Research Stimulus Fund

Final Report

‘Biogeochemistry of Irish Forests—ForFlux Project’

DAFM Project Ref No: RSF 07 510
Start date: 1st December 2007
End date: 31st November 2010
Revised end date: 31st December 2011

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Other Principal Collaborating Researchers:
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Jim Johnson, Trent University
Pat Neville, Coillte

Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL [X] APPLIED/PRE COMMERCIAL

Key words: (max 4) forest health; atmospheric deposition; soil solution; nutrient budgets
1. **Rationale for Undertaking the Research**

The primary objective of this research was to provide a better understanding of forest biogeochemical cycles and the interaction of forests with nutrient and rainwater fluxes. This is needed to underpin ongoing monitoring of forest health, which itself reflects complex whole-ecosystem processes including nutrient flows and biogeochemical interactions. In addition to protecting the forest ecosystem, such monitoring and research contribute to our understanding of ecosystem function as it relates to ecosystem services, such as the filtering function of the forest and soil, which affects runoff-water quality. Furthermore, under changing climatic drivers (including changes in the chemical climate), and new directions in forest management (especially removal of more biomass as a major source of biofuel to offset fossil-fuel greenhouse-gas emissions), there is a need to understand the whole-ecosystem nutrient budget of forests, accounting for both long-term trends over decades, and shorter-term variability over seasons and years. Developing this baseline knowledge will provide for models that can be used by forest managers in site-specific scenario-testing, by policymakers for national sensitivity assessment, and by climate researchers for detecting long-term change. Specific problem-sets the research can contribute to are toxicities to tree-roots, nutrient supply to sustain forest-crop production, runoff- and groundwater-quality, and the assessment of critical loads of acidity and of nutrient nitrogen.

2. **Research Approach**

Existing long-term monitoring data from three forest plots in Ireland were used to assess trends in precipitation, throughfall and soil water chemistry. These observations were supplemented with extensive soil and vegetation chemical analysis, and soil hydrological analysis to enable chemical fluxes and pools to be quantified. These data were supplement with bioavailable nutrient-supply-rate observations using Plant Root Simulator (PRS™) probes. Quantifying nutrient pools and exchanges between pools is a route towards developing a mass-balance model of forest nutrition, which may be used to assess proposed scenarios of more-intensive biomass removal for fuel. Hydrological and geochemical models were used to further investigate input–output budgets and provide new ways to assess future ecosystem quality. Soil-weathering rates were assessed, as an input to nutrient cycles, based on an innovative total-oxide analytical and modeling technique. Ammonia concentrations were monitored using passive-diffusion samplers, allied to comparison among competing sampler models, towards assessing ammonium deposition as a nutrient input to forests.

3. **Research Achievements**

**Sulphur deposition** in precipitation to Irish forests has responded in the long term to reduced emissions from large combustion plants (legislated under the NEC directive and UNECE Gothenburg Protocol); long-term monitoring data for forest ecosystems have responded in increased throughfall and soil-solution pH, and reduced concentration of potentially toxic root-zone aluminium.

**Nutrient outputs following clearfell** have been published, comparing forests in Ireland and Germany (DOI: 10.1007/s10533-010-9459-9).

**Nutrient pools** have been prepared for Irish forests for the first time. This important development allows the establishment of management-oriented input–output budgets for forests, allowing scenario-testing of proposed management changes. This is particularly important for site-specific assessment of the feasibility of increased biomass and forest-residue removals proposed for biofuel and other uses, and a project proposal has been submitted to develop this output.
**Ambient atmospheric ammonia concentrations**, measured in Ireland, distant from major emission sources, vary with strong seasonality indicative of spring management of grasslands with stored organic manures and nitrogen fertilizers. NO₂ & SO₂ measurements were also made.

**Long-term forest-ecosystem monitoring data** contribute to large European networks. Data variability includes seasonality, long-term trends, multi-annual impacts of deposition events, and regional variation, confirming the need for continuous long-term monitoring.

Soil mineral weathering rates were assessed by a novel method of measuring **total-oxide content**. This was done across the BioSoils network (n = 38), and supported by measurement of **soil surface area** at a sub-set of sites, and **modelling of soil base-cation weathering rates**. Together these measurements allow a first quantification of the role of mineral-weathering as a continuous input of nutrients of significance for forest ecosystems.

