock in the morning and ended between 22 and 23 o'clock in the evening.

2) In early July the highest tree-level transpiration in litres was observed from the largest spruce (53.4 l/day, Fig. 4). The spruce trees were larger but older and thus had relatively smaller sapwood area–diameter ratio than pines. However, their larger total sapwood and needle areas resulted in clearly higher daily transpiration rates.

3) The stand level transpiration was estimated with a very simplified method. This was done because the two sample trees did not permit stratification of the actual tree size distribution among to the different-sized sample trees. The average daily transpiration of the two sample trees was assumed to represent the water use of the mean tree in the stand. In FIP4 the average sample tree was somewhat smaller than the average tree in the stand while the contrary was true in FIP10 (see Tables 1 and 2).

The daily mean transpiration rate was multiplied by the number of trees in the stand (ha^{-1}) and used as the stand-level estimate of transpiration. In FIP10, transpiration of birch trees was assumed to be equal to that of spruces, i.e., the average rate of transpiration of the sample trees was multiplied by the total number of trees in the stand (878 trees ha^{-1}). In the pine stand transpiration varied between 0.34 mm and 0.87 mm and in the spruce stand between 1.06 and 2.34 mm (Fig. 5). These values are in accord with those given in other studies, although they are somewhat low in FIP4 (Table 3). Furthermore, there is probably more water available in the soil in the spruce stand than in the pine stand where soil water content may occasionally limit transpiration.

4) In FIP4, the mean daily transpiration of sample trees was positively correlated with radiation and temperature, and negatively with humidity (Fig. 6). This is in accord with results from several other studies (e.g. Ford et al. 2000) in which the water pressure deficit in the air and radiation have been shown to be the most important variables explaining the rate of forest transpiration. This can be seen also in figure 7, where daily stand level transpiration rates in both stands and the corresponding daily temperatures and air humidity are shown for the period from June 8 to November 16.

5. METHOD RELIABILITY AND SOURCES OF ERRORS

The estimation of true value of vegetation transpiration is very challenging and the results differ more or less among the methods. Even though the determination of sap flow density from the temperature difference recordings with the constant heat method is based on an empirical formula (Eq. 1), with the same constants applied to all tree species, its' reliability has been proven in numerous studies.

The sources of errors of this method are related to the number of sample trees (among-tree variability) and the spatial variability of sap flow within the tree – both around the circumference of the sapwood, and in the different depths of the sapwood. According to Cermak et al. (1995), increasing the number of sample trees from 1 to 10 decreases the standard error in mean sap flow rate from 40% to 10%. With 3 trees the standard error still is 15-35%. Three trees give the possibility to check among-tree differences in the measured rates, and thus exclude clear measurement errors.

Because the sap flow rate may be different in different sectors of the tree, the measurement accuracy can be increased by using several sensors inserted into tree from several angles (Cermak et al. 2004). Generally trees larger than 20 cm in diameter are recommended to be monitored with two sensors. However, more important is to realize that the sap flow velocity is highest at the uppermost layers of sapwood. Due to this, the measurement range of the needle sensor is aimed to give an average of the different flux velocities within the sapwood. According to Nadezhina et al. (2002), the correct sap flow rate of Scots pine is that measured at 80% of tree radius. This variation is important in trees with large sapwood areas, and may be a problem with Scots pine in situations where severe drought is limiting transpiration (Nadezhina and Cermak 2000).

The error related to the up-scaling of sample tree measurements to stand-level transpiration estimates is assumed to be significantly lower than errors related to the correct measurement of sap flow. In this procedure, one source of error is the determination of sapwood area of transpiration sample trees. This fact probably generated some error in the results of this report, because the sapwood area of the transpiration trees was estimated with a model. Especially on FIP10 the high transpiration rate of the largest spruce tree is due to its high sapwood area, which is obtained by extrapolating the regression model beyond the sapwood sample tree data. This possible error can be lowered by increasing the size of sapwood tree sample. Correct determination of sapwood area presumes destructive sampling from the sap flow trees, which, in turn, should not be done before sufficient sap flow data have been collected.

6. OTHER CONSIDERATIONS

If more serious water balance calculations are aimed, it would be advisable to double the number of sample trees for monitoring sap flow. Calculating stand transpiration by multiplying the mean rate of 2-3 trees by the number of trees in the stand, as made here, can give only robust and possibly biased estimates of stand level transpiration.

From both study sites more sapwood sample trees should be collected to increase the accuracy of sapwood area estimates of the transpiration sample trees. It is also necessary to re-measure the sample plots in order to update tree dimensions and permit more reliable calculation of stand level transpiration.

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Figure 1. *Sap flow sample tree with radiation shield installed over sensor pair.*

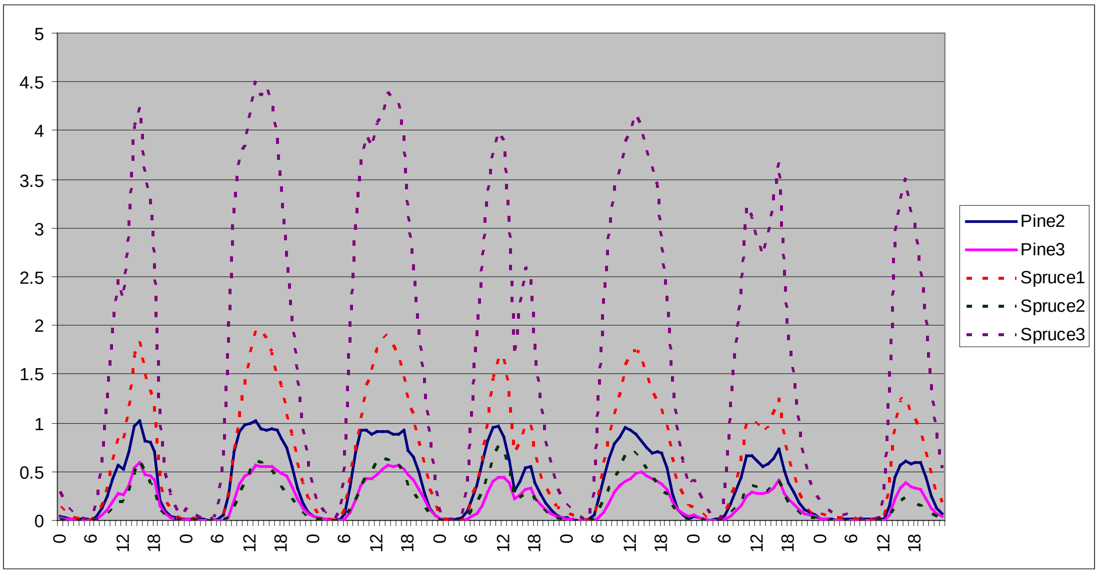


Figure 3. *Transpiration rate (l/h) of pine and spruce sample trees on July 1 – July 7, 2007.*

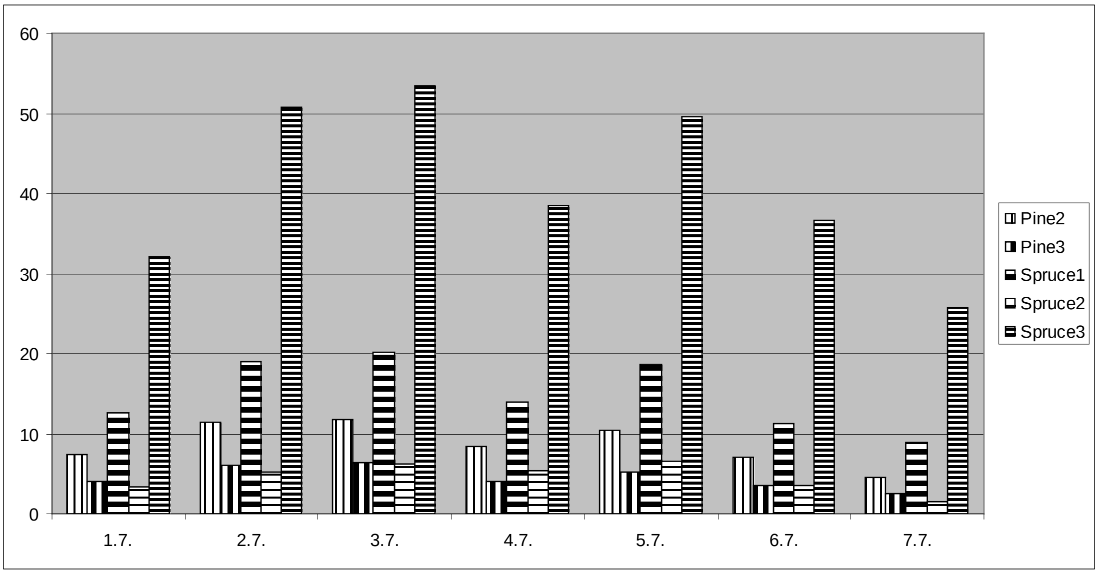


Figure 4. *Total daily transpiration (l/day) of pine (Pine2 and Pine3) and spruce sample trees (Spruce1 – Spruce3) on July 1 – July 7, 2007.*

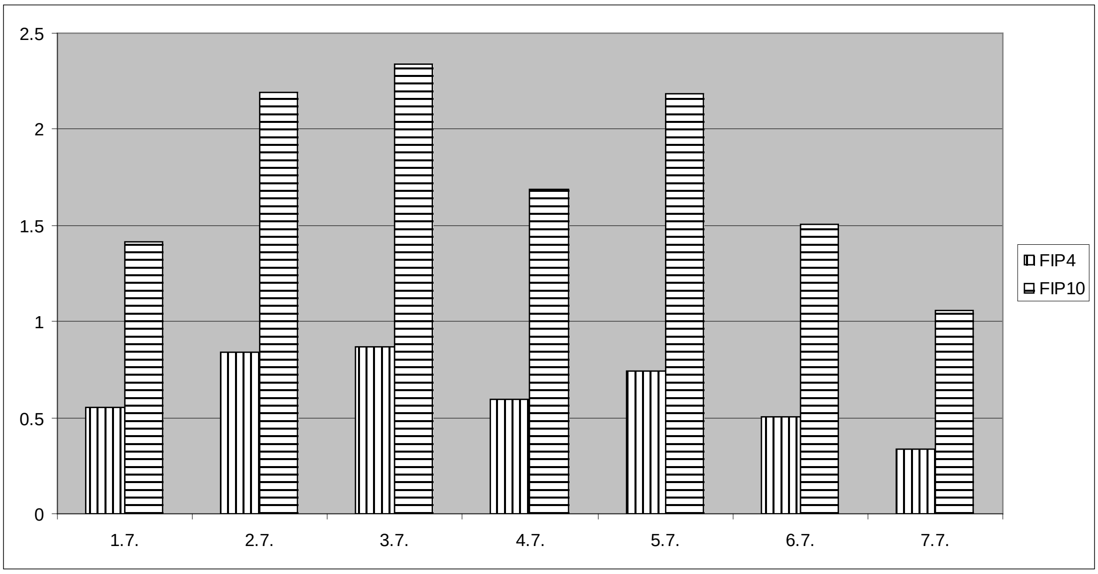
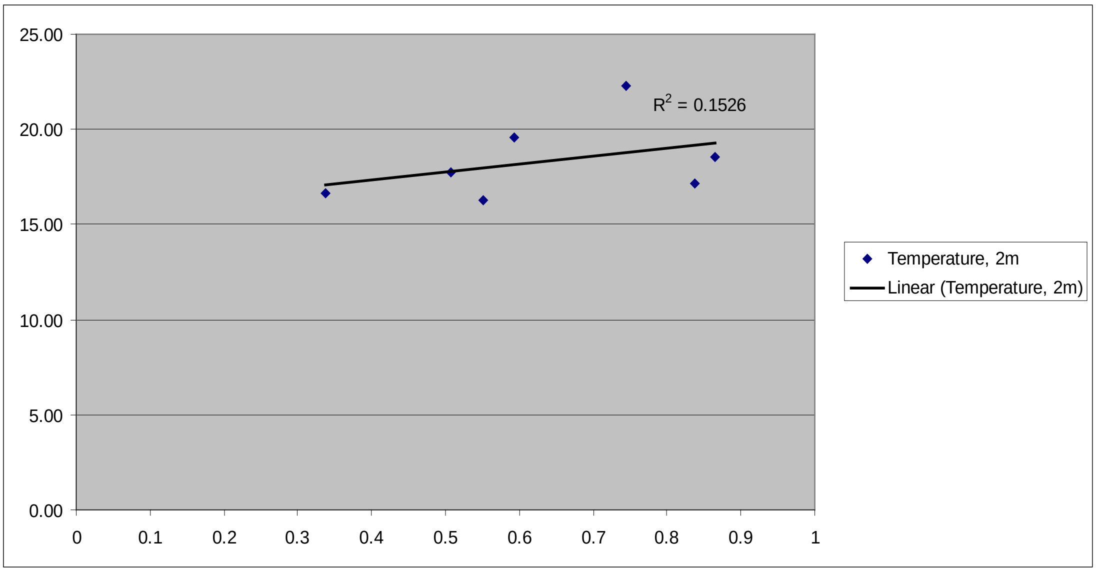
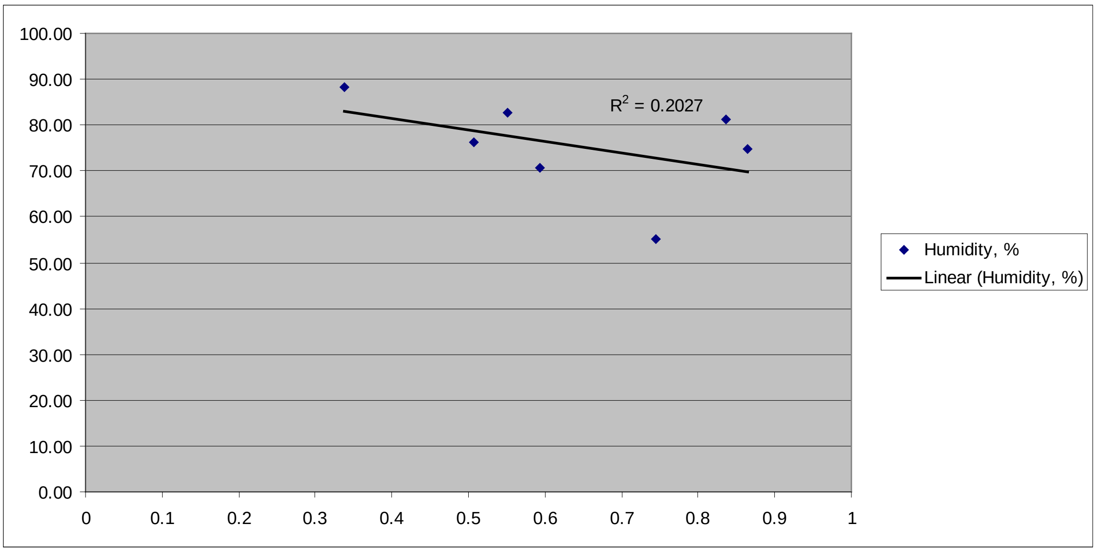


Figure 5. *Estimated stand-level transpiration (mm/d) in FIP4 and FIP10 in July 1 – 7, 2007.*





