Results of Forest Monitoring on Olkiluoto Island in 2013

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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 2013. In general, the precipitation amount was relatively low in 2013. The NH$_4$-N deposition that decreased in 2012 compared to the situation in 2011 remained relatively low also in 2013. The NO$_3$-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004–2012. However, the NO$_3$-N deposition decreased in 2013. The soil solution quality in 2013 was quite comparable to that in earlier years. Annual total litterfall production (191–630 g$_{dw}$/m$^2$ without larger branches) was higher in 2012 than in 2011, but the increase can be explained by natural reasons. High Al and Fe concentrations were found in remaining litter, and were most likely due to soil dust. No harmful effects of human activities on the forest condition were observed in the Nature conservation area.

Keywords: Bulk deposition, forest ecosystems, litterfall production, soil solution chemistry, stand throughfall, tree stand transpiration.
OLKILUODON METSIEN TILAN SEURANTA 2013

TIIVISTELMÄ


Avainsanat: Karikesato, laskeuma, maavesi, metsäkiitosadanta, metsäekosysteemit, puuston haihdunta.
CONTENTS

1 INTRODUCTION ............................................................................................................... 3
2 MONITORING SYSTEM.................................................................................................... 5
  2.1 Description of the forest monitoring network ......................................................... 5
  2.2 Description of the MRK and FIP networks .............................................................. 6
    2.2.1 Bulk deposition and stand throughfall plots (MRK) ........................................ 6
    2.2.2 Forest intensive monitoring plots (FIP) ............................................................ 7
3 MATERIAL AND METHODS .......................................................................................... 13
  3.1 Bulk deposition and stand throughfall on MRK plots ............................................. 13
  3.2 Soil solution on FIP plots ....................................................................................... 15
    3.2.1 Method of sampling soil solution .................................................................... 15
    3.2.2 Amounts of percolation water ....................................................................... 16
    3.2.3 Chemical composition of the soil solution on FIP plots .................................. 18
  3.3 Tree stand transpiration on the plots FIP4 and FIP10 ............................................. 19
  3.4 Litterfall production and element return to the forest floor on FIP plots ............... 20
  3.5 Temperature sum and stand meteorology in the area ........................................... 22
  3.6 POTTI database and Kronodoc ............................................................................. 22
4 RESULTS AND DISCUSSION ....................................................................................... 25
  4.1 Bulk deposition and stand throughfall ................................................................. 25
  4.2 Soil solution ........................................................................................................... 28
  4.3 Tree stand transpiration ......................................................................................... 32
  4.4 Litterfall production and element return to the forest floor ................................... 34
5 CONCLUDING REMARKS ......................................................................................... 41
6 REFERENCES ................................................................................................................. 43
APPENDICES .................................................................................................................. 45
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 2013 supplements preceding reporting. Results of forest monitoring during 2009–2012 have been reported by Aro et al. (2010, 2011, 2013 and 2014).

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 Natural Resources Institute Finland (Luke). Antti-Jussi Lindroos is responsible for bulk deposition, stand through-fall and soil solution chemistry and Pasi Rautio for litterfall production and element return to the forest floor. 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).

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.
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.

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 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. Two new MRK plots were established in Ilavainen in late 2013 (Figure 3): the plots were marked in the field and bases for deposition and litterfall collectors were built (Figure 4). The monitoring of stand throughfall and litterfall will start in 2014.
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, FIP15 and FIP16) consists of three square sub-plots (30 m x 30 m, total area 900 m²) 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 m²) where litter sampling, deposition, soil water collection and micro-meteorological measurements are concentrated. Plot FET930231 (total area 300 m²), which is used for tree growth measurements and vegetation studies (see Figure 2), is located beside the OA2 sub-plot.

FIP15 consist of only one rectangle (OA2, 20m x 35 m = 700 m²) where litter sampling and deposition will be concentrated. FIP16 consist of only one square sub-plot as well (OA2, 30m x 30m = 900 m²) including litterfall and deposition monitoring systems. The same plots are used for tree measurements which can be done with two alternative methods, i.e. all trees will be measured from the whole plot area or trees will be measured from a circle plot (r=9.77 m) being sited in the centre of the plot (Figure 5).