Maps of modeled **soil-water percolation** for forest landcovers have been prepared for the first time for Ireland.

The research has developed important new datasets for Ireland, representing a wide range of forest sites, and many key processes involved in nutrient supply to forests. The following figure shows the sites involved in the measurements, and the table lists the datasets developed. “Level I” and “Level II” sites refer to plots contributing to the ICP-Froests networks.

<table>
<thead>
<tr>
<th>Observations</th>
<th>Forflux</th>
<th>Level I</th>
<th>Level I &amp; II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient availability [PRS probes]</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Bulk and throughfall chemistry [IER]</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Total oxides [BioSoils]</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Atmospheric gaseous NH₃, NO₂ and SO₂</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Nitrogen mineralisation</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
Bulk density (fixed-volume soil cores) 6  x  x
Water holding characteristic 7  x  x
Biomass nutrients 8  x  x
HOBO data loggers 9  x
Soil surface area 10  x
Soil sulphate adsorption 11  x
Absorbance and DOC in soil solution 12  x
Biomass 13  x  x

1. Plant Root Simulator (PRS) probes used for soil chemistry [www.westernag.ca/innov]
2. Ion Exchange Resin (IER) columns for precipitation and throughfall chemistry
3. Total oxides measured on 85 soil samples [BioSoils]; mineralogy measured on Level III where data gaps
4. Atmospheric gaseous concentrations measured using Gradko samplers [Level II]
5. Nitrogen mineralisation (buried bag) measured across four seasons at Level III plots and two seasons at forflux plots, including pH, loss-on-ignition, particle size and carbon-nitrogen-sulphur
6. Fixed volume cores for bulk density, particle size, field moisture, loss-on-ignition and pH (n = 175)
7. Fixed volume cores for soil water holding capacity determined by Cranfield, UK (n = 64)
8. Measurement of biomass nutrients (needles, branches, bark, roots, bole) at Level II and forflux plots (n = 325)
9. Data loggers for soil moisture and temperature (and air temperature) installed at Ballinastoe, Cloosh and Brackloon (water content and temperature at @ 2 depths)
10. Soil surface area estimated using BET analysis at Level III and Ballyhooly and Roundwood
11. Soil sulphate adsorption at Level III and Ballyholly and Roundwood
12. Relationship between soil solution DOC and absorbance [Level III only]
13. DBH measured at Ballinastoe (omitted from BioSoils) and coarse woody debris measured at forflux sites

4. Impact of the Research

This research has provided assessments of long-term trends in atmospheric deposition and biogeochemical cycling, which have confirmed the long-term ecosystem response to reduced sulphur emissions from large combustion plants. Nutrient pools have been further characterised (based on extensive observations for forest-tree and forest-soil pools), and better assessments made of key outputs following clearfell harvesting. Atmospheric ambient ammonia concentrations measured at these sites have continued the only long-term monitoring of this major source of nutrient export from farms to low-nitrogen ecosystems such as forests and heathlands.

The continued monitoring of atmospheric deposition and throughput of nutrients in forest ecosystems has satisfied Ireland’s commitment to supply forest-biogeochemistry data under the United Nations Convention on Long-Range Transboundary Air Pollution, through the International Cooperative Programme ICP-Forests.

The end-users of this research are forest managers, forest-management policymakers, water-resource managers, and researchers into ecosystem-scale processes of nutrient cycling, greenhouse-gas emissions, nitrogen transformation, and plant health.

5. Exploitation of the Research

This research is of a basic rather than an applied nature, as it addresses concepts of ecosystem functioning. In addition, its output of long-term monitoring data provides application in modelling
The research has brought forward the possibility of developing a nutrient mass-balance model for forests, using mineral weathering, atmospheric deposition, nutrient cycling, and management actions as inputs to assess sustainability of nutrient availability. This possibility has been formulated into a research proposal currently under consideration, which could lead to a significant input to the Code of Best Forest Practice.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents
The products of this research are in the public domain.

(b) Innovations adopted by industry
Recommendations for industry have not been made from this research. The proposed dependent research to formulate a nutrient model for site-specific forest management can, we believe, have important and wide-ranging implications for innovation in forest management. Specifically, it can be a basis for guiding proposed innovations by forest managers towards implementing those more-intensive harvesting approaches that can be undertaken, while ensuring sustainable nutrient supply to subsequent forest stands.

(c) Number of companies in receipt of information
The products of this research are in the public domain.