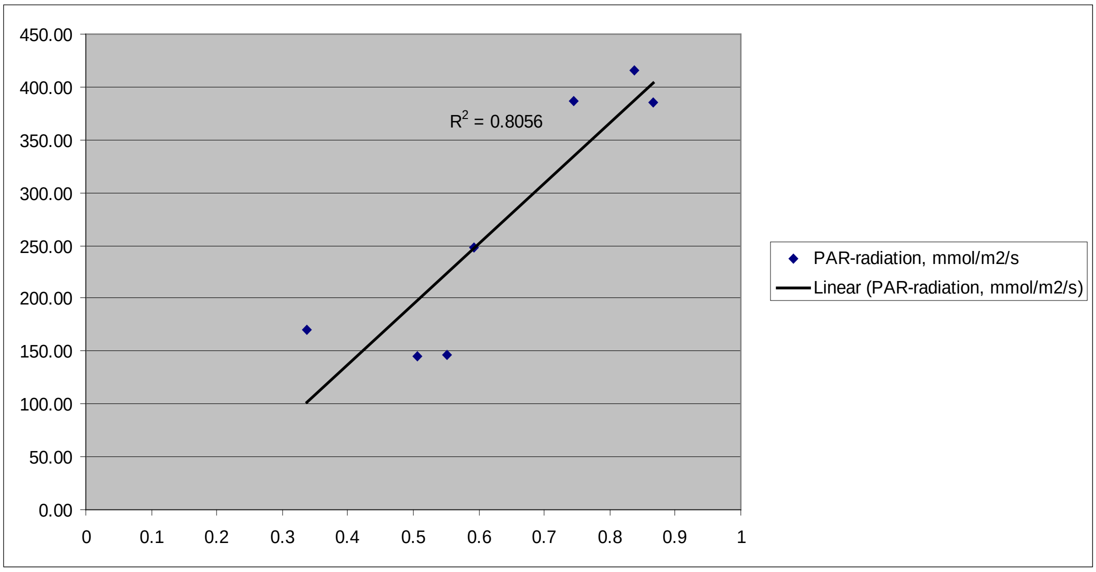
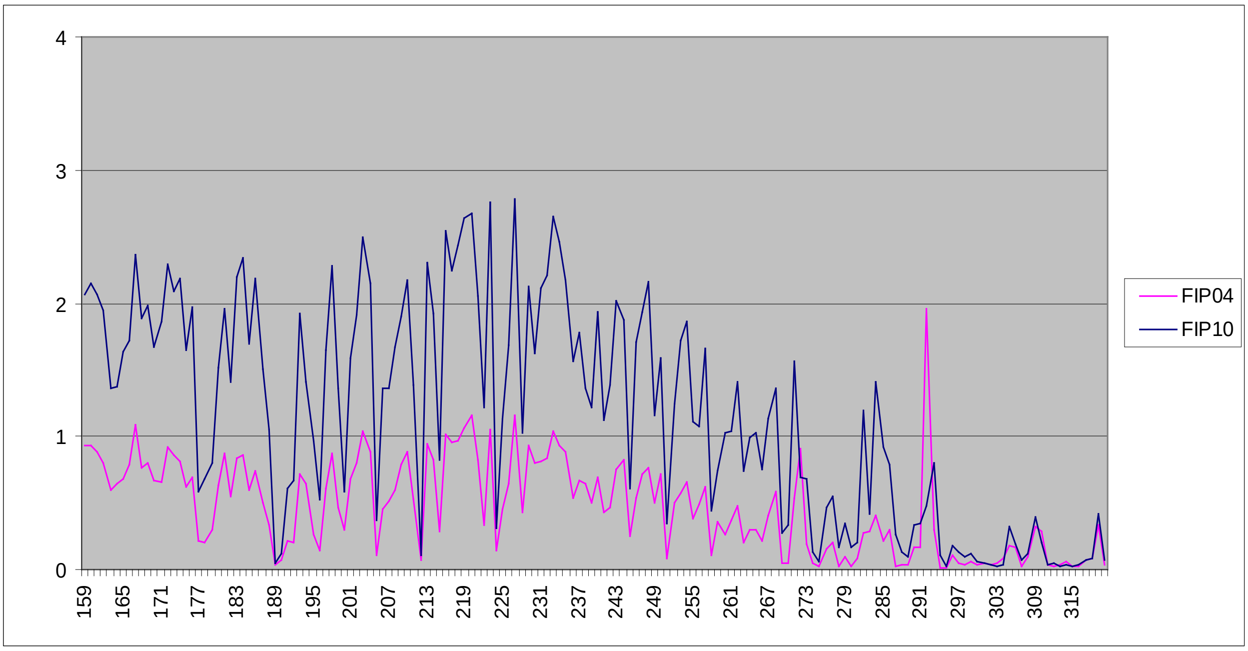


Figure 6. *Correlation of daily transpiration of the pine stand (July 1 – 7, 2007) and daily mean temperature, air humidity, and radiation measured in FIP4 weather station.*



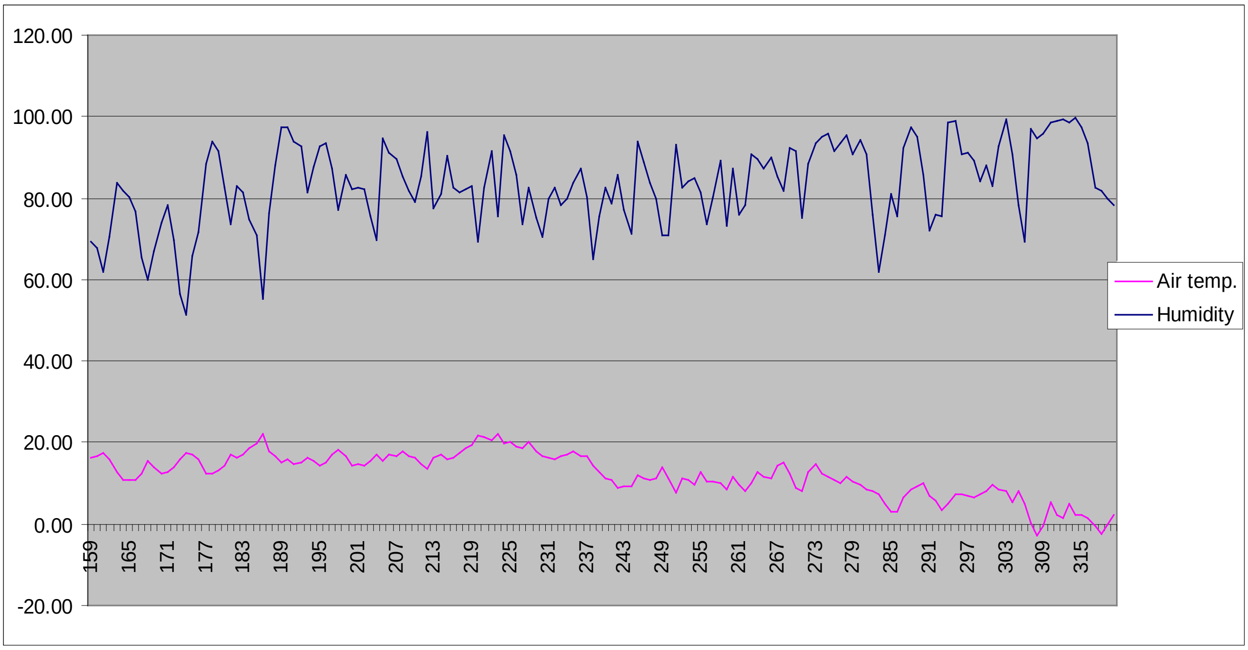


Figure 7. *Daily transpiration rates (l/day) of FIP4 and FIP10 and the corresponding daily mean relative humidity (%) and temperature (^{o}C) in June 8 – Oct 16, 2007 (Day of year 159-320). The high transpiration peak on Sept. 30 (day 291) is a measurement error.*

APPENDIX 3

Tree stand transpiration in forest intensive monitoring plots (FIP4 and FIP10) on Olkiluoto Island – estimates of annual transpiration June 2007 – June 2008

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1. BACKGROUND

Forest vegetation has an important role in the water cycle between soil and atmosphere because it transfers the precipitated water back to atmosphere through evapotranspiration. In Finnish conditions the proportion of evapotranspiration (ET) of precipitation varies between 50-60% (Vakkilainen 1986). In boreal forests, tree stand transpiration contributes to the majority of the total evapotranspiration but there is high variation depending on the stand leaf area index (LAI). However, the maximum forest ET may not change much as LAI decreases, because the proportion of understory will increase accordingly (Kelliher et al. 1993). Transpiration is the so-called 'active' component of forest ET, in which trees uptake water from different soil layers and transfer it into the air. However, transpiration is almost entirely controlled by the weather conditions: only lack of water in the soil can make the trees to limit transpiration by closing their stomata. The weather conditions influence transpiration in multiple ways:

- radiation provides the necessary energy - water pressure deficit in the air is the prerequisite for the atmospheric demand needed to move water molecules from the plant to the air
- wind mixes the air and transfers water vapour away from the tree canopy and enables more water to move the air next to stomata
- as an example, high rate of transpiration occurs on a warm, dry, windy day, while on a rainy, cool day transpiration is generally low.

The tree stand transpiration measurements on Olkiluoto island were initiated in two FIP areas, in which measurement systems were installed in early May (FIP4) and early June (FIP10) 2007. The aim was to measure tree-level transpiration using the sap flow measurement system as a basis to calculate stand transpiration rate and variability in the FIP areas. This information was considered necessary for the environmental monitoring program. The measurement systems collect transpiration data that are stored in data loggers. Since weather conditions determine the rate of transpiration, the meteorological data collected in FIP4 weather station are needed in the analysis.

The approach, the measurement methods, and tentative results concerning year 2007 have been reported in Hökkä (2008; Posiva memo POS-003795). In June 6th 2008 one full year of data became available, from which it was possible to calculate the annual rate of transpiration in both intensive plots. These calculations are reported here. In addition to the first estimates of annual transpiration in Scots pine and Norway spruce stands in Olkiluoto, results will also be used for estimation of water balance in forests on Olkiluoto Island later on this year, and finally in the report "Olkiluoto Biosphere Description 2009".

2. MATERIAL AND METHODS

The experimental design has been remained virtually the same as described in Hökkä (2008), ie. the temperature difference between two needle sensors installed in the sapwood of 3 Scots pines (FIP4) and 3 Norway spruces (FIP10) were monitored, and the readings converted to mass flow of water using equation developed by Granier (1985) and described in Hökkä (2008). However, some amendments and additional measurements were made to solve problems noticed when reporting tentative results from 2007.

First, one sap flow sample pine showed no signal despite of several checks during 2007 and thus the stand transpiration estimates in FIP4 were based on two sample trees only. The reason for the poor signal was eventually determined as a serious fungus infection in the sap flow tree. Another, healthy sap flow sample tree was chosen on April 18th 2008. Starting from that date, it was possible to use transpiration data from three trees in calculating results of this report.

The tree dimensions of all trees in the sub-plot (OA2) of the FIP plots were re-measured in May 2008, and stand characteristics were updated to correspond to the present time (Table 1). Simultaneously, additional sapwood sample trees were cored and sapwood areas were determined for those trees (originally, 5 trees were sampled from both plots). This confirmed the relationship between tree diameter and sapwood area which was further utilized in up-scaling the transpiration measurements from tree level to stand level. There was no reason to change the relationship developed for the pine stand (FIP4) based on 2007 data, but in the spruce stand (FIP10) the additional sample trees suggested that as a function of dbh (tree diameter at breast height, i.e. 1.3 m) the sapwood area increased somewhat less than estimated in Hökkä (2008) (Fig 1). Due to this, a slightly decreased spruce stand transpiration was obtained in this report. For birch trees in FIP10, all under bark basal area was assumed to conduct water.

Table 1. *Stand characteristics of the FIP sites in May 2008.*

Site	Species	Stems, ha^{-1}	Basal area m^2 ha^{-1}	D_{gM} cm	H_{dom} m	Volume m^3 ha^{-1}
FIP4 OA2	Scots pine	911	34.4	22.8	18.0	303
FIP10 OA2	Norway spruce & Pubescent birch	867	41.6	31.2	28.4	473

Calculation of stand level transpiration for year 2007 was made by assuming that the average transpiration of sample trees represented transpiration of an average tree in the stand. This assumption was not quite correct especially for FIP10. In this report, the total sapwood area of the sap flow trees was related to the total sap wood area of all trees in the stand. The latter was estimated with the help of the equations developed for predicting the sapwood area from tree diameters (see Fig 1). Sapwood area for all trees in the plot was estimated and summed up as the total sapwood area. The sum of the measured transpiration of sap flow trees was multiplied by this ratio to calculate stand level transpiration. As a result, the values of stand transpiration slightly decreased compared to those shown in Hökkä (2008) in FIP10, where the average tree in the stand was smaller than the average sap flow tree.

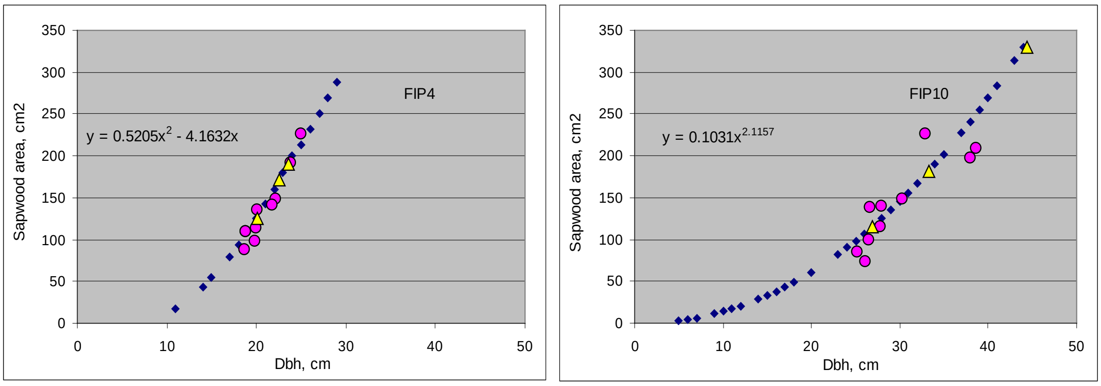

Figure 1. *The observed relationship between tree diameter (dbh) and sapwood area in sapwood sample trees (red dots) and that modeled for the sap flow trees (yellow triangles) and all tally trees (blue squares) in FIP4 and FIP10.*

3. RESULTS

The values of monthly and annual transpiration at stand level are given in Figure 2. In general, monthly transpiration in July 2007 was relatively low in FIP4, only 17 mm. A possible reason is the rainy and cool weather (Figure 3), because also in FIP10 the highest rate of transpiration occurred in August. Annual transpiration estimated for the period June 2007 – May 2008 was 132 mm in FIP4 and 200 mm in FIP10.