*Figure 4.* A view of the intensive monitoring plots FIP15 (top left, a pine mire, picture taken 6.6.2013, L. Aro/Luke; top right, bases for litterfall and deposition samplers 24.10.2013, J. Ilomäki/Luke) and FIP16 (bottom left, a rocky forest, 6.6.2013, L. Aro; bottom right, bases for litterfall and deposition samplers 24.10.2013, J. Ilomäki).
Table 1. Performed monitoring activities and their frequency on the FIP plots.

<table>
<thead>
<tr>
<th>Performed activities FIP4</th>
<th>FIP10</th>
<th>FIP11</th>
<th>FIP14</th>
<th>FIP15</th>
<th>FIP16</th>
<th>Normal Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location and measurement of trees</td>
<td>2004</td>
<td>2005</td>
<td>2008</td>
<td>2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil condition</td>
<td>2007</td>
<td>2007</td>
<td>2007</td>
<td>2008</td>
<td></td>
<td>Every 10 yrs</td>
</tr>
<tr>
<td>Stand throughfall and precipitation measurements (MRK, OA2)</td>
<td>2003</td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Sap flow measurements</td>
<td>2007</td>
<td>2007</td>
<td>no</td>
<td>no</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Soil water sampling (OA2)</td>
<td>2003</td>
<td>2005</td>
<td>2007</td>
<td>2010</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Litterfall sampling (OA2)</td>
<td>2004</td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Micrometeorology (OA2)</td>
<td>2004</td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Stem diameter growth (OA2)</td>
<td>2004</td>
<td>2005</td>
<td>no</td>
<td>no</td>
<td></td>
<td>Continuous</td>
</tr>
<tr>
<td>Tree growth (OA1)</td>
<td>2009</td>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td>Every 5 yrs</td>
</tr>
<tr>
<td>Crown condition survey 2</td>
<td>2006</td>
<td>2006</td>
<td>no</td>
<td>no</td>
<td></td>
<td>Biennial</td>
</tr>
<tr>
<td>Soil microbial community structure and activity</td>
<td>2006</td>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass and chemical composition of vegetation and humus layers</td>
<td>2008</td>
<td>2008</td>
<td></td>
<td>2008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 5. Sample plot design on the plots FIP15 and FIP16, and the location of deposition and litterfall samplers.

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 2). The third intensive monitoring plot (FIP11) was established in a young birch dominated stand in the Liiklansuo catchment area during 2006–2007 (Figure 2). 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 2) was established in an alder stand of a herb-rich type in 2009. The basic characteristics of the soil and vegetation of the FIP plots is presented in Table 2 and instrumentation in Table 3. Details of tree stand characteristics during 2004–2009 were presented by Aro et al. (2013).
Table 2. Basic characteristics of soil and vegetation of the FIP plots (Aro et al. 2014).

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

1 based on the vegetation survey of FET930231 (Aro et al. 2011)
Table 3. 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).