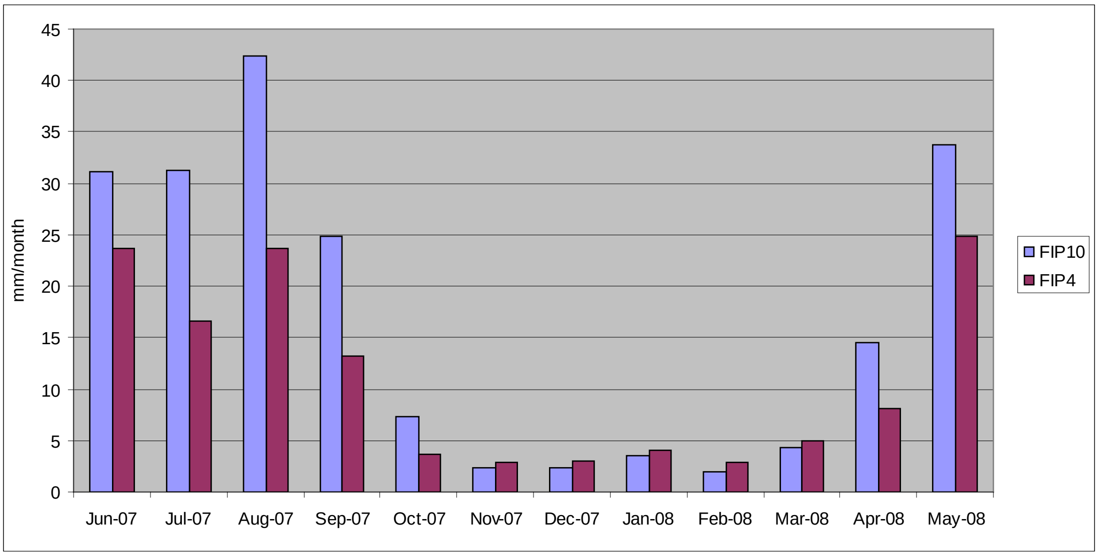

Figure 2. *Monthly stand level transpiration (June 2007 to May 2008) in FIP4 and FIP10 sample plots.*

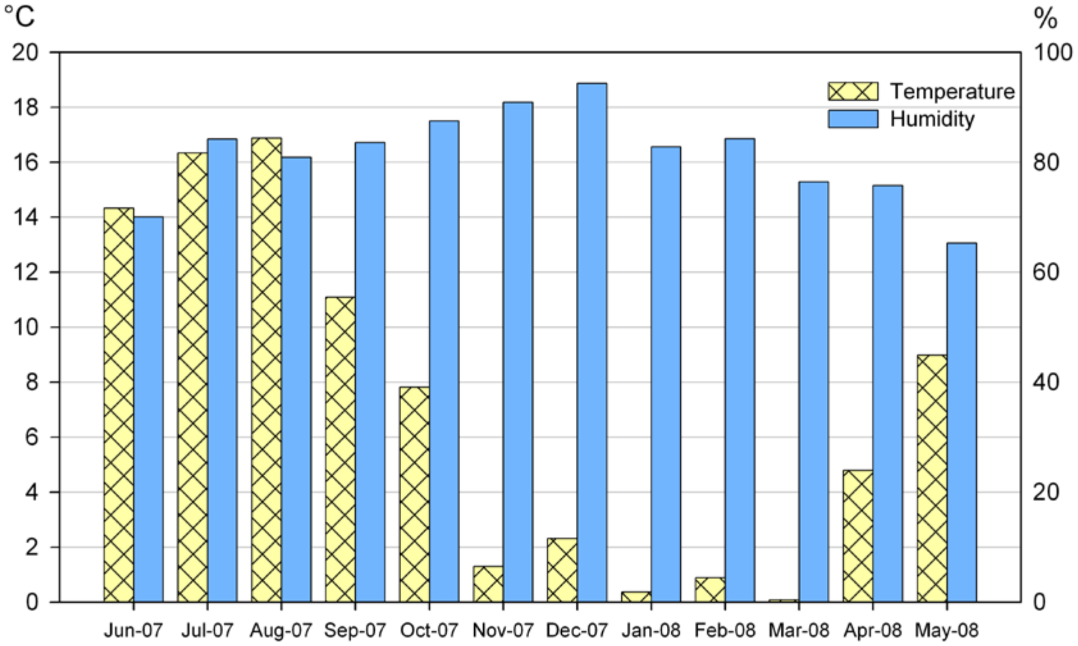

Figure 3. *Monthly mean relative humidity (%) and temperature (˚C, 2 m above ground) in FIP4 plot.*

Results of hourly and daily transpiration at stand level from June 6 2007 to June 6 2008 are not presented here, but those will be delivered in two separate files in excel format.

4. DISCUSSION

The transpiration estimates presented here have been calculated in a more accurate way when compared to the tentative results from 2007 in Hökkä (2008). The sapwood area estimates are more reliable and thus the stand level estimates should be more realistic as well. If the monthly values are considered, the presented figures are relatively low, but still in accord with those given in other studies earlier. For example, in similar conditions Cermak et al. (1995), Cienciela et al. (1997) and Lagergren & Lindroth (2002), have reported stand daily transpiration to vary between 0.3 – 2.0 mm/day, which result in a range of 9 – 60 mm of total transpiration in a 30-day (month) period. However, it should be kept in mind that in FIP4 the stand level estimate was based on two trees only until April 17, 2008. Values calculated after that date are more reliable.

The sources of errors of the method used in this study are related to the number of sample trees (among-tree variability) and the spatial variability of sap flow within the tree – both around the circumference of the sapwood, and in the different depths of the sapwood. According to Cermak et al. (1995), increasing the number of sample trees from 1 to 10 decreases the standard error in mean sap flow rate from 40% to 10%. With 3 trees the standard error still is 15-35%. Three trees give the possibility to check among-tree differences in the measured rates, and thus exclude clear measurement errors. Consequently, to increase reliability of stand level estimates, it is recommended to increase the number of sap flow sample trees.

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APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	Repeat	Date	Material	Digestion	As mg/kg dw	Cd mg/kg dw	Co mg/kg dw	Cr mg/kg dw	Cu mg/kg dw	Hg mg/kg dw	I mg/kg dw	Mn mg/kg dw	Mo mg/kg dw	Ni mg/kg dw
FIP4	1	19.9.2008	humus	HNO_3	0.385	0.257	1.670	2.160	12.8	0.192	2.39	1130		5.75
FIP4	2	19.9.2008	humus	HNO_3	0.7	0.436	1.740	2.170	14.7	0.217	2.72	1200		5.13
FIP10	1	19.9.2008	humus	HNO_3	0.559	0.573	3.090	1.200	21.4	0.320	3.91	153		7.03
FIP10	2	19.9.2008	humus	HNO_3	2.82	0.360	3.870	4.370	44.1	0.339	8.51	17.5		18.8
FIP4	1	19.9.2008	Scots pine branches c	HNO_3	<0,1	0.318	0.531	0.128	3.88		0.14	187		1.31
FIP4	1	19.9.2008	Scots pine branches c+1	HNO_3	<0,1	0.358	0.424	0.141	4.53		0.16	191		0.796
FIP4	1	19.9.2008	Scots pine buds	HNO_3	<0,1	0.151	0.275		3.24			165		4.81
FIP4	2	19.9.2008	Scots pine branches c	HNO_3	<0,1	0.221	0.462	0.084	4.85		0.12	136		1.63
FIP4	2	19.9.2008	Scots pine branches c+1	HNO_3	<0,1	0.245	0.265	0.067	4.36		0.09	189		0.703
FIP4	2	19.9.2008	Scots pine buds	HNO_3	<0,1	0.092	0.229		4.26		0.08	136		5.26
FIP4	1	19.9.2008	Scots pine needles c	HNO_3	<0,1	0.164	0.419		2.7		0.14	499		1.42
FIP4	1	19.9.2008	Scots pine needles c+1	HNO_3	<0,1	0.184	0.522	0.093	2.71	0.026	0.2	895		0.844
FIP4	2	19.9.2008	Scots pine needles c	HNO_3	<0,1	0.124	0.415		3.35		0.11	467		2.75
FIP4	2	19.9.2008	Scots pine needles c+1	HNO_3	<0,1	0.140	0.395		2.46	0.028	0.16	730		1.08
FIP10	1	19.9.2008	Norway spruce branches c	HNO_3	<0,1	0.051	0.357		3.81	<0,02	0.1	156		1.06
FIP10	1	19.9.2008	Norway spruce branches c+1	HNO_3	<0,1	0.060	0.750	0.094	4.32	<0,02	0.15	153		1.23
FIP10	2	19.9.2008	Norway spruce branches c	HNO_3	<0,1	0.043	0.249		4.09	<0,01	0.08	129		0.9
FIP10	2	19.9.2008	Norway spruce branches c+1	HNO_3	<0,1	0.066	0.437	0.086	6.5	<0,01	0.21	141		1.98
FIP10	1	19.9.2008	Norway spruce needles c	HNO_3	<0,1	0.028	0.301	<0,05	2.11		0.13	252		0.587
FIP10	1	19.9.2008	Norway spruce needles c+1	HNO_3	<0,1	0.023	0.293	<0,05	1.75	0.023	0.12	278		0.517
FIP10	2	19.9.2008	Norway spruce needles c	HNO_3	<0,1	0.030	0.297	<0,04	2.29		0.11	244		0.887
FIP10	2	19.9.2008	Norway spruce needles c+1	HNO_3	<0,1	0.024	0.283	<0,05	2.05	0.024	0.1	302		0.654
FIP4	1	19.9.2008	DRYOCART	HNO_3		1.070	1.180	0.223	6.99	0.061	0.53	3510		5.75
FIP4	2	19.9.2008	DRYOCART	HNO_3	0.206	0.617	1.300	0.145	6.06	0.059	0.418	1920		5.23
FIP10	1	19.9.2008	DRYOCART	HNO_3	0.318	0.711	1.050	0.139	4.8	0.058	0.312	1800		3.39
FIP10	2	19.9.2008	DRYOCART	HNO_3		0.503	0.658	0.089	5.56	0.059	0.415	1220		2.48
FIP10	1	19.9.2008	OXALACET	HNO_3		0.017	0.567	0.105	3.53	0.019	0.361	515		0.84
FIP4	1	19.9.2008	VACCVITI leaves c	HNO_3		0.016	0.118	0.049	3.31		0.13	2100		0.601
FIP4	1	19.9.2008	VACCVITI stems c	HNO_3		0.092	0.205	0.141	5.02		0.13	1340		1.16
FIP4	2	19.9.2008	VACCVITI leaves c	HNO_3		0.024	0.063		3.38		0.15	1890		0.387
FIP4	2	19.9.2008	VACCVITI stems c	HNO_3		0.114	0.116	0.132	3.89		0.13	943		0.641
FIP4	1	19.9.2008	VACCMYRT leaves	HNO_3		0.036	0.149	0.129	5.31	0.018	0.293	8740		1.55
FIP4	1	19.9.2008	VACCMYRT stems c	HNO_3		0.166	0.098		5.33		0.06	2850		0.781
FIP4	2	19.9.2008	VACCMYRT leaves	HNO_3		0.041	0.203	0.129	4.8	0.022	0.288	3910		1.4
FIP4	2	19.9.2008	VACCMYRT stems c	HNO_3	0.303	0.129	0.157	0.130	6.11		0.08	2330		0.793
FIP10	1	19.9.2008	VACCMYRT leaves	HNO_3		0.094	0.162	0.089	5.09	0.026	0.311	2040		1.18

APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	**Repeat**	**Date**	**Material**	**Digestion**	**As** mg/kg dw	**Cd** mg/kg dw	**Co** mg/kg dw	**Cr** mg/kg dw	**Cu** mg/kg dw	**Hg** mg/kg dw	**I** mg/kg dw	**Mn** mg/kg dw	**Mo** mg/kg dw	**Ni** mg/kg dw
FIP10	1	19.9.2008	VACCMYRT stems c	HNO_3		0.326	0.110		5.9		0.06	1790		0.621
FIP10	2	19.9.2008	VACCMYRT leaves	HNO_3		0.159	0.497	0.119	5.93	0.021	0.305	2880		1.55
FIP10	2	19.9.2008	VACCMYRT stems c	HNO_3	0.31	0.446	0.338		6.69		0.05	2020		1.16
FIP4	1	19.9.2008	mineral soil 0-10 cm	HNO_3	4.93	0.332	8.440	35.300	38	0.103	4.6			14.1
FIP4	1	19.9.2008	mineral soil 10-30 cm	HNO_3	2.55	0.077	3.830	21.900	6.42					8.87
FIP4	2	19.9.2008	mineral soil 0-10 cm	HNO_3	1.48	0.068	2.430	18.800	6.85					7.15
FIP4	2	19.9.2008	mineral soil 10-30 cm	HNO_3	2.95	0.084	3.470	21.100	7.52					8.9
FIP10	1	19.9.2008	mineral soil 0-10 cm	HNO_3	1.16		1.430	11.500	2.52		2.87			5.15
FIP10	1	19.9.2008	mineral soil 10-30 cm	HNO_3	0.673		1.490	11.000	2.25					5.04
FIP10	2	19.9.2008	mineral soil 0-10 cm	HNO_3	0.133		1.320	11.900	3.33					4.68
FIP10	2	19.9.2008	mineral soil 10-30 cm	HNO_3	0.382		1.410	9.860	2.65					4.85
FET914254	1	19.9.2008	DESCCESP	HNO_3	<0,3	0.027	0.219	0.101	8.59	0.018	0.372	116		3.89
FET914254	2	19.9.2008	DESCCESP	HNO_3	<0,3	0.024	0.175	0.168	6.36	0.021	0.374	67.9		4.24
FEH914254	1	19.9.2008	RUBUIDAE leaves	HNO_3	<0,3	0.042	0.286	0.300	9.11	0.032	0.822	194		2.22
FEH914254	2	19.9.2008	RUBUIDAE leaves	HNO_3	<0,1	0.055	0.321	0.284	7.96	0.025	0.642	235		3.52
FET914254	1	19.9.2008	Black alder branches	HNO_3	<0,1	0.037	0.388	0.060	12.3	<0,02	0.16	156		2.29
FET914254	1	19.9.2008	Black alder leaves	HNO_3	<0,1	<0,008	0.668	0.129	13.2	0.021	0.648	269		12.2
FET914254	1	19.9.2008	Black alder buds	HNO_3	<0,1	<0,008	0.451	<0,05	17.5	<0,02	<0,05	112		5.04
FET914254	2	19.9.2008	Black alder branches	HNO_3	<0,1	0.031	0.346	0.080	9.24	<0,02	0.21	109		1.28
FET914254	2	19.9.2008	Black alder leaves	HNO_3	<0,1	<0,009	0.398	0.131	10.7	0.030	0.618	121		7.39
FET914254	2	19.9.2008	Black alder buds	HNO_3	<0,1	<0,008	0.244	<0,05	13.5	<0,02	0.1	60.3		3.35
FEH914254	1	19.9.2008	humus	HNO_3	4.14	0.150	6.570	8.800	63.3	0.147	6.83	56.6		34.5
FEH914254	2	19.9.2008	humus	HNO_3	1.95	0.208	4.000	6.910	57.3	0.106	5.15	38.5		15.3
FET914254	1	19.9.2008	mineral soil 0-10 cm	HNO_3	0.656	<0,01	1.030	8.860	3.11	<0,04	<2			3.83
FET914254	1	19.9.2008	mineral soil 10-30 cm	HNO_3	1.51	0.093	1.610	11.300	4.56	<0,04	<2			5.76
FET914254	2	19.9.2008	mineral soil 0-10 cm	HNO_3	0.669	0.013	1.800	13.300	5.87	<0,04	2.22			5.96
FET914254	2	19.9.2008	mineral soil 10-30 cm	HNO_3	4.36	0.017	3.620	19.900	8.58	<0,04	<2			10.3
KK14	TR1-1A	5/5/2008	Scots pine, heart wood	HNO_3/HF									0.005	
KK14	TR1-1B	5/5/2008	Scots pine, heart wood	HNO_3/HF							0.076		0.003	
KK14	TR1	5/5/2008	Scots pine, sapwood	HNO_3/HF							0.030		0.009	
KK14	TR2	5/5/2008	Scots pine, heart wood	HNO_3/HF							0.042		0.004	
KK14	TR2	5/5/2008	Scots pine, sapwood	HNO_3/HF							0.023		0.006	
KK14	TR2	5/5/2008	Scots pine, stem bark	HNO_3/HF							0.477		0.065	
KK14	TR1	5/5/2008	Scots pine, stem bark	HNO_3/HF							0.354		0.075	
FET911275	TR5	6/5/2008	Black alder, stem wood	HNO_3/HF							0.055		0.602	
FET911275	TR6	6/5/2008	Black alder, stem wood	HNO_3/HF							0.032		0.847	

APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	Repeat	Date	Material	Digestion	As mg/kg dw	Cd mg/kg dw	Co mg/kg dw	Cr mg/kg dw	Cu mg/kg dw	Hg mg/kg dw	I mg/kg dw	Mn mg/kg dw	Mo mg/kg dw	Ni mg/kg dw
FET911275	TR6-1A	6/5/2008	Black alder, stem bark	HNO_3/HF							0.552		0.218	
FET911275	TR6-1B	6/5/2008	Black alder, stem bark	HNO_3/HF									0.238	
FET911275	TR5	6/5/2008	Black alder, stem bark	HNO_3/HF							0.715		0.308	

APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	Repeat	Date	Material	Digestion	Pb mg/kg dw	Se mg/kg dw	V mg/kg dw	Zn mg/kg dw
FIP4	1	19.9.2008	humus	HNO_3	9.57	0.315		85
FIP4	2	19.9.2008	humus	HNO_3	15.8	0.31		55.5
FIP10	1	19.9.2008	humus	HNO_3	15.3	0.28		67.4
FIP10	2	19.9.2008	humus	HNO_3	28.5	0.71		20
FIP4	1	19.9.2008	Scots pine branches c	HNO_3	0.151			35.5
FIP4	1	19.9.2008	Scots pine branches c+1	HNO_3	0.35	0.015		30.8
FIP4	1	19.9.2008	Scots pine buds	HNO_3				24.9
FIP4	2	19.9.2008	Scots pine branches c	HNO_3	0.083	0.011		28.1
FIP4	2	19.9.2008	Scots pine branches c+1	HNO_3	0.147	0.015		25.1
FIP4	2	19.9.2008	Scots pine buds	HNO_3				27.4
FIP4	1	19.9.2008	Scots pine needles c	HNO_3	0.128	0.014		31
FIP4	1	19.9.2008	Scots pine needles c+1	HNO_3	0.256	0.026		42.9
FIP4	2	19.9.2008	Scots pine needles c	HNO_3		0.018		41.6
FIP4	2	19.9.2008	Scots pine needles c+1	HNO_3	0.115	0.028		44.1
FIP10	1	19.9.2008	Norway spruce branches c	HNO_3	0.102			47.6
FIP10	1	19.9.2008	Norway spruce branches c+1	HNO_3	0.504	0.015		73
FIP10	2	19.9.2008	Norway spruce branches c	HNO_3	0.072			41
FIP10	2	19.9.2008	Norway spruce branches c+1	HNO_3	0.572	0.022		69.4
FIP10	1	19.9.2008	Norway spruce needles c	HNO_3	<0,06	<0,01		35.3
FIP10	1	19.9.2008	Norway spruce needles c+1	HNO_3	<0,07	0.01		29.9
FIP10	2	19.9.2008	Norway spruce needles c	HNO_3	<0,05	<0,01		36.3
FIP10	2	19.9.2008	Norway spruce needles c+1	HNO_3	<0,07	<0,01		32.5
FIP4	1	19.9.2008	DRYOCART	HNO_3	1.100	0.039		217
FIP4	2	19.9.2008	DRYOCART	HNO_3	0.609	0.029		149
FIP10	1	19.9.2008	DRYOCART	HNO_3	0.632	0.033		120
FIP10	2	19.9.2008	DRYOCART	HNO_3	0.386	0.026		91.2
FIP10	1	19.9.2008	OXALACET	HNO_3	0.181	0.019		20.6
FIP4	1	19.9.2008	VACCVITI leaves c	HNO_3	0.107	0.01		21.7
FIP4	1	19.9.2008	VACCVITI stems c	HNO_3	0.399	0.023		21
FIP4	2	19.9.2008	VACCVITI leaves c	HNO_3		0.012		24.3
FIP4	2	19.9.2008	VACCVITI stems c	HNO_3	0.253	0.019		19.1
FIP4	1	19.9.2008	VACCMYRT leaves	HNO_3	0.171	0.027		13.9
FIP4	1	19.9.2008	VACCMYRT stems c	HNO_3	0.106			44.2
FIP4	2	19.9.2008	VACCMYRT leaves	HNO_3	0.182	0.029		11.6
FIP4	2	19.9.2008	VACCMYRT stems c	HNO_3	0.086			31.3
FIP10	1	19.9.2008	VACCMYRT leaves	HNO_3	0.177	0.024		19.4

APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	Repeat	Date	Material	Digestion	Pb mg/kg dw	Se mg/kg dw	V mg/kg dw	Zn mg/kg dw
FIP10	1	19.9.2008	VACCMYRT stems c	HNO$_3$	0.110	0.01		52.5
FIP10	2	19.9.2008	VACCMYRT leaves	HNO$_3$	0.213	0.029		17.7
FIP10	2	19.9.2008	VACCMYRT stems c	HNO$_3$	0.068	<0,01		37
FIP4	1	19.9.2008	mineral soil 0-10 cm	HNO$_3$	25.7	0.133	40.8	89.6
FIP4	1	19.9.2008	mineral soil 10-30 cm	HNO$_3$	7.86		21.5	37.7
FIP4	2	19.9.2008	mineral soil 0-10 cm	HNO$_3$	8.62		16	27.3
FIP4	2	19.9.2008	mineral soil 10-30 cm	HNO$_3$	6.71		21.7	30.5
FIP10	1	19.9.2008	mineral soil 0-10 cm	HNO$_3$	1.69		13.5	12.2
FIP10	1	19.9.2008	mineral soil 10-30 cm	HNO$_3$	1.33		10.9	13.2
FIP10	2	19.9.2008	mineral soil 0-10 cm	HNO$_3$	2.56		9.58	12.5
FIP10	2	19.9.2008	mineral soil 10-30 cm	HNO$_3$	1.19		8.52	14.1
FET914254	1	19.9.2008	DESCCESP	HNO$_3$	0.147	0.018		17.8
FET914254	2	19.9.2008	DESCCESP	HNO$_3$	0.187	0.03		20
FEH914254	1	19.9.2008	RUBUIDAE leaves	HNO$_3$	0.305	0.032		29.1
FEH914254	2	19.9.2008	RUBUIDAE leaves	HNO$_3$	0.309	0.029		22.5
FET914254	1	19.9.2008	Black alder branches	HNO$_3$	0.184	0.01		42.8
FET914254	1	19.9.2008	Black alder leaves	HNO$_3$	0.147	0.016		34.8
FET914254	1	19.9.2008	Black alder buds	HNO$_3$	<0,06	<0,01		28.4
FET914254	2	19.9.2008	Black alder branches	HNO$_3$	0.318	0.017		31.6
FET914254	2	19.9.2008	Black alder leaves	HNO$_3$	0.154	0.018		29.1
FET914254	2	19.9.2008	Black alder buds	HNO$_3$	<0,06	<0,01		23.4
FEH914254	1	19.9.2008	humus	HNO$_3$	15	0.485		17.5
FEH914254	2	19.9.2008	humus	HNO$_3$	16.7	0.315		21
FET914254	1	19.9.2008	mineral soil 0-10 cm	HNO$_3$	2.22	<0,05	8.02	12.5
FET914254	1	19.9.2008	mineral soil 10-30 cm	HNO$_3$	2.58	<0,05	11.2	14.1
FET914254	2	19.9.2008	mineral soil 0-10 cm	HNO$_3$	3.77	<0,05	11.1	15.9
FET914254	2	19.9.2008	mineral soil 10-30 cm	HNO$_3$	6.58	<0,05	20.3	28.8
KK14	TR1-1A	5/5/2008	Scots pine, heart wood	HNO$_3$/HF		0.023		
KK14	TR1-1B	5/5/2008	Scots pine, heart wood	HNO$_3$/HF		0.027		
KK14	TR1	5/5/2008	Scots pine, sapwood	HNO$_3$/HF		0.025		
KK14	TR2	5/5/2008	Scots pine, heart wood	HNO$_3$/HF		0.004		
KK14	TR2	5/5/2008	Scots pine, sapwood	HNO$_3$/HF		0.006		
KK14	TR2	5/5/2008	Scots pine, stem bark	HNO$_3$/HF		0.026		
KK14	TR1	5/5/2008	Scots pine, stem bark	HNO$_3$/HF		0.025		
FET911275	TR5	6/5/2008	Black alder, stem wood	HNO$_3$/HF		0.006		
FET911275	TR6	6/5/2008	Black alder, stem wood	HNO$_3$/HF		0.004		

APPENDIX 4A: Additional elemental analyses on the FIP and FET plots and sample trees from KK14 pit in 2008.

Plot	Repeat	Date	Material	Digestion	Pb mg/kg dw	Se mg/kg dw	V mg/kg dw	Zn mg/kg dw
FET911275	TR6-1A	6/5/2008	Black alder, stem bark	HNO_3/HF		0.028		
FET911275	TR6-1B	6/5/2008	Black alder, stem bark	HNO_3/HF		0.027		
FET911275	TR5	6/5/2008	Black alder, stem bark	HNO_3/HF		0.032		

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	Al mg/kg dw	As µg/kg dw	Ba mg/kg dw	Be µg/kg dw	Br µg/kg dw	Ca mg/kg dw	Cd µg/kg dw	Cl mg/kg dw	Co µg/kg dw	Cr µg/kg dw
KK14		5/2008	mineral soil 10-15 cm	$HClO_4/HF$	52800	4120	464	1880		10400			10800	53800
KK14		5/2008	humus	$HClO_4/HF$	21400	2540	207			4080	770		5030	21800
KK14		5/2008	mineral soil 10-15 cm	HNO_3/H_2O_2										
KK14		5/2008	humus	HNO_3/H_2O_2										
MRK1	1A	9/2011	humus	NH_4Ac	349	125	11.3	32.8		2032	303		809	880
MRK1	1B	9/2011	humus	NH_4Ac	361	136	12.5	38.8	751	2050	334	89.6	777	797
MRK3		9/2011	humus	NH_4Ac	438	93	11.0	69.3	734	1200	437	105.1	884	835
MRK5		9/2011	humus	NH_4Ac	166	74.5	16.5	19.8	555	3160	338	120.6	1016	464
MRK8		9/2011	humus	NH_4Ac	19	72.2	30.9	4.8	728	5327	503	141.7	525	58.2
MRK1	1A	9/2011	humus	HNO_3/HF	10378	4306	79.3	383.0		4426	507		3806	16753
MRK1	1B	9/2011	humus	HNO_3/HF	6512	4844	52.8	266.0	8956	3034	376	189.6	2491	10936
MRK3		9/2011	humus	HNO_3/HF	9680	2811	75.4	573.0	9713	3165	718	189.7	3532	12473
MRK5		9/2011	humus	HNO_3/HF	11210	1734	98.1	344.0	3169	6668	488	136.2	5235	20537
MRK8		9/2011	humus	HNO_3/HF	3127	1437	124.1	123.0	6707	10127	872	156.8	2602	4253
MRK1	1A	9/2011	mineral soil 0-30 cm	NH_4Ac	469	154	5.1	44.1		256	70		214	1275
MRK1	1B	9/2011	mineral soil 0-30 cm	NH_4Ac	495	140	5.7	41.8	466	276	66	14.6	247	1421
MRK3		9/2011	mineral soil 0-30 cm	NH_4Ac	342	68.8	3.1	51.1	283	56	42	11.6	131	715
MRK5		9/2011	mineral soil 0-30 cm	NH_4Ac	319	96.2	4.3	17.7	303	104	32	4.9	92	611
MRK8		9/2011	mineral soil 0-30 cm	NH_4Ac	222	85.4	6.9	38.4	478	806	158	9.4	1096	643
MRK1	1A	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)		1397					123		3011	
MRK1	1B	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	53112	1372	377.2	1304	2266	5927	119	43.0	2883	103587
MRK3		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	52019	675	479.1	1123	1151	4830	100	29.9	2270	77691
MRK5		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	48616	619	402.6	961	702	3740	58	22.3	2530	113410
MRK8		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	59422	1864	370.6	1554	6689	4910	299	27.4	7287	115022
MRK1	1A	3/2010	Scots pine needles c	HNO_3/HF	223	23.7	0.596	1.9		3118	137		181	141
MRK1	1B	3/2010	Scots pine needles c	HNO_3/HF	237	22.6	0.588	1.9	268	3239	132	109.7	191	168
MRK1	2	3/2010	Scots pine needles c	HNO_3/HF	254	34.6	0.691	2.6	341	3530	127	142.1	295	137
MRK1	3	3/2010	Scots pine needles c	HNO_3/HF	200	25.6	0.528	1.7	284	2582	86	134.8	120	242
MRK3	1	3/2010	Scots pine needles c	HNO_3/HF	259	22	0.442	4.7	302	1602	89	141.6	447	83.1
MRK3	2	3/2010	Scots pine needles c	HNO_3/HF	253	28.7	1.291	6.8	440	2573	121	120.2	351	130
MRK3	3	3/2010	Scots pine needles c	HNO_3/HF	407	70.6	0.624	4.1	236	2252	98	135.0	255	93.6
MRK4	1	3/2010	Scots pine needles c	HNO_3/HF	215	41.7	1.207	2.3	358	2896	157	109.5	383	93.1
MRK4	2	3/2010	Scots pine needles c	HNO_3/HF	155	61.3	2.166	3.6	2938	3059	182	83.0	480	40.2
MRK4	3	3/2010	Scots pine needles c	HNO_3/HF	212	21.8	0.872	2.1	527	2182	101	98.3	211	34.4
MRK5	1	3/2010	Norway spruce needles c	HNO_3/HF	54	13.1	19.4	5.0	230	5491	26	75.3	101	132
MRK5	2	3/2010	Norway spruce needles c	HNO_3/HF	44	8.85	21.4	3.7	153	5593	32	68.9	99	73.1