<table>
<thead>
<tr>
<th>Description</th>
<th>FIP plot</th>
<th>Instrument</th>
<th>Quant.</th>
<th>Installation site</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>4</td>
<td>FW-5k</td>
<td>3</td>
<td>2, 9 &amp; 24 m</td>
<td>1.9.2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>FW-5k</td>
<td>1</td>
<td>2 m</td>
<td>23.5.2005</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>FW-5k</td>
<td>1</td>
<td>2 m</td>
<td>19.6.2007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Vishay-10k</td>
<td>1</td>
<td>2 m</td>
<td>3.11.2009</td>
</tr>
<tr>
<td>Radiation</td>
<td>4</td>
<td>LI-190/200SZ</td>
<td>2</td>
<td>24 m</td>
<td>1.9.2004</td>
</tr>
<tr>
<td>Air pressure</td>
<td>4</td>
<td>PTB210</td>
<td>1</td>
<td>2 m</td>
<td>26.4.2005</td>
</tr>
<tr>
<td>Wind</td>
<td>4</td>
<td>Adcon</td>
<td>1</td>
<td>24 m</td>
<td>1.9.2004</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>4</td>
<td>HMP45D</td>
<td>2</td>
<td>2 &amp; 9 m</td>
<td>1.9.2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>HMP45D</td>
<td>1</td>
<td>2 m</td>
<td>23.5.2005</td>
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<tr>
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<td>HMP45D</td>
<td>1</td>
<td>2 m</td>
<td>19.6.2007</td>
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<tr>
<td></td>
<td>14</td>
<td>HMP45D</td>
<td>1</td>
<td>2 m</td>
<td>3.11.2009</td>
</tr>
<tr>
<td>Precipitation</td>
<td>4</td>
<td>RMY-52203</td>
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<td>1 m</td>
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<tr>
<td></td>
<td>10</td>
<td>RMY-52203</td>
<td>1</td>
<td>1 m</td>
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</tr>
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<td></td>
<td>11</td>
<td>RMY-52203</td>
<td>1</td>
<td>1 m</td>
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</tr>
<tr>
<td>Soil temperature</td>
<td>4</td>
<td>FW-5k</td>
<td>13</td>
<td>-10 … -90 cm</td>
<td>1.9.2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>FW-5k</td>
<td>13</td>
<td>-10 … -90 cm</td>
<td>23.5.2005</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>FW-5k</td>
<td>13</td>
<td>-10 … -90 cm</td>
<td>19.6.2007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Vishay-10k</td>
<td>13</td>
<td>-10 … -90 cm</td>
<td>3.11.2009</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>4</td>
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<td>2</td>
<td>-20 cm</td>
<td>1.9.2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Theta Probe</td>
<td>2</td>
<td>-20 cm</td>
<td>23.5.2005</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Theta Probe</td>
<td>2</td>
<td>-20 cm</td>
<td>19.6.2007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Theta Probe</td>
<td>2</td>
<td>-20 cm</td>
<td>3.11.2009</td>
</tr>
<tr>
<td>Soil solution</td>
<td>4</td>
<td>Plate lysimeter</td>
<td>8</td>
<td>-5 cm</td>
<td>Sept. 2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suction cup</td>
<td>12</td>
<td>-10, -20, -30 cm</td>
<td>Sept. 2003</td>
</tr>
<tr>
<td></td>
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<td>Plate lysimeter</td>
<td>12</td>
<td>-5 cm</td>
<td>May 2005</td>
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<td></td>
<td>Suction cup</td>
<td>24</td>
<td>-20, -30 cm</td>
<td>May 2005</td>
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<tr>
<td></td>
<td>11</td>
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<td>8</td>
<td>-5 cm</td>
<td>13.12.2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suction cup</td>
<td>12</td>
<td>-10, -20, -30 cm</td>
<td>13.12.2006</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Plate lysimeter</td>
<td>4</td>
<td>-5 cm</td>
<td>29.10.2009</td>
</tr>
<tr>
<td>Litterfall</td>
<td>4</td>
<td>Funnel type sampler</td>
<td>12</td>
<td>150 cm</td>
<td>June 2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Funnel type sampler</td>
<td>12</td>
<td>150 cm</td>
<td>12.5.2005</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Funnel type sampler</td>
<td>12</td>
<td>150 cm</td>
<td>25.4.2007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Funnel type sampler</td>
<td>12</td>
<td>150 cm</td>
<td>15.5.2009</td>
</tr>
<tr>
<td>Stand throughfall</td>
<td>4</td>
<td>Snow sampler</td>
<td>5</td>
<td>180 cm</td>
<td>2.6.2003</td>
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<tr>
<td></td>
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<td>Snow sampler</td>
<td>5</td>
<td>180 cm</td>
<td>23.5.2005</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Snow sampler</td>
<td>5</td>
<td>180 cm</td>
<td>16.11.2007</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Snow sampler</td>
<td>5</td>
<td>180 cm</td>
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</tr>
<tr>
<td>Tree growth</td>
<td>4</td>
<td>Girth band</td>
<td>2</td>
<td>130 cm</td>
<td>1.9.2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Girth band</td>
<td>2</td>
<td>130 cm</td>
<td>23.5.2005</td>
</tr>
</tbody>
</table>
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 2013 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 7.1.2013–8.1.2014 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 2013. The results for 2013 are compared to the deposition load during the period 2004–2012 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.