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

					Al	As	Ba	Be	Br	Ca	Cd	Cl	Co	Cr
Plot	**Repeat**	**Date**	**Material**	**Digestion**	mg/kg dw	µg/kg dw	mg/kg dw	µg/kg dw	µg/kg dw	mg/kg dw	µg/kg dw	mg/kg dw	µg/kg dw	µg/kg dw
MRK5	3	3/2010	Norway spruce needles c	HNO_3/HF	51	15.3	40.1	2.8	240	6871	55	85.3	131	65.8
MRK6	1	3/2010	Norway spruce needles c	HNO_3/HF	41	14.9	24.5	2.7	182	5860	79	75.4	496	109
MRK6	2	3/2010	Norway spruce needles c	HNO_3/HF	45	15.9	15.8	3.4	123	5737	54	93.6	433	118
MRK6	3	3/2010	Norway spruce needles c	HNO_3/HF	50	16.7	16.9	4.4	269	3993	42	78.9	469	143
MRK8	1	3/2010	Norway spruce needles c	HNO_3/HF	30	15.7	48.3	2.3	286	5172	118	92.1	472	57.9
MRK8	2	3/2010	Norway spruce needles c	HNO_3/HF	35	16.3	26.9	1.7	342	3541	101	109.9	331	76
MRK8	3	3/2010	Norway spruce needles c	HNO_3/HF	39	17.1	36.0	1.8	462	7196	46	137.6	258	68.1
MRK10	1	3/2010	Norway spruce needles c	HNO_3/HF	21	10.8	15.1	1.2	178	4120	51	156.2	297	35.1
MRK10	2	3/2010	Norway spruce needles c	HNO_3/HF	20	10.8	9.6	2.1	287	3950	24	185.1	200	59.3
MRK10	3	3/2010	Norway spruce needles c	HNO_3/HF	28	12.6	31.1	2.8	295	4306	33	187.3	170	40.3

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	Cs	Cu	Fe	I	K	Li	Mg	Mn	Mo	Na
					µg/kg dw	mg/kg dw	mg/kg dw	µg/kg dw	mg/kg dw	µg/kg dw	mg/kg dw	mg/kg dw	µg/kg dw	mg/kg dw
KK14		5/2008	mineral soil 10-15 cm	$HClO_4$/HF		19.2	24900		21900	23800	7430	510	720	13900
KK14		5/2008	humus	$HClO_4$/HF		65.0			9040		1380	103	1220	
KK14		5/2008	mineral soil 10-15 cm	HNO_3/H_2O_2				967						
KK14		5/2008	humus	HNO_3/H_2O_2				12600						
MRK1	1A	9/2011	humus	NH_4Ac	5	0.6	711		565	61	745	118	3	122
MRK1	1B	9/2011	humus	NH_4Ac	6	0.5	696	233	640	73	780	116	4	130
MRK3		9/2011	humus	NH_4Ac	9	0.6	531	232	424	80	547	38	5	196
MRK5		9/2011	humus	NH_4Ac	9	0.5	73.7	170	1105	139	843	962	2	35
MRK8		9/2011	humus	NH_4Ac	52	0.3	8.7	186	1273	71	771	429	0	69
MRK1	1A	9/2011	humus	HNO_3/HF	1219	30.1	15430		2484	3209	1951	183	974	705
MRK1	1B	9/2011	humus	HNO_3/HF	785	19.0	9861	10122	1678	2229	1258	120	672	431
MRK3		9/2011	humus	HNO_3/HF	913	28.1	8919	9220	2103	2395	1223	82	853	761
MRK5		9/2011	humus	HNO_3/HF	2441	24.9	10761	5116	3866	7198	3721	1311	698	773
MRK8		9/2011	humus	HNO_3/HF	434	25.6	2709	7975	2527	1037	1286	564	743	577
MRK1	1A	9/2011	mineral soil 0-30 cm	NH_4Ac	28	0.7	847		67	91	109	4.7	8	24
MRK1	1B	9/2011	mineral soil 0-30 cm	NH_4Ac	28	0.9	906	218	70	81	113	5.1	3	25
MRK3		9/2011	mineral soil 0-30 cm	NH_4Ac	35	0.5	209	120	29	74	27	0.6	2	18
MRK5		9/2011	mineral soil 0-30 cm	NH_4Ac	25	0.3	411	158	37	72	47	6.3	1	6
MRK8		9/2011	mineral soil 0-30 cm	NH_4Ac	41	1.4	337	434	53	93	174	23.5	1	16
MRK1	1A	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)		9.9				12780			276	
MRK1	1B	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	4207	9.6	18497	1587	20802	12468	4054	225	245	11345
MRK3		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	4162	8.6	14207	740	28665	10037	3359	198	209	13450
MRK5		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	3721	4.0	15317	528	24403	10626	3291	171	112	11509
MRK8		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	5370	21.7	22103	2861	31216	23172	5423	266	313	9621
MRK1	1A	3/2010	Scots pine needles c	HNO_3/HF	72	2.4	45.0		5243	97	1075	637	37	42
MRK1	1B	3/2010	Scots pine needles c	HNO_3/HF	70	2.7	49.0	188	5669	101	1074	662	37	43
MRK1	2	3/2010	Scots pine needles c	HNO_3/HF	73	2.9	60.2	177	5019	121	1071	543	82	72
MRK1	3	3/2010	Scots pine needles c	HNO_3/HF	89	2.0	49.7	152	5255	71	935	458	53	37
MRK3	1	3/2010	Scots pine needles c	HNO_3/HF	117	2.2	77.7	162	4695	147	909	119	36	68
MRK3	2	3/2010	Scots pine needles c	HNO_3/HF	81	2.2	91.9	219	6239	282	770	225	21	99
MRK3	3	3/2010	Scots pine needles c	HNO_3/HF	82	2.7	79.7	243	5742	174	850	226	38	98
MRK4	1	3/2010	Scots pine needles c	HNO_3/HF	48	2.2	43.9	151	5685	103	746	397	24	106
MRK4	2	3/2010	Scots pine needles c	HNO_3/HF	38	2.9	44.1	145	6685	131	1124	407	48	167
MRK4	3	3/2010	Scots pine needles c	HNO_3/HF	43	2.2	35.4	142	5280	81	785	330	48	79
MRK5	1	3/2010	Norway spruce needles c	HNO_3/HF	74	1.5	31.4	93	6457	904	1088	523	25	118
MRK5	2	3/2010	Norway spruce needles c	HNO_3/HF	195	1.6	27.1	89.2	6535	411	1186	635	17	77

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	**Repeat**	**Date**	**Material**	**Digestion**	**Cs** μg/kg dw	**Cu** mg/kg dw	**Fe** mg/kg dw	**I** μg/kg dw	**K** mg/kg dw	**Li** μg/kg dw	**Mg** mg/kg dw	**Mn** mg/kg dw	**Mo** μg/kg dw	**Na** mg/kg dw
MRK5	3	3/2010	Norway spruce needles c	HNO_3/HF	189	1.6	29.3	84	6723	834	1150	703	14	55
MRK6	1	3/2010	Norway spruce needles c	HNO_3/HF	213	1.8	27.2	94.2	6559	213	1130	269	19	156
MRK6	2	3/2010	Norway spruce needles c	HNO_3/HF	163	1.8	28.8	83.7	5744	1118	1041	316	14	47
MRK6	3	3/2010	Norway spruce needles c	HNO_3/HF	197	1.8	34.7	97.5	6709	410	1082	175	17	103
MRK8	1	3/2010	Norway spruce needles c	HNO_3/HF	87	1.8	26.5	83.1	5769	332	884	518	16	89
MRK8	2	3/2010	Norway spruce needles c	HNO_3/HF	114	1.7	34.4	95	7464	460	854	403	15	143
MRK8	3	3/2010	Norway spruce needles c	HNO_3/HF	104	1.6	32.7	127	5724	391	1205	577	13	96
MRK10	1	3/2010	Norway spruce needles c	HNO_3/HF	139	1.7	21.9	99.7	7830	172	969	207	47	79
MRK10	2	3/2010	Norway spruce needles c	HNO_3/HF	83	1.7	21.8	82.8	6651	189	949	199	20	123
MRK10	3	3/2010	Norway spruce needles c	HNO_3/HF	359	1.7	28.8	85.1	6860	229	1187	206	30	112

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	Nb µg/kg dw	Ni mg/kg dw	P mg/kg dw	Pb µg/kg dw	Pd µg/kg dw	S mg/kg dw	Se µg/kg dw	Si mg/kg dw	Sn µg/kg dw	Sr mg/kg dw
KK14		5/2008	mineral soil 10-15 cm	$HClO_4$/HF		25.1	524	16300					2200	139
KK14		5/2008	humus	$HClO_4$/HF		16.1	965	52800		957				59.5
KK14		5/2008	mineral soil 10-15 cm	HNO_3/H_2O_2							113			
KK14		5/2008	humus	HNO_3/H_2O_2							696			
MRK1	1A	9/2011	humus	NH_4Ac	14	1.3	30	10072	<4.24	108	26	52	6	7.0
MRK1	1B	9/2011	humus	NH_4Ac	16	1.2	30	11160	<5.12	103	28	51	6	8.3
MRK3		9/2011	humus	NH_4Ac	12	1.5	33	9473	<8.54	103	14	48	4	6.2
MRK5		9/2011	humus	NH_4Ac	34	1.2	72	8467	<2.36	140	18	66	1	8.6
MRK8		9/2011	humus	NH_4Ac	3	0.6	316	6370	<2.14	154	18	67	1	24.7
MRK1	1A	9/2011	humus	HNO_3/HF	1663	15.1	1348	52006	<52.4	2101	647	1809	396	25.5
MRK1	1B	9/2011	humus	HNO_3/HF	1160	9.9	878	35290	<38.2	1364	635	1174	282	17.1
MRK3		9/2011	humus	HNO_3/HF	1292	13.6	1157	48920	<68.2	2044	771	2451	169	21.5
MRK5		9/2011	humus	HNO_3/HF	2663	14.2	1292	30013	<32.2	1508	337	1896	688	27.6
MRK8		9/2011	humus	HNO_3/HF	507	9.4	1294	30699	<12.82	2338	683	2687	683	59.8
MRK1	1A	9/2011	mineral soil 0-30 cm	NH_4Ac	33.7	0.7	26	4110	<2.86	22	10	14	29	1.5
MRK1	1B	9/2011	mineral soil 0-30 cm	NH_4Ac	34.7	0.9	27	4228	<2.58	30	27	19	13	1.5
MRK3		9/2011	mineral soil 0-30 cm	NH_4Ac	16.4	0.5	14	1241	<2.68	11	0	10	8	0.6
MRK5		9/2011	mineral soil 0-30 cm	NH_4Ac	23.8	0.4	47	2916	<1.554	11	0	13	36	0.7
MRK8		9/2011	mineral soil 0-30 cm	NH_4Ac	13.4	1.0	8	2427	<4.68	15	31	16	13	3.8
MRK1	1A	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)		10.6		10078	<39.8	313	333		292	
MRK1	1B	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	6413	10.1	468	8756	<33.8	317	319	326209	268	109
MRK3		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	5398	7.4	473	4895	<33.2	217	0	408262	282	117
MRK5		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	4491	8.7	400	5829	<32.2	46	0	361290	400	95.4
MRK8		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	7369	21.7	502	8055	<44.6	312	84	371964	562	91.7
MRK1	1A	3/2010	Scots pine needles c	HNO_3/HF	5.1	0.8	1336	133	<0.1536	935	11	277	5	1.3
MRK1	1B	3/2010	Scots pine needles c	HNO_3/HF	5.1	1.0	1470	134	<0.1886	964	12	295	4	1.3
MRK1	2	3/2010	Scots pine needles c	HNO_3/HF	5.4	1.0	1482	135	<0.274	1076	25	663	9	1.8
MRK1	3	3/2010	Scots pine needles c	HNO_3/HF	3.7	1.0	1471	95.6	-0.1914	927	14	404	4	1.3
MRK3	1	3/2010	Scots pine needles c	HNO_3/HF	6.5	2.0	1483	125	<0.1802	967	19	1391	7	0.7
MRK3	2	3/2010	Scots pine needles c	HNO_3/HF	11.2	1.6	1380	112	<0.35	849	21	443	13	2.5
MRK3	3	3/2010	Scots pine needles c	HNO_3/HF	8.3	1.0	1553	149	<0.254	971	11	428	13	1.5
MRK4	1	3/2010	Scots pine needles c	HNO_3/HF	3.7	1.3	1328	104	<0.248	799	20	567	9	3.1
MRK4	2	3/2010	Scots pine needles c	HNO_3/HF	3.5	1.5	1404	530	<0.37	868	8	522	66	4.9
MRK4	3	3/2010	Scots pine needles c	HNO_3/HF	2.4	1.3	1328	66.6	<0.1796	784	16	376	32	2.2
MRK5	1	3/2010	Norway spruce needles c	HNO_3/HF	4.6	1.1	1389	54.4	<0.502	618	11	2919	10	10.7
MRK5	2	3/2010	Norway spruce needles c	HNO_3/HF	3.7	1.1	1669	41.9	<0.526	786	6	2183	11	11.1

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	Nb µg/kg dw	Ni mg/kg dw	P mg/kg dw	Pb µg/kg dw	Pd µg/kg dw	S mg/kg dw	Se µg/kg dw	Si mg/kg dw	Sn µg/kg dw	Sr mg/kg dw
MRK5	3	3/2010	Norway spruce needles c	HNO_3/HF	3.8	1.1	1692	49.4	<0.666	783	6	2471	12	13.2
MRK6	1	3/2010	Norway spruce needles c	HNO_3/HF	4.2	0.8	1207	53.8	<0.768	730	3	1761	5	15.2
MRK6	2	3/2010	Norway spruce needles c	HNO_3/HF	3.9	1.3	1408	46.7	<0.692	836	4	1928	9	13.3
MRK6	3	3/2010	Norway spruce needles c	HNO_3/HF	5.7	1.2	1239	53.1	<0.56	707	11	1541	8	11.7
MRK8	1	3/2010	Norway spruce needles c	HNO_3/HF	2.4	0.8	1404	43.4	<1.008	741	7	1542	5	19.7
MRK8	2	3/2010	Norway spruce needles c	HNO_3/HF	5.5	0.7	1543	60.9	<0.742	687	9	1499	11	13.2
MRK8	3	3/2010	Norway spruce needles c	HNO_3/HF	4.6	1.2	1412	53.8	<1.04	746	6	2827	7	22.0
MRK10	1	3/2010	Norway spruce needles c	HNO_3/HF	1.6	0.7	1245	34.4	<1.24	733	8	3171	2	23.7
MRK10	2	3/2010	Norway spruce needles c	HNO_3/HF	1.9	0.8	1080	39.7	<0.878	687	8	2506	2	18.5
MRK10	3	3/2010	Norway spruce needles c	HNO_3/HF	2.3	1.0	1302	41.4	<0.64	752	6	3130	2	14.6

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	Ti mg/kg dw	U µg/kg dw	V µg/kg dw	Zn mg/kg dw
KK14		5/2008	mineral soil 10-15 cm	$HClO_4$/HF	3250		57800	58.7
KK14		5/2008	humus	$HClO_4$/HF	752		14800	
KK14		5/2008	mineral soil 10-15 cm	HNO_3/H_2O_2				
KK14		5/2008	humus	HNO_3/H_2O_2				
MRK1	1A	9/2011	humus	NH_4Ac	1.6	446	391	33.7
MRK1	1B	9/2011	humus	NH_4Ac	1.6	495	395	32.2
MRK3		9/2011	humus	NH_4Ac	1.6	1073	281	20.8
MRK5		9/2011	humus	NH_4Ac	1.4	259	273	55.5
MRK8		9/2011	humus	NH_4Ac	0.2	138	75	40.2
MRK1	1A	9/2011	humus	HNO_3/HF	385	2203	19226	96.8
MRK1	1B	9/2011	humus	HNO_3/HF	257	1494	12717	65.8
MRK3		9/2011	humus	HNO_3/HF	207	3912	12360	61.8
MRK5		9/2011	humus	HNO_3/HF	786	1370	24425	137
MRK8		9/2011	humus	HNO_3/HF	142	1067	8284	123
MRK1	1A	9/2011	mineral soil 0-30 cm	NH_4Ac	4.4	335	583	4.1
MRK1	1B	9/2011	mineral soil 0-30 cm	NH_4Ac	4.6	349	602	4.1
MRK3		9/2011	mineral soil 0-30 cm	NH_4Ac	1.7	435	280	2.9
MRK5		9/2011	mineral soil 0-30 cm	NH_4Ac	3.0	63	314	2.8
MRK8		9/2011	mineral soil 0-30 cm	NH_4Ac	1.7	1549	333	3.7
MRK1	1A	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)				31.4
MRK1	1B	9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	2008	2741	32990	31.3
MRK3		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	1580	3660	27274	25.4
MRK5		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	1132	1754	25324	29.0
MRK8		9/2011	mineral soil 0-30 cm	HNO_3/HF ($LiBO_2$)	1717	4564	36537	62.1
MRK1	1A	3/2010	Scots pine needles c	HNO_3/HF	3.0	2	72	41.2
MRK1	1B	3/2010	Scots pine needles c	HNO_3/HF	2.9	2	77	42.4
MRK1	2	3/2010	Scots pine needles c	HNO_3/HF	2.7	3	71	38.4
MRK1	3	3/2010	Scots pine needles c	HNO_3/HF	2.8	1	53	31.3
MRK3	1	3/2010	Scots pine needles c	HNO_3/HF	4.6	3	105	31.4
MRK3	2	3/2010	Scots pine needles c	HNO_3/HF	7.9	6	159	30.5
MRK3	3	3/2010	Scots pine needles c	HNO_3/HF	5.4	4	133	31.8
MRK4	1	3/2010	Scots pine needles c	HNO_3/HF	2.4	3	62	33.0
MRK4	2	3/2010	Scots pine needles c	HNO_3/HF	2.1	2	42	43.9
MRK4	3	3/2010	Scots pine needles c	HNO_3/HF	1.5	2	36	31.5
MRK5	1	3/2010	Norway spruce needles c	HNO_3/HF	1.9	3	44	55.6
MRK5	2	3/2010	Norway spruce needles c	HNO_3/HF	1.5	2	33	53.3

APPENDIX 4B: Additional elemental analyses on the MRK plots and soil of KK14 during 2008-2011.

Plot	Repeat	Date	Material	Digestion	**Ti** mg/kg dw	**U** µg/kg dw	**V** µg/kg dw	**Zn** mg/kg dw
MRK5	3	3/2010	Norway spruce needles c	HNO_3/HF	1.7	2	40	58.3
MRK6	1	3/2010	Norway spruce needles c	HNO_3/HF	1.7	3	38	33.3
MRK6	2	3/2010	Norway spruce needles c	HNO_3/HF	1.7	4	37	35.8
MRK6	3	3/2010	Norway spruce needles c	HNO_3/HF	2.5	4	53	27.5
MRK8	1	3/2010	Norway spruce needles c	HNO_3/HF	1.0	2	27	38.2
MRK8	2	3/2010	Norway spruce needles c	HNO_3/HF	3.1	3	47	37.2
MRK8	3	3/2010	Norway spruce needles c	HNO_3/HF	2.7	2	41	53.2
MRK10	1	3/2010	Norway spruce needles c	HNO_3/HF	0.8	2	22	30.7
MRK10	2	3/2010	Norway spruce needles c	HNO_3/HF	0.9	3	25	29.0
MRK10	3	3/2010	Norway spruce needles c	HNO_3/HF	2.5	2	22	23.6

APPENDIX 5

DATA. Weather observations in a forest stand

WOM 2

Science	ENVI
Method Categories	Vegetation inventories
Method	WOM2,Weather Observation Mast 2
Description	Posiva Oy Memo POS-003125, Posiva WR 2009-45
Target type	Weather mast
Target	WOM2
Processing stage	MEAS
Subtext files	
Method variables	Date Channel1 Soil temperature -30 cm °C (not in use 2012-) Channel2 Soil temperature -40 cm °C Channel3 Soil temperature -50 cm °C Channel4 Soil temperature -60 cm °C Channel5 Soil temperature -70 cm °C Channel6 Soil temperature -80 cm °C Channel7 Soil temperature -90 cm °C Channel8 Battery voltageV Channel9 Soil temperature -10 cm 1 °C Channel10 Soil temperature -10 cm 2 °C Channel11 Soil temperature -10 cm 3 °C Channel12 Soil temperature -20 cm 1 °C Channel13 Soil temperature -20 cm 2 °C Channel14 Soil temperature -20 cm 3 °C Channel15 Temperature (inside crown), 9 m (mean) °C Channel16 Temperature (top of mast), 24 m (mean) °C Channel17 Girth Band 1, tree No. 395 mm Channel18 Girth Band 2, tree No. 93 mm Channel19 Temperature, 2 m°C Channel20 Proportional humidity, 2 m % Channel21 Air pressure, 2m hPa Channel25 PAR-radiation, 24 m (mean) µmol s^{-1} m^{-2} Channel26 Total radiation, 24 m (mean) W m^{-2} Channel27 Proportional humidity, 9 m (mean) % Channel28 Wind direction, 24 m (mean) ° Channel29 Wind speed, 24 m (mean) m/s Channel30 Soil moisture –20 cm 1, % Channel31 Soil moisture –20 cm 2, % Channel32 Rain mm Channel33 Temperature (inside crown), 9 m (min) °C Channel34 Temperature (inside crown), 9 m (max) °C Channel35 Temperature (top of mast), 24 m (min) °C Channel36 Temperature (top of mast), 24 m (max) °C Channel37 PAR-radiation, 24 m (min) µmol s^{-1} m^{-2}

	Channel38 PAR-radiation, 24 m (max) μmol s^{-1} m^{-2} Channel39 Total radiation, 24 m (min) W m^{-2} Channel40 Total radiation, 24 m (max) W m^{-2} Channel41 Proportional humidity, 9 m (min) % Channel42 Proportional humidity, 9 m (max) % Channel43 Wind direction, 24 m (min) ° Channel44 Wind direction, 24 m (max) ° Channel45 Wind speed, 24 m (min) m/s Channel46 Wind speed, 24 m (max) m/s Channel22 Soil temperature -30 cm °C
Method parametes	Document reference

WOM 3

Science	ENVI
Method Categories	Vegetation inventories
Method	WOM3, Weather Observation Mast 3
Description	Posiva WR 2009-45
Target type	Weather mast
Target	WOM3
Processing stage	MEAS
Subtext files	
Method variables	Date Channel1 Soil temperature -30 cm (°C) Channel2 Soil temperature -40 cm (°C) Channel3 Soil temperature -50 cm (°C) Channel4 Soil temperature -60 cm (°C) Channel5 Soil temperature -70 cm (°C) Channel6 Soil temperature -80 cm (°C) Channel7 Soil temperature -90 cm (°C) Channel8 Battery voltage (V) Channel9 Soil temperature -10 cm 1 (°C) Channel10 Soil temperature -10 cm 2 (°C) Channel11 Soil temperature -10 cm 3 (°C) Channel12 Soil temperature -20 cm 1 (°C) Channel13 Soil temperature -20 cm 2 (°C) Channel14 Soil temperature -20 cm 3 (°C) Channel17 Girth Band 1, tree No. 29 (mm) Channel18 Girth Band 2, tree No. 119 (mm) Channel19 Temperature, 2 m (°C) Channel20 Proportional humidity, 2 m (%) Channel30 Soil moisture –20 cm 1 (%) Channel31 Soil moisture –20 cm 2 (%) Channel32 Rain (mm)
Method parametes	Document reference

WOM4

Science	ENVI
Method Categories	Vegetation inventories
Method	WOM4, Weather Observation Mast 4
Description	Posiva WR 2009-45
Target type	Weather mast
Target	WOM4
Processing stage	MEAS
Subtext files	
Method variables	Date Channel1 Soil temperature -30 cm (°C) Channel2 Soil temperature -40 cm (°C) Channel3 Soil temperature -50 cm (°C) Channel4 Soil temperature -60 cm (°C) Channel5 Soil temperature -70 cm (°C) Channel6 Soil temperature -80 cm (°C) Channel7 Soil temperature -90 cm (°C) Channel8 Battery voltage (V) Channel1B Soil temperature -10 cm 1 (°C) Channel2B Soil temperature -10 cm 2 (°C) Channel3B Soil temperature -10 cm 3 (°C) Channel4B Soil temperature -20 cm 1 (°C) Channel5B Soil temperature -20 cm 2 (°C) Channel6B Soil temperature -20 cm 3 (°C) Channel7B Soil moisture –20 cm 1 (%) Channel8B Soil moisture –20 cm 2 (%) Channel1C Temperature, 2 m (°C) Channel6C Channel7C Proportional humidity, 2 m (%) Channel8C Rain (mm)
Method parametes	Document reference

WOM5

Science	ENVI
Method Categories	Vegetation inventories
Method	WOM5, Weather Observation Mast 5
Description	Posiva WR 2009-45
Target type	Weather mast
Target	WOM5
Processing stage	MEAS
Subtext files	
Method variables	Date Channel1 Soil temperature -30 cm (°C) Channel2 Soil temperature -40 cm (°C) Channel3 Soil temperature -50 cm (°C) Channel4 Soil temperature -60 cm (°C) Channel5 Soil temperature -70 cm (°C) Channel6 Soil temperature -80 cm (°C) Channel7 Soil temperature -90 cm (°C) Channel8 Battery voltage (V) Channel1B Soil temperature -10 cm 1 (°C) Channel2B Soil temperature -10 cm 2 (°C) Channel3B Soil temperature -10 cm 3 (°C) Channel4B Soil temperature -20 cm 1 (°C) Channel5B Soil temperature -20 cm 2 (°C) Channel6B Soil temperature -20 cm 3 (°C) Channel7B Soil moisture -20 cm 1 (%) Channel8B Soil moisture -20 cm 2 (%) Channel1C Temperature, 2 m (°C) Channel7C Proportional humidity, 2 m (%)
Method parametes	Document reference

DATA. Wet deposition analysis

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Wet deposition analysis
Description	Posiva WR 2009-45
Target type	Wet deposition monitoring plot
Target	MRKgroup
Processing stage	MEAS
Subtext files	
Method variables	Lab ID Plot Type Sampling date Amount (l/m2 = mm) pH Alkalinity (mmol/l) H+ (mg/l) Conductivity (µS/cm) Conductivity_ctrl DOC (mg/l) DOC_ctrl TOT-N (mg/l) TOT-N_ctrl NH4-N (mg/l) NH4-N_ctrl NO3-N (mg/l) NO3-N_ctrl Ca (mg/l) Ca_ctrl Mg (mg/l) Mg_ctrl K (mg/l) K_ctrl Na (mg/l) Na_ctrl PO4-P (mg/l) PO4-P_ctrl SO4-S (mg/l) SO4-S_ctrl Cl (mg/l) Cl_ctrl Al (mg/l) Al_ctrl Fe (mg/l)

	Fe_ctrl Mn (mg/l) Mn_ctrl Cu (mg/l) Cu_ctrl Zn (mg/l) Zn_ctrl Si (mg/l) Si_ctrl Notes B (mg/l) B_ctrl Cd (mg/l) Cd_ctrl Cr (mg/l) Cr_ctrl Ni (mg/l) Ni_ctrl P (mg/l) P_ctrl Pb (mg/l) Pb_ctrl S (mg/l) S_ctrl Ba (mg/l) Ba_ctrl Nb (mg/l) Nb_ctrl Pd (mg/l) Pd_ctrl Sn (mg/l) Sn_ctrl Sr (mg/l) Sr_ctrl Ta (mg/l) Ta_ctrl Te (mg/l) Te_ctrl V (mg/l) V_ctrl W (mg/l) W_ctrl
Method parametes	

DATA. Forest inventory: tree measurements

Science	ENVI
Method Categories	Vegetation inventories
Method	Forest inventory: tree measurements (FET)
Description	FET: Posiva WR 2005-39, p. 7-9
Target type	Forest extensive monitoring plot
Target	FETgroup
Processing stage	MEAS
Subtext files	VMI9.pdf
Method variables	FET/ FIP ID Tree ID TR-1 Subplot OA-1 (compartment number) Zone ID MZ-1 (radius of tree measurement plot, m) New center distance m New center direction 0-360 Degrees Tree distance cm (from new center) Tree direction 0-360 Degrees (from new center) Tree Northing N & m (-) & - & 6780000 & 6799000 Tree Easting N & m (-) & - & 15200000 & 15300000 Tree species (class: 1=Scots pine, 2=Norway spruce, 3=silver birch, 4=downy birch, 5=aspen, 6=grey alder, 7=black alder, 8=rowan, 9=goat willow …… etc) Diameter at a height of 1.3m (mm) Tree class (class) Tree class extension (class) Crown layer (class) Age (for sample trees, y) Age_ctrl Mode of regeneration (for sample trees) Upper diameter (at 6.0m, cm of trees over 8m in height (for sample trees)) Upper diameter_ctrl Dead branch limit (for sample trees) (dm) Dead branch limit_ctrl Lower limit of living crown (for sample trees) (dm) Lower limit of living crown_ctrl Height (dm, for sample trees) Height_ctrl Length of broken stem (for sample trees) (dm) Damage symptoms (for sample trees) Damage symptoms_ctrl Time of damage occurrence (for sample trees) (y) Time of damage occurrence_ctrl Cause of damage (for sample trees) Degree of damage (for sample trees) Surveyor Date of inventory
Method parametes	Classification system Document reference Measured by Time

Science	ENVI
Method Categories	Vegetation inventories
Method	Forest inventory: tree measurements (FIP/MRK)
Description	MRK: Lindroos et al. 2008 (Kronodoc POS-003852); FIP: Aro 2006 (Kronodoc POS-003125)
Target type	Forest intensive monitoring plot, Wet deposition monitoring plot
Target	FIP MRK
Processing stage	MEAS
Subtext files	VMI9.pdf
Method variables	FIP/MRK ID Tree ID TR-1 Subplot OA-1 (compartment number) Zone ID MZ-1 (radius of tree measurement plot, m) Tree distance cm (from center) Tree direction 0-360 Degrees (from center) (Tree Northing N & m (-) & - & 6780000 & 6799000 Tree Easting N & m (-) & - & 15200000 & 15300000 Tree species (class: 1=Scots pine, 2=Norway spruce, 3=silver birch, 4=downy birch, 5=aspen, 6=grey alder, 7=black alder, 8…. as agreed) Crown layer (class) Tree group (class) D_1.3_1 D_1.3_2 Technical quality (class) Lower limit of living crown (dm) Height (dm) Damage symptoms (class) Time of damage occurrence Cause of damage (class) Degree of damage (class) Surveyor Date of inventory Sample tree
Method parametes	Classification system Document reference Measured by Time