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; see also Aro et al. 2013).

<table>
<thead>
<tr>
<th>MRK plot</th>
<th>Established</th>
<th>Type</th>
<th>Tree species (dominating)</th>
<th>V (m$^3$/ha)</th>
<th>Monitoring period</th>
</tr>
</thead>
</table>

$^a$ in May 2008  $^b$ in May 2008  $^c$ in June 2008  $^d$ in November 2009
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.

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>LOQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mmol/l</td>
<td></td>
</tr>
<tr>
<td>H+</td>
<td>mg/l</td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm/25 °C</td>
<td>8</td>
</tr>
<tr>
<td>DOC</td>
<td>mg/l</td>
<td>0.6</td>
</tr>
<tr>
<td>Tot-N</td>
<td>mg/l</td>
<td>0.05</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>mg/l</td>
<td>0.03</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>mg/l</td>
<td>0.04</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>mg/l</td>
<td>0.13</td>
</tr>
<tr>
<td>SO₄-S</td>
<td>mg/l</td>
<td>0.05</td>
</tr>
<tr>
<td>Al</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Ca</td>
<td>mg/l</td>
<td>0.0004</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/l</td>
<td>0.0007</td>
</tr>
<tr>
<td>Cl</td>
<td>mg/l</td>
<td>0.1</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>K</td>
<td>mg/l</td>
<td>0.06</td>
</tr>
<tr>
<td>Mg</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Na</td>
<td>mg/l</td>
<td>0.01</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>P</td>
<td>mg/l</td>
<td>0.06</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>Si</td>
<td>mg/l</td>
<td>0.006</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>Ba</td>
<td>mg/l</td>
<td>0.0001</td>
</tr>
<tr>
<td>Nb</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>Pd</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>Sn</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Sr</td>
<td>mg/l</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ta</td>
<td>mg/l</td>
<td>0.006</td>
</tr>
<tr>
<td>Te</td>
<td>mg/l</td>
<td>0.010</td>
</tr>
<tr>
<td>V</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>W</td>
<td>mg/l</td>
<td>0.010</td>
</tr>
</tbody>
</table>
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 2013. 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.

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.

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 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.

3.2.2 Amounts of percolation water

Percolation water was collected during the snow-free periods in 2004–2013 on plot FIP4, in 2005–2013 on plot FIP10, in 2007–2013 on plot FIP11 and in 2010–2013 on FIP14 using plate lysimeters with a surface area of 0.1 m² (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.

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>LOQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mmol/l</td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm/25 °C</td>
<td>8</td>
</tr>
<tr>
<td>DOC</td>
<td>mg/l</td>
<td>0.6</td>
</tr>
<tr>
<td>Tot-N</td>
<td>mg/l</td>
<td>0.05</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>mg/l</td>
<td>0.03</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>mg/l</td>
<td>0.04</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>mg/l</td>
<td>0.13</td>
</tr>
<tr>
<td>SO₄-S</td>
<td>mg/l</td>
<td>0.05</td>
</tr>
<tr>
<td>Al</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Ca</td>
<td>mg/l</td>
<td>0.0004</td>
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<tr>
<td>Cd</td>
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<tr>
<td>Cl</td>
<td>mg/l</td>
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</tr>
<tr>
<td>Cr</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>K</td>
<td>mg/l</td>
<td>0.06</td>
</tr>
<tr>
<td>Mg</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>Na</td>
<td>mg/l</td>
<td>0.01</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>P</td>
<td>mg/l</td>
<td>0.06</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>S</td>
<td>mg/l</td>
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<tr>
<td>Si</td>
<td>mg/l</td>
<td>0.006</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>Ba</td>
<td>mg/l</td>
<td>0.0001</td>
</tr>
<tr>
<td>Nb</td>
<td>mg/l</td>
<td>0.002</td>
</tr>
<tr>
<td>Pd</td>
<td>mg/l</td>
<td>0.005</td>
</tr>
<tr>
<td>Sn</td>
<td>mg/l</td>
<td>0.004</td>
</tr>
<tr>
<td>Sr</td>
<td>mg/l</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ta</td>
<td>mg/l</td>
<td>0.006</td>
</tr>
<tr>
<td>Te</td>
<td>mg/l</td>
<td>0.010</td>
</tr>
<tr>
<td>V</td>
<td>mg/l</td>
<td>0.001</td>
</tr>
<tr>
<td>W</td>
<td>mg/l</td>
<td>0.010</td>
</tr>
</tbody>
</table>
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.

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 were presented in Aro et al. (2014).

Basically, some problems occurred in sap flow measurements especially during the winter season in 2009 and 2010. In particular some measuring observations were missing which resulted in unreal peaks in calculated transpiration. Therefore calculated values for tree transpiration of the FIP plots 4 and 10 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 2008–2010, and on FIP4 also in 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. In 2013 the sap flow measurements of the FIP4 plot were mostly reliable during 1.4.–31.12.2013 although calculation of the stand level transpiration was based on five trees in April and May, and on three trees instead of six trees during June to December. 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, and for January to March 2013.

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. Problems continued to occur in 2013. Therefore we are not able to report the transpiration of the Norway spruce stand in 2011–2013.

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 2012. The litterfall collectors were funnel-shaped traps with a collection area of 0.5 m² placed about 1.5 m above ground level (see Figure 4). Litterfall collection was started on the plots (FIP4, FIP10, FIP11 and FIP14) in May 2012 (10.–15.5.2012, see Figures 17a–17d). Since the last collection date in 2011 was at the end of October (31.10.2011), the mass of the first collection in May 2012 (in FIP14 in February) 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 2012 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. 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 m²). 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/m²; 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 (HNO₃/H₂O₂) 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.

Table 7. Problems in the stand meteorological measurements, their date of occurrence and the correction method applied on the FIP plots.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Parameter</th>
<th>Channel no.</th>
<th>Date</th>
<th>Correction method/comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIP4</td>
<td>Soil temperature -10 cm (3)</td>
<td>11</td>
<td>22.6. – 2.10.2013</td>
<td>False data removed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>3.10. – 31.12.2013</td>
<td>No data (sensor broken). Previous and following true values used to replace data spikes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>30.10.2013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil temperature -50 cm</td>
<td>7</td>
<td>23.10.2013</td>
<td>Previous and following true values used to replace data spikes</td>
</tr>
<tr>
<td></td>
<td>Soil temperature -90 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Girth band, tree no 395</td>
<td>17</td>
<td>27.5.2013</td>
<td>Previous and following true values used to replace data spikes</td>
</tr>
<tr>
<td></td>
<td>Relative humidity, 9 m (mean, min, max)</td>
<td>27, 41, 42</td>
<td>2013</td>
<td>Removed values over 100%, no data for correction</td>
</tr>
<tr>
<td>FIP10</td>
<td>Soil temperature -30 cm</td>
<td>1</td>
<td>17.1.2013, 22.1.2013, 23.9.2013, 14.12.2013</td>
<td>Previous and following true values used to replace data spikes</td>
</tr>
<tr>
<td>FIP10</td>
<td>Soil moisture –20 cm (2)</td>
<td>31</td>
<td>30.12.2013</td>
<td>Previous and following true values used to fill data gaps</td>
</tr>
<tr>
<td></td>
<td>Soil moisture –20 cm (1)</td>
<td>B7</td>
<td>1.1.00:00–2.1. 22:00, 15.4. 13:00 – 20.4. 21:00, 26.4. 11:00 – 27.4. 06:00, 27.12. 15:00 – 29.12. 05:00</td>
<td>False data removed</td>
</tr>
<tr>
<td>FIP14</td>
<td>Soil moisture –20 cm (2)</td>
<td>B8</td>
<td>17.12.2013 13:00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.12. 18:00 – 31.12.2013 23:00</td>
<td>Previous and following true values used to fill data gaps</td>
</tr>
</tbody>
</table>
3.5 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 2013 were as follows (see also Table 8):