Science	ENVI
Method Categories	Vegetation inventories
Method	Forest inventory: tree measurements (WOM1)
Description	WOMpuustoinv_ohje2011.doc / 16.3.2011 / L. Aro
Target type	Weather mast
Target	WOM1
Processing stage	MEAS
Subtext files	VMI9.pdf, MT257
Method variables	OBS ID Measurement line Line direction (from WOM1, /360°) Plot Tree species Tree species in Finnish Height (dm) Plot mean height (dm) Surveyor Date of inventory Comments Photo
Method parametes	Classification system

DATA. Forest inventory by plots: plot characteristics

Science	ENVI
Method Categories	Vegetation inventories
Method	Forest inventory by plots: plot characteristics
Description	
Target type	Forest extensive monitoring plot
Target	FETgroup
Processing stage	MEAS
Subtext files	
Method variables	FET ID Subplot Sample trees Limitations in wood prod. Limitations in wood prod. sg Estim prop of sp in rp_9.77 Estim prop of sp in rp_5.64 Estim prop of sp in rp_3.09 Land class Land sub-class Main site type Mixed site type Site type Site type extension State of drainage Drainage carried out Time of drainage Ditch spacing Condition of ditches Position of storey Number of tree storeys Development class Development class_2 Proportion of v_a_r_s Dominant tree species Prop of domin.tree species 1st sub-tree species Prop of 1st sub-tree species 2nd sub-tree species Proportion of conifers 1 Proportion of conifers 2 Stem number Total number of seedlings Age at breast height Damage symptom Time of occurrence of damage Cause of damage

	Degree of damage Beard lichens Foliose lichens Crustose lichens Quality of tree stand Cause of decrease in quality Fellings carried out Time of fellings Site preparation Time of site preparation S-cultural meas carried out Time of s-cultural measures Data link to field form 1 Data link to field form 2
Method parametes	Classification system Document reference Surveyor

DATA. Vegetation nutrition analysis

Science	ENVI
Method Categories	Vegetation inventories
Method	Vegetation nutrition analysis
Description	
Target type	Forest extensive monitoring plot, (Forest intensive monitoring plot)
Target	FET, (FIP)
Processing stage	MEAS
Subtext files	
Method variables	FET/FIP ID Sample ID Plant species Plant part: whole, all aboveground, stem, branches, shoots, leaves, buds, roots, rhizome, berries/fruits, flowers, inflorescences, light-coloured (for lichens), not known etc. Age class (c, c+1 ...c+n, young shoots, living shoots) Sampling date (dd.mm.yy) Analysing date Partition ID Lab ID Al (mg/kg$_{dw}$) Al_ctrl B (mg/kg$_{dw}$) B_ctrl Ca (g/kg$_{dw}$) Ca_ctrl Cd (mg/kg$_{dw}$) Cd_ctrl Cr (mg/kg$_{dw}$) Cr_ctrl Cu (mg/kg$_{dw}$) Cu_ctrl Fe (mg/kg$_{dw}$) Fe_ctrl K (g/kg$_{dw}$) K_ctrl Mg (g/kg$_{dw}$) Mg_ctrl Mn (mg/kg$_{dw}$) Mn_ctrl Mo (mg/kg$_{dw}$) Mo_ctrl Na (mg/kg$_{dw}$)

	Na_ctrl Ni (mg/kg_{dw}) Ni_ctrl P (g/kg_{dw}) P_ctrl Pb (mg/kg_{dw}) Pb_ctrl S (mg/kg_{dw}) S_ctrl Zn (mg/kg_{dw}) Zn_ctrl C (m-%, dw) C_ctrl H (m-%, dw) H_ctrl N (m-%, dw) N_ctrl
Method parametes	Sampling round

DATA. Soil chemical analysis

Science	ENVI
Method Categories	Soil inventories
Method	Soil chemical analysis (Metla)
Description	Posiva WR 2007-78
Target type	Forest intensive monitoring plot, Forest extensive monitoring plot
Target	FIP FET
Processing stage	MEAS
Subtext files	
Method variables	FET/FIP ID Sampling point ID (e.g. repeat HS1-HS3, MS1-MS2, PS1-PS3 etc.) Sample type (mineral soil, humus, peat, litter) Top of sampling interval (only mineral soil and peat, from mineral and peat soil surface, cm) Bottom of sampling interval (only mineral soil and peat, from mineral and peat soil surface, cm) Sampling date Analysing date Partition ID (e.g. parallel or control analyses) Lab ID Moisture (%) Ash content (%) Organic matter (%) Al (mg/kgdw) B (mg/kgdw) Ca (mg/kgdw) Cd (mg/kgdw) Cr (mg/kgdw) Cu (mg/kgdw) Fe (mg/kgdw) K (mg/kgdw) Mg (mg/kgdw) Mn (mg/kgdw) Mo (mg/kgdw) Na (mg/kgdw) Ni (mg/kgdw) P (mg/kgdw) Pb (mg/kgdw) S (mg/kgdw) Zn (mg/kgdw) C (m-%, dw) H (m-%, dw) N (m-%, dw) pH-H2O pH-CaCl2 Exchangeable acidity (Hmmol) (mg/kgdw) Al_BaCl2 (mg/kgdw) Ca_BaCl2 (mg/kgdw) Fe_BaCl2 (mg/kgdw) K_BaCl2 (mg/kgdw) Mg_BaCl2 (mg/kgdw) Mn_BaCl2 (mg/kgdw) Na_BaCl2 (mg/kgdw) P_BaCl2 (mg/kgdw)
Method parametes	Sampling round Document reference

Science	ENVI	
Method Categories	Soil inventories	
Method	Soil chemical analysis (Metla)	
Description	Posiva WR 2007-78	
Target type	(Forest intensive monitoring plot), Forest extensive monitoring plot	
Target	(FIP) FET	
Processing stage	PROC	
Subtext files		
Method variables	FET/ FIP ID	
	Sampling point ID (e.g. repeat HS1-HS3, MS1-MS2 etc.)	
	Sample type	(mineral soil, humus, peat, litter)
	Top of sampling interval (only mineral soil and peat, from mineral and peat soil surface, cm)	
	Bottom of sampling interval (only mineral soil and peat, from mineral and peat soil surface, cm)	
	Sampling date	
	Analysing date	
	Partition ID (e.g. parallel or control analyses)	
	Lab ID	
	OM_kgha (kg/ha dw)	amount of organic matter (in dw)
	C_kgha (kg/ha dw)	total carbon amount, Leco CHN-2000 or Leco CHN-1000 analyser, dw
	N_kgha (kg/ha dw)	total nitrogen amount, Leco CHN-2000 or Leco CHN-1000 analyser, dw
	Ca_exc_kgha (kg/ha dw)	amount of exchangeable base cation, dw, BaCl2 extraction
	K_exc_kgha (kg/ha dw)	amount of exchangeable base cation, dw, BaCl2 extraction
	Mg_exc_kgha (kg/ha dw)	amount of exchangeable base cation, dw, BaCl2 extraction
	Na_exc_kgha (kg/ha dw)	amount of exchangeable base cation, dw, BaCl2 extraction
	Al_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	B_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Ca_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Cd_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Cr_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Cu_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Fe_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	K_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Mg_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Mn_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Mo_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Na_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Ni_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	P_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Pb_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	S_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	Zn_kgha (kg/ha dw)	total element amount, wet digestion+ICP/AES, dw
	BC_sum (mmol/kg)	sum of base cation concentrations (mmol/kg): Cammol+Kmmol+Mgmmol+Nammol
	CEC (mmol(+)/kg)	cation exchange capacity (BC sum+exchangeable acidity)
	BS (%)	Base saturation = 100*BC/CEC
Method parametes	Sampling round Document reference	

DATA. Foliage chemical analysis

Science	ENVI
Method Categories	Vegetation inventories
Method	Foliage chemical analysis
Description	
Target type	Forest extensive monitoring plot, (Forest intensive monitoring plot)
Target	FET (FIP)
Processing stage	MEAS
Subtext files	
Method variables	FET/FIP ID Sampling point ID (e.g. repeat 1…., TRxx etc.; composite sample) Number of sample trees Tree species Sample type (needle, leaf) Age class (c, c+1, …. c+n) Sampling date Analysing date (mostly date of approval) Partition ID (e.g. parallel or control analyses) Lab ID Al (mg/kgdw) B (mg/kgdw) Ca (g/kgdw) Cd (mg/kgdw) Cr (mg/kgdw) Cu (mg/kgdw) Fe (mg/kgdw) K (g/kgdw) Mg (g/kgdw) Mn (mg/kgdw) Mo (mg/kgdw) Na (mg/kgdw) Ni (mg/kgdw) P (g/kgdw) Pb (mg/kgdw) S (mg/kgdw) Zn (mg/kgdw) C (m-%, dw) H (m-%, dw) N (m-%, dw) Dry weight (g) *(of 100 needles/leaves)* Ba (mg/kg) Nb (mg/kg) Pd (mg/kg) Sn (mg/kg) Sr (mg/kg) Ta (mg/kg) Te (mg/kg) V (mg/kg) W (mg/kg)
Method parametes	Document reference Sample taken by Sampling round

DATA. Sampler and sensor locations

FIP

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Sampler and sensor locations
Description	
Target type	Forest intensive monitoring plot
Target	FIP
Processing stage	MEAS
Subtext files	
Method variables	FIP ID Easting Northing Sampler type in Finnish Sampler type Sampler ID Sampler/sensor depth/height cm (in relation to soil surface: + upwards, - depth in soil) Notes
Method parametes	Survey type Surveyed by

MRK

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Sampler and sensor locations
Description	
Target type	Wet deposition monitoring plot
Target	MRK
Processing stage	MEAS
Subtext files	
Method variables	MRK ID Sampler type in Finnish Sampler type Number Northing Easting
Method parametes	Survey type Surveyed by

DATA. Forest soil water analysis

Science	ENVI
Method Categories	Vegetation inventories
Method	Forest soil water analysis
Description	
Target type	Test pit, Investigation trench, Infiltration test area
Target	KK TK TMA10
Processing stage	MEAS
Subtext files	
Method variables	Lab ID Evacuation day Sampling day Analysing date Analysed by Plate lysimeter Sample Depth (m) Sample type Conductivity (µS/cm / 25°C) pH Alkalinity (mmol/l) Cl (mg/l) PO4-P (mg/l) NO3-N (mg/l) SO4-S (mg/l) NH4-N (mg/l) TOT-N (mg/l) DOC (mg/l) Al (mg/l) B (mg/l) Ca (mg/l) Ca_2 (mg/l)

	Cd (mg/l) Cr (mg/l) Cu (mg/l) Fe (mg/l) K (mg/l) K_2 (mg/l) Mg (mg/l) Mn (mg/l) Na (mg/l) Na_2 (mg/l) Ni (mg/l) P (mg/l) Pb (mg/l) S (mg/l) Si (mg/l) Zn (mg/l) Remarks Ba (mg/l) Nb (mg/l) Pd (mg/l) Sn (mg/l) Sr (mg/l) Ta (mg/l) Te (mg/l) V (mg/l) W (mg/l)
Method parameters	

DATA. Sap flow measurement

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Sap flow measurement
Description	Hökkä 2008 (Kronodoc POS-003795), Prosalog Manual version 1.1 (2005), UP Sap Flow-System User Manual Version 2.6
Target type	Forest intensive monitoring plot
Target	FIP
Processing stage	MEAS
Subtext files	
Method variables	FIP ID Date (dd.mm.yyyy hh:mm:ss) Sap flow signal_tree 1 (mV) Sap flow signal_tree 2 (mV) Sap flow signal_tree 3 (mV) Sap flow signal_tree 4 (mV) Sap flow signal_tree 5 (mV) Sap flow signal_tree 6 (mV)
Method parametes	Document reference

DATA. Sap flow measurement: tree stand transpiration.

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Sap flow measurement: tree stand transpiration
Description	Hökkä 2008 (Kronodoc POS-003795), Prosalog Manual version 1.1 (2005), UP Sap Flow-System User Manual Version 2.6
Target type	Forest intensive monitoring plot
Target	FIP
Processing stage	PROC
Subtext files	
Method variables	Date (dd.mm.yyyy hh:mm:ss) Stand transpiration (mm)
Method parametes	Calibration method Document reference Processed by

DATA. Spring and ditch water chemical analysis

Science	ENVI
Method Categories	
Method	Spring and ditch water chemical analysis
Description	
Target type	Spring, Ditch
Target	TMAspring DI10
Processing stage	MEAS
Subtext files	
Method variables	Subplot Analysing date Analysed by Sample type Conductivity (µS/cm / 25°C) pH Alkalinity (mmol/l) DOC (mg/l) TOT-N (mg/l) Cl (mg/l) PO4-P (mg/l) NO3-N (mg/l) SO4-S (mg/l) NH4-N (mg/l) Al (mg/l) B (mg/l) Ca (mg/l) Ca_2 (mg/l) Cd (mg/l) Cr (mg/l) Cu (mg/l) Fe (mg/l) K (mg/l) K_2 (mg/l) Mg (mg/l) Mn (mg/l) Na (mg/l) Na_2 (mg/l) Ni (mg/l) P (mg/l) Pb (mg/l) S (mg/l) Si (mg/l) Zn (mg/l)
Method parametes	

DATA. Nutrient analysis of litter fractions

Science	ENVI
Method Categories	Continuous forest monitoring
Method	Nutrient analysis of litter fractions
Description	Aro 2006 (Kronodoc POS-003125); Rautio, P. & Aro, L. 2009 (Kronodoc POS-005671)
Target type	Forest intensive monitoring plot
Target	FIP
Processing stage	MEAS
Subtext files	
Method variables	FIP ID Sampling date Analysing date Partition ID Lab ID Litter fraction Moisture (%) Ash content (%) Al (mg/kgdw) B (mg/kgdw) Ca (g/kgdw) Cd (mg/kgdw) Cr (mg/kgdw) Cu (mg/kgdw) Fe (mg/kgdw) K (g/kgdw) Mg (g/kgdw) Mn (mg/kgdw) Mo (mg/kgdw) Na (mg/kgdw) Ni (mg/kgdw) P (g/kgdw) Pb (mg/kgdw) S (mg/kgdw) Zn (mg/kgdw) C (m-%, dw) N (m-%, dw) H (m-%, dw) Remarks Ba (mg/kg) Nb (mg/kg) Pd (mg/kg) Sn (mg/kg) Sr (mg/kg) Ta (mg/kg) Te (mg/kg) V (mg/kg) W (mg/kg)
Method parametes	

APPENDIX 6. List of data in the POTTI database (site = Olkiluoto, science = environment)