<table>
<thead>
<tr>
<th>Plot Code</th>
<th>Start Date</th>
<th>End Date</th>
<th>GDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIP4 (WOM2)</td>
<td>2.5.–19.11.2013</td>
<td>1528 GDD</td>
<td></td>
</tr>
<tr>
<td>FIP10 (WOM3)</td>
<td>2.5.–19.11.2013</td>
<td>1544 GDD</td>
<td></td>
</tr>
<tr>
<td>FIP11 (WOM4)</td>
<td>6.5.–15.10.2013</td>
<td>1384 GDD</td>
<td></td>
</tr>
<tr>
<td>FIP14 (WOM5)</td>
<td>6.5.–19.11.2013</td>
<td>1410 GDD</td>
<td></td>
</tr>
</tbody>
</table>

Measurement of the stand meteorology suffered some problems during 2013 (Table 7). The revised data (e.g. Figure 7) were stored in the POTTI database. Original primary data have also been stored in the POTTI database (processing stage = MEAS, status = not in use).

3.6 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 1, and a list of data in the POTTI database in Appendix 2.

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.

Table 8. Weather conditions in the study area during 2003–2013. 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, Pere et al., in prep.).

<table>
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<td>1651</td>
<td>497</td>
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</table>
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 9 (for the period 2003–2013, see Appendix 3).
Table 9. Material stored in Kronodoc related to forest monitoring on Olkiluoto island in 2013.

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<td>Results of forest monitoring on Olkiluoto Island in 2013</td>
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</tr>
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<td>Stand meteorology (FIP plots, WOM2-WOM5)</td>
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<td>Results of deposition monitoring at MRK and FIP plots</td>
<td>PRJ-004074/POS-010859</td>
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4 RESULTS AND DISCUSSION

4.1 Bulk deposition and stand throughfall

The amount of precipitation in 2013 in open areas (bulk deposition, BD) and stand throughfall (TF) was lower than in any other years during the whole monitoring period except in 2005 when the precipitation amounts were low as well (Figure 8). There were no clear increasing or decreasing trends in the pH of BD and TF during the period 2004–2013. 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.

There was variation in the deposition of total nitrogen in BD and TF during 2004–2013. The values decreased further in BD during 2013 compared to 2012 and 2011. In 2011 deposition 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 but the values decreased in 2013. 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 2004–2013 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 and 2013 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

![Figure 8. Annual precipitation (mm) in open areas (bulk deposition) and stand throughfall in Scots pine (FIP4), Norway spruce (FIP10), birch (FIP11) and black alder (FIP14) dominated stands during 2004–2013.](image)
Figure 9. The NO$_3$-N deposition in bulk deposition (BD, open area) and stand throughfall (TF, inside the stand) on Olkiluoto in 2004–2013. 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 2004–2013. 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.
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.

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. In 2013 the sulphur deposition decreased close to the level measured during 2004–2008, and this was especially the case on plot MRK2. The S deposition in an open area on Olkiluoto was higher during 2009–2013 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 2009–2013 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 2011–2013. 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

![Figure 11](image_url)

*Figure 11. The SO$_4$-S deposition in bulk deposition (BD, open area) and stand throughfall (TF, inside the stand) on Olkiluoto in 2004–2013. 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.*
Al, Fe, Mn, Si, Cu, Zn and PO₄-P in BD and TF were relatively similar in 2013 compared to the values in earlier years.

The concentrations of all the measured BD and TF samples during 2013 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 2013 for Ba and Sr.

In general, the precipitation amount was relatively low in 2013. The NH₄-N deposition that decreased in 2012 compared to the situation in 2011 remained relatively low also in 2013. The NO₃-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004–2012. However, in 2013 the NO₃-N deposition decreased.

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 2004–2013. In 2013, the value was 16%. Corresponding values on the plots FIP10 (during 2005–2013) and FIP11 (during 2007–2013) were 1–28% (14% in 2013) and 1–17% (11% in 2013), 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, 29% during 2012, and 20% during 2013, 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 10-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 2004–2013 (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 ten 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 2013 was comparable to a general level measured on this plot during the earlier years (2005–
2012). 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 2004–2013 (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 2004–2013. The bars denote the standard error of the mean.
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 NH₄-N, and especially the NO₃-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 (NH₄ and NO₃) mineralized from the organic layer is rapidly taken up by the roots of the trees and ground vegetation. The low NO₃-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 NO₃-N concentration exceeded 1 mg/l in the soil solution. The nitrate concentrations were far below this limit in Olkiluoto also in 2013. The nitrogen situation was totally different on the black alder plot, FIP14, where nitrate concentrations were high in the soil solution in 2010 and even in 2011–2013, although the concentration has clearly decreased (Figure 14a).