Target	Method	Time	Proc stage	Activity ID
OL-TK4	Forest soil water analysis	15.11.2011	MEAS	67888
OL-TK4	Forest soil water analysis	16.8.2011	MEAS	60263
OL-TK4	Forest soil water analysis	30.5.2011	MEAS	60262
OL-TK4	Forest soil water analysis	9.12.2008	MEAS	54677
OL-TK4	Forest soil water analysis	12.10.2010	MEAS	54702
OL-TK4	Forest soil water analysis	26.7.2010	MEAS	54754
OL-TK4	Forest soil water analysis	19.5.2010	MEAS	54695
OL-TK4	Forest soil water analysis	26.11.2009	MEAS	36573
OL-TK4	Forest soil water analysis	11.12.2009	MEAS	36760
OL-TK4	Forest soil water analysis	16.6.2009	MEAS	36367
OL-FIP04	Sap flow measurement	1.1.2009	PROC	67719
OL-FIP04	Sap flow measurement	1.1.2008	PROC	67718
OL-FIP04	Sap flow measurement	8.5.2007	PROC	67717
OL-FIP04	Sap flow measurement: tree stand transpiration	1.4.2012	PROC	73378
OL-FIP04	Sap flow measurement: tree stand transpiration	1.4.2011	PROC	73374
OL-FIP04	Sap flow measurement: tree stand transpiration	1.4.2010	PROC	63421
OL-FIP04	Sap flow measurement: tree stand transpiration	1.1.2009	PROC	35128
OL-FIP04	Sap flow measurement: tree stand transpiration	1.1.2008	PROC	34035
OL-FIP04	Sap flow measurement: tree stand transpiration	8.5.2007	PROC	35335
OL-FIP04	Nutrient analysis of litter fractions	1.1.2011	MEAS	73457
OL-FIP04	Nutrient analysis of litter fractions	6.5.2010	MEAS	67802
OL-FIP04	Nutrient analysis of litter fractions	14.5.2009	MEAS	56255
OL-FIP04	Nutrient analysis of litter fractions	1.4.2008	MEAS	56939
OL-FIP04	Nutrient analysis of litter fractions	8.5.2007	MEAS	56938
OL-FIP04	Nutrient analysis of litter fractions	25.4.2006	MEAS	56937
OL-FIP04	Nutrient analysis of litter fractions	13.4.2005	MEAS	56936
OL-FIP04	Nutrient analysis of litter fractions	29.6.2004	MEAS	56935
OL-FIP04	Forest inventory: tree measurements (FIP/MRK)	26.3.2009	MEAS	32953
OL-FIP04	Forest inventory: tree measurements (FIP/MRK)	30.6.2004	MEAS	26356
OL-FIP04	Soil chemical analysis(Metla)	24.5.2007	MEAS	28236
OL-FIP04	Sampler and sensor locations	1.1.2007	MEAS	26127
OL-FIP10	Sap flow measurement	1.1.2009	PROC	67722
OL-FIP10	Sap flow measurement	1.1.2008	PROC	67720
OL-FIP10	Sap flow measurement	6.6.2007	PROC	67720
OL-FIP10	Sap flow measurement: tree stand transpiration	1.4.2010	PROC	63422
OL-FIP10	Sap flow measurement: tree stand transpiration	1.1.2009	PROC	35129
OL-FIP10	Sap flow measurement: tree stand transpiration	1.1.2008	PROC	35127
OL-FIP10	Sap flow measurement: tree stand transpiration	6.6.2007	PROC	35334
OL-FIP10	Nutrient analysis of litter fractions	1.1.2011	MEAS	78294
OL-FIP10	Nutrient analysis of litter fractions	6.5.2010	MEAS	67821
OL-FIP10	Nutrient analysis of litter fractions	15.5.2009	MEAS	56256
OL-FIP10	Nutrient analysis of litter fractions	1.4.2008	MEAS	56943
OL-FIP10	Nutrient analysis of litter fractions	8.5.2007	MEAS	56942
OL-FIP10	Nutrient analysis of litter fractions	25.4.2006	MEAS	56941
OL-FIP10	Nutrient analysis of litter fractions	7.6.2005	MEAS	56940
OL-FIP10	Forest inventory: tree measurements (FIP/MRK)	29.9.2009	MEAS	32952
OL-FIP10	Soil chemical analysis(Metla)	24.5.2007	MEAS	28237
OL-FIP10	Forest inventory: tree measurements (FIP/MRK)	16.6.2005	MEAS	26382

APPENDIX 6. List of data in the POTTI database (site = Olkiluoto, science = environment)

Target	Method	Time	Proc stage	Activity ID
OL-FIP10	Sampler and sensor locations	1.9.2003	MEAS	22004
OL-FIP11	Nutrient analysis of litter fractions	1.1.2011	MEAS	73459
OL-FIP11	Nutrient analysis of litter fractions	6.5.2010	MEAS	67822
OL-FIP11	Nutrient analysis of litter fractions	14.5.2009	MEAS	56257
OL-FIP11	Nutrient analysis of litter fractions	1.4.2008	MEAS	56945
OL-FIP11	Nutrient analysis of litter fractions	28.5.2007	MEAS	56944
OL-FIP11	Forest inventory: tree measurements (FIP/MRK)	4.6.2008	MEAS	26378
OL-FIP11	Sampler and sensor locations	1.1.2007	MEAS	22009
OL-FIP14	Nutrient analysis of litter fractions	1.1.2011	MEAS	73460
OL-FETgroup	Vegetation nutrition analysis	11.8.2010	MEAS	57255
OL-FETgroup	Soil chemical analysis(Metla)	29.10.2008	MEAS	38745
OL-FETgroup	Forest inventory by plots: plot characteristics	14.5.2004	MEAS	42797
OL-FETgroup	Foliage chemical analysis	24.8.2009	MEAS	33734
OL-FETgroup	Soil chemical analysis(Metla)	29.10.2008	PROC	46447
OL-FETgroup	Foliage chemical analysis	7.3.2006	MEAS	26365
OL-FETgroup	Soil chemical analysis(Metla)	17.5.2005	PROC	28437
OL-FETgroup	Forest inventory: tree measurements (FET)	14.5.2004	MEAS	28056
OL-FETgroup	Soil chemical analysis(Metla)	17.5.2005	MEAS	27976
OL-FETgroup	FET plot locations	1.5.2003	MEAS	21929
OL-FETgroup	Vegetation nutrition analysis	29.7.2005	MEAS	20922
OL-MRK01	Sampler and sensor locations	2.6.2003	MEAS	26115
OL-MRK03	Sampler and sensor locations	2.6.2003	MEAS	26116
OL-MRK05	Sampler and sensor locations	26.8.2003	MEAS	26117
OL-MRK06	Sampler and sensor locations	26.8.2003	MEAS	26118
OL-MRK08	Sampler and sensor locations	2.6.2003	MEAS	26119
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2012	PROC	72773
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2011	PROC	73465
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2010	PROC	67662
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2009	PROC	67229
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2008	PROC	67228
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2007	PROC	67227
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2006	PROC	67226
OL-WOM2	WOM2,Weather Observation Mast 2	1.1.2005	PROC	67225
OL-WOM2	WOM2,Weather Observation Mast 2	1.9.2004	PROC	67224
OL-WOM1	Forest inventory: tree measurements (WOM1)	30.3.2011	MEAS	55570
OL-WOM3	WOM3,Weather Observation Mast 3	23.5.2005	PROC	67664
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2006	PROC	67666
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2007	PROC	67668
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2008	PROC	67669
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2009	PROC	67670
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2010	PROC	67671
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2011	PROC	67672
OL-WOM3	WOM3,Weather Observation Mast 3	1.1.2012	PROC	72772
OL-WOM4	WOM4,Weather Observation Mast 4	28.6.2007	PROC	67674
OL-WOM4	WOM4,Weather Observation Mast 4	1.1.2008	PROC	67675
OL-WOM4	WOM4,Weather Observation Mast 4	1.1.2009	PROC	67676
OL-WOM4	WOM4,Weather Observation Mast 4	1.1.2010	PROC	67677
OL-WOM4	WOM4,Weather Observation Mast 4	1.1.2011	PROC	67678

APPENDIX 6. List of data in the POTTI database (site = Olkiluoto, science = environment)

Target	Method	Time	Proc stage	Activity ID
OL-WOM4	WOM4,Weather Observation Mast 4	1.1.2012	PROC	72774
OL-MRKgroup	Foliage chemical analysis	19.12.2003	MEAS	66082
OL-MRKgroup	Foliage chemical analysis	29.3.2010	MEAS	73463
OL-MRKgroup	Wet deposition analysis	14.2.2011	MEAS	67764
OL-MRKgroup	Wet deposition analysis	2.2.2009	MEAS	53456
OL-MRKgroup	Wet deposition analysis	2.2.2010	MEAS	56946
OL-MRKgroup	Wet deposition analysis	1.1.2003	MEAS	26161
OL-MRKgroup	Wet deposition analysis	1.1.2006	MEAS	26159
OL-MRKgroup	Wet deposition analysis	1.1.2007	MEAS	26157
OL-MRKgroup	Wet deposition analysis	1.1.2008	MEAS	26153
OL-TMAspring	Spring and ditch water chemical analysis	30.10.2009	MEAS	36299
OL-TMAspring	Spring and ditch water chemical analysis	28.4.2010	MEAS	42224
OL-TMAspring	Spring and ditch water chemical analysis	16.6.2009	MEAS	36300
OL-TMAspring	Spring and ditch water chemical analysis	23.9.2008	MEAS	26386
OL-TMAspring	Spring and ditch water chemical analysis	13.2.2008	MEAS	26385
OL-KK17	Forest soil water analysis	15.11.2011	MEAS	67884
OL-KK17	Forest soil water analysis	30.5.2011	MEAS	60255
OL-KK17	Forest soil water analysis	9.12.2008	MEAS	54674
OL-KK17	Forest soil water analysis	12.10.2010	MEAS	54697
OL-KK17	Forest soil water analysis	19.5.2010	MEAS	54691
OL-KK17	Forest soil water analysis	7.12.2009	MEAS	36762
OL-KK17	Forest soil water analysis	2.6.2009	MEAS	36382
OL-DI10	Spring and ditch water analysis	20.7.2010	MEAS	54755
OL-DI10	Spring and ditch water analysis	30.10.2009	MEAS	49889
OL-DI10	Spring and ditch water analysis	28.4.2010	MEAS	50573
OL-KK21	Forest soil water analysis	15.11.2011	MEAS	67886
OL-KK21	Forest soil water analysis	16.8.2011	MEAS	60259
OL-KK21	Forest soil water analysis	30.5.2011	MEAS	60258
OL-KK21	Forest soil water analysis	12.10.2010	MEAS	54700
OL-FIP14	Nutrient analysis of litter fractions	1.1.2011	MEAS	73460
OL-FIP14	Nutrient analysis of litter fractions	6.5.2010	MEAS	67823
OL-FIP14	Nutrient analysis of litter fractions	4.8.2009	MEAS	56258
OL-KK14	Forest soil water analysis	15.11.2011	MEAS	67885
OL-KK14	Forest soil water analysis	16.8.2011	MEAS	60254
OL-KK14	Forest soil water analysis	30.5.2011	MEAS	60253
OL-KK14	Forest soil water analysis	12.10.2010	MEAS	54696
OL-KK14	Forest soil water analysis	26.7.2010	MEAS	54750
OL-KK14	Forest soil water analysis	19.5.2010	MEAS	54690
OL-KK14	Forest soil water analysis	2.6.2009	MEAS	36359
OL-KK14	Forest soil water analysis	17.9.2008	MEAS	36580
OL-KK14	Forest soil water analysis	16.11.2009	MEAS	36574
OL-KK14	Forest soil water analysis	7.12.2009	MEAS	36761
OL-WOM5	WOM5,Weather Observation Mast 5	1.1.2012	PROC	72775
OL-WOM5	WOM5,Weather Observation Mast 5	1.1.2011	PROC	67684
OL-WOM5	WOM5,Weather Observation Mast 5	1.1.2010	PROC	67683
OL-WOM5	WOM5,Weather Observation Mast 5	3.11.2009	PROC	67682
OL-KK18	Forest soil water analysis	30.5.2011	MEAS	60256
OL-KK18	Forest soil water analysis	9.12.2008	MEAS	54675

APPENDIX 6. List of data in the POTTI database (site = Olkiluoto, science = environment)

Target	Method	Time	Proc stage	Activity ID
OL-KK18	Forest soil water analysis	12.10.2010	MEAS	54698
OL-KK18	Forest soil water analysis	26.7.2010	MEAS	54751
OL-KK18	Forest soil water analysis	19.5.2010	MEAS	54692
OL-KK18	Forest soil water analysis	16.11.2009	MEAS	36575
OL-KK18	Forest soil water analysis	2.6.2009	MEAS	36389
OL-KK18	Forest soil water analysis	7.12.2009	MEAS	36763
OL-KK19	Forest soil water analysis	30.5.2011	MEAS	60257
OL-KK19	Forest soil water analysis	9.12.2008	MEAS	54676
OL-KK19	Forest soil water analysis	12.10.2010	MEAS	54699
OL-KK19	Forest soil water analysis	26.7.2010	MEAS	54752
OL-KK19	Forest soil water analysis	19.5.2010	MEAS	54693
OL-KK19	Forest soil water analysis	16.11.2009	MEAS	36576
OL-KK19	Forest soil water analysis	7.12.2009	MEAS	36764
OL-KK19	Forest soil water analysis	2.6.2009	MEAS	36392
OL-TK15	Forest soil water analysis	15.11.2011	MEAS	67887
OL-TK15	Forest soil water analysis	16.8.2011	MEAS	60261
OL-TK15	Forest soil water analysis	30.5.2011	MEAS	60260
OL-TK15	Forest soil water analysis	12.10.2010	MEAS	54701
OL-TK15	Forest soil water analysis	26.7.2010	MEAS	54753
OL-TK15	Forest soil water analysis	19.5.2010	MEAS	54694
OL-TMA01	Spring and ditch water analysis	20.7.2010	MEAS	54756
OL-TMA01	Spring and ditch water analysis	13.2.2008	MEAS	50574
OL-TMA01	Spring and ditch water analysis	30.10.2009	MEAS	49890
OL-TMA01	Spring and ditch water analysis	23.9.2008	MEAS	50576
OL-TMA01	Spring and ditch water analysis	16.6.2009	MEAS	50586
OL-TMA01	Spring and ditch water analysis	28.4.2010	MEAS	50577
OL-TMA02	Spring and ditch water analysis	20.7.2010	MEAS	54757
OL-TMA02	Spring and ditch water analysis	30.10.2009	MEAS	49893
OL-TMA02	Spring and ditch water analysis	28.4.2010	MEAS	50582
OL-TMA02	Spring and ditch water analysis	23.9.2008	MEAS	50580
OL-TMA02	Spring and ditch water analysis	16.6.2009	MEAS	50579
OL-TMA02	Spring and ditch water analysis	13.2.2008	MEAS	50578
OL-TMA07	Spring and ditch water analysis	20.7.2010	MEAS	54758
OL-TMA07	Spring and ditch water analysis	30.10.2009	MEAS	49892
OL-TMA07	Spring and ditch water analysis	28.4.2010	MEAS	50585
OL-TMA07	Spring and ditch water analysis	23.9.2008	MEAS	50584
OL-TMA07	Spring and ditch water analysis	16.6.2009	MEAS	50583
OL-TMA07	Spring and ditch water analysis	13.2.2008	MEAS	50581