Sulphate concentrations at a 5 cm depth on FIP4 were at the same level in all ten 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 SO₄-S concentrations during 2004–2013 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 2013 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
Figure 14b. Annual mean sulphate (SO₄-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 2004–2013. The bars denote the standard error of the mean.

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 2013 were relatively similar to those in earlier years. The concentrations of Al³⁺ 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 2013 to the values measured in earlier years.

The concentrations of heavy metals (Cd, Cr, Ni, Pb) at all depths at Olkiluoto during 2004–2013 continued in many cases to be quite low. In 2013, 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.

4.3 Tree stand transpiration

The monthly stand level transpiration of the Scots pine (FIP4) dominated stand is presented in Figure 15. In 2013 the monthly level of transpiration on the plot FIP4 was lower during May to August than during previous years (2008–2012, Figure 16). High values (6.1 – 8.7 mm/month) in winter months (January – March 2013) 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 2013. Data for the Norway spruce stand (FIP10) is missing due to measurement problems during 2013.

Figure 16. Monthly stand level transpiration (mm) on the FIP4 (left) and FIP10 (right) sample plots during 2008–2013. Results are only reliable for the period of April–November (FIP4 2008–2011 and FIP10 2008–2010), April–October (FIP4, 2012) or April–December (FIP4, 2013).
4.4 Litterfall production and element return to the forest floor

Total annual litterfall production on coniferous plots (FIP4 and 10) and on birch plot (FIP11) was higher in 2012 compared to 2011 (Figure 18). The temporal trends, however, on coniferous plots (Figures 17a and 17b), on birch plot (Figure 17c) and on alder plot (Figure 17d) were more or less the same as during the previous collection period (2011, Aro et al. 2014).

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

Figure 17a. Mass (g$_{dw}$/m$^2$) of different fractions of litterfall on different collection dates during 2012 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 2012 on the Norway spruce dominated plot. Fraction legends, see Figure 17a.
Norway spruce in 13 Finnish ICP Forests plots (mainly in southern Finland) during 1996–
2003. The corresponding values for the FIP plots were 630 g$_{dw}$/m$^2$ (Scots pine stand), 452
(Norway spruce stand), 191 (birch-dominated stand) and 391 (alder stand) during 2012. Higher
(and increasing) values found on Olkiluoto Island are due to natural reasons. The
Scots pine stand (FIP4) is too dense because the stand has not been thinned for a long
time, and additionally Scots pine blister rust (caused by fungi Cronartium flaccidum (Alb.
et Schw.) Wint. and Peridermium pini (Pers.) Lev.) is causing trees to shed more and
more needles each year. The spruce stand (FIP10), located in the nature protection area of
old growth forests, is deteriorating because no silvicultural measures are allowed to do
there. In birch plot large part of the trees are just getting high enough to shed leaves to the
collectors, and hence the amount of litter has been increasing more or less linearly since
the beginning of litter collection (Figure 18).
The most notable differences in element concentrations between the plots are those of Al and N concentrations (Tables 10 and 11). Al is commonly higher in living pine needles than in spruce needles and this can also be seen in the Al concentration (Table 10) in litterfall on the pine plot (FIP4) compared to the spruce plot (FIP10). High Al (Table 10) and Fe (Table 12) 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 11, 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 11).

**Figure 18.** Annual total litterfall production (g$_{dry}$/m$^2$) without large branches on the FIP plots during 2004–2012. All branches excluded in 2004–2005.
Table 10. Aluminium concentration (mg/kg dry) in the seven fractions of litterfall on the FIP plots during 2012. The annual total is given if there has not been enough material for chemical analysis in individual collection periods.

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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 11. Nitrogen concentration (%) in the seven fractions of litterfall on the FIP plots during 2012. The annual total is given if there hasn’t been enough material for chemical analysis in individual collection periods.

<table>
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</table>

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 12. Iron concentration (mg/kg dw) in the seven fractions of litterfall on the FIP plots during 2012. The annual total is given if there hasn’t been enough material for chemical analysis in individual collection periods.

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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"
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 2013, excluding litterfall production, results of which cover the previous year, 2012. 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 current monitoring networks during 2013. Two new intensive monitoring plots were established.

In general, the precipitation amount was relatively low in 2013. The NH$_4$-N deposition that decreased in 2012 compared to the situation in 2011 remained relatively low also in 2013. The NO$_3$-N deposition values increased in 2012 and were the highest for the whole monitoring period during 2004–2012. However, in 2013 the NO$_3$-N deposition decreased. The increase in NO$_3$-N in bulk deposition in 2012 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 2013 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 2004–2013 continued in many cases to be relatively low.

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 2013 the monthly level of transpiration in the Scots pine dominated stand (FIP4) was lower during May to August than during previous years (2008–2012). 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 higher in coniferous plots and in birch plot in 2012 compared to the previous collection period 2011. Total annual litterfall production (without larger branches) was 630 g dry/m² (Scots pine stand), 452 (Norway spruce stand), 191 (young birch-dominated stand) and 391 (alder stand). High values (increased since 2009) found on Olkiluoto Island are due to natural reasons. The Scots pine stand (FIP4) is too dense because the stand has not been thinned for a long time, and additionally Scots pine blister rust is causing trees to shed more and more needles each year. The spruce stand (FIP10), located in the nature protection area of old growth forests, is deteriorating because no silvicultural measures are allowed to do there. On birch plot trees have grown high enough to shed leaves to the collectors, and hence the amount of litter has been increasing more or less linearly since the beginning of litter collection. 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.

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


Appendix 1. Data definition in the POTTI database.

DATA. Weather observations in a forest stand

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| Subtext files |

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<td>Channel7</td>
<td>Soil temperature -90 cm °C</td>
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<td>Proportional humidity, 2 m %</td>
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<td>Air pressure, 2m hPa</td>
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<td>Temperature (top of mast), 24 m (max) °C</td>
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<td>Channel35</td>
<td>PAR-radiation, 24 m (min) µmol s⁻¹ m⁻²</td>
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<td>Channel37</td>
<td>Total radiation, 24 m (min) W m⁻²</td>
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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

WOM 3

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<td>Channel9 Soil temperature -10 cm 1 °C</td>
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<td>Channel14 Soil temperature -20 cm 3 °C</td>
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<td>Channel17 Girth Band 1, tree No. 29 (mm)</td>
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<td>Channel20 Proportional humidity, 2 m %</td>
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Method variables

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- 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
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Method parameters
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**DATA. Vegetation nutrition analysis**

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**DATA. Soil chemical analysis**

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<td>OM_kgha (kg/ha dw) amount of organic matter (in dw)</td>
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<td>Al_kgha (kg/ha dw) total element amount, wet digestion+ICP/AES, dw</td>
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**DATA. Foliage chemical analysis**

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### Digestion + ICP/AES, dw
- **Na_kgha** (kg/ha dw): total element amount, wet
- **Ni_kgha** (kg/ha dw): total element amount, wet
- **P_kgha** (kg/ha dw): total element amount, wet
- **Pb_kgha** (kg/ha dw): total element amount, wet
- **S_kgha** (kg/ha dw): total element amount, wet
- **Zn_kgha** (kg/ha dw): total element amount, wet

### Sum of base cation concentrations (mmol/kg):
- **BC_sum (mmol/kg)**: Cammol + Kmmol + Mgmol + Nammol
- **CEC (mmol(+)/kg)**: cation exchange capacity (BC sum + exchangeable acidity)
- **BS (%)**: Base saturation = 100*BC/CEC
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**DATA. Sampler and sensor locations**

**FIP**

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**DATA. Nutrient analysis of litter fractions**

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Method parameters
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**Appendix 3.** Material related to forest monitoring on Olkiluoto island stored in Kronodoc during 2003–2013.

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