(d) Outcomes with economic potential
1. Quantification of nutrient pools and exchanges, and providing a means to test scenarios of greater biomass removal, are essential to protecting the sustained financial yield from forests.

(e) Outcomes with national/policy/social/environmental potential
1. Forest biogeochemical monitoring has provided a basis for quantifying forest nutrient pools and turnover for major biomass compartments, and for soil, as well as inputs in deposition, cycling, and outputs by plant-uptake and soil-solution throughflow. These provide essential inputs to proposed mass-balance models for use by forest managers, with which proposed management scenarios such as increased biomass removal for fuel can be assessed in terms of their nutrient sustainability.

2. Ammonia monitoring, by association with the only long-term ambient ammonia monitoring network, has provided important independent measurement of the background levels, their seasonal and inter-annual variability, and long-term trends. This will be important in characterising the national emission and deposition states for this eutrophying and acidifying substance.

(f) Peer-reviewed publications, International Journal/Book chapters.

http://www.sisef.it/iforest/show.php?id=538
Scientific abstracts or articles including those presented at conferences


12. Huber, C., Aherne, J., Weis, W., Cummins, T., Farrell, E.P. and Göttlein, A. Impacts of forest clear-cutting on seepage water quality of Norway spruce stands at Ballyhooly (Ireland) and Höglwald...
(Germany) under high sea salt and nitrogen deposition. EUROSOIL 2008, Vienna, Austria, August 23-31, 2008 [poster presentation].


(h) National Report

(i) Popular non-scientific publications

(j) Workshops/seminars/open days at which results were presented (excluding those in (g))


7. Permanent Researchers

<table>
<thead>
<tr>
<th>Institution Name</th>
<th>Number of Permanent staff contributing to project</th>
<th>Total Time contribution (months)</th>
<th>Average time contribution per permanent staff member</th>
</tr>
</thead>
<tbody>
<tr>
<td>University College Dublin</td>
<td>3</td>
<td>7.92</td>
<td>2.64 months</td>
</tr>
<tr>
<td>Trent University</td>
<td>1</td>
<td>0.96</td>
<td>0.96 months</td>
</tr>
<tr>
<td>Coillte</td>
<td>1</td>
<td>0.96</td>
<td>0.96 months</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td><strong>9.84</strong></td>
<td><strong>1.97 months</strong></td>
</tr>
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</table>
8. **Researchers Funded by RSF**

<table>
<thead>
<tr>
<th>Type of Researcher</th>
<th>Number</th>
<th>Total Time contribution (months)</th>
<th>Average time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Doctorates</td>
<td>2</td>
<td>1.72</td>
<td>0.86 months</td>
</tr>
<tr>
<td>Contract Researchers</td>
<td>1</td>
<td>5.4</td>
<td>5.4 months</td>
</tr>
<tr>
<td>PhD postgraduates</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Masters postgraduates</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Temporary researcher</td>
<td>4</td>
<td>15.84</td>
<td>3.96 months</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7</strong></td>
<td><strong>22.96</strong></td>
<td><strong>3.28 months</strong></td>
</tr>
</tbody>
</table>

9. **Postgraduate Research**

Total Number of PhD theses: 1


Total Number of Masters theses: 3


10. **Project Expenditure**

Total expenditure of the project: € 220,726

Total Award by RSF: € 225,374.91

Other sources of funding (specify) €

1.
2.
Breakdown of Total Expenditure

<table>
<thead>
<tr>
<th>Category</th>
<th>UCD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract staff</td>
<td>16,099</td>
<td>16,099</td>
</tr>
<tr>
<td>Temporary staff</td>
<td>30,049</td>
<td>30,049</td>
</tr>
<tr>
<td>Post doctorates</td>
<td>5,997</td>
<td>5,997</td>
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<tr>
<td>Post graduates</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Consumables</td>
<td>27,620</td>
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<tr>
<td>Travel and subsistence</td>
<td>28,700</td>
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<tr>
<td><strong>Sub total</strong></td>
<td>108,464</td>
<td>108,464</td>
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<tr>
<td>Durable equipment</td>
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<td>2,401</td>
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<tr>
<td>Subcontracts</td>
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<td>Overheads</td>
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<tr>
<td><strong>Total</strong></td>
<td>220,726</td>
<td>220,726</td>
</tr>
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</table>

11. **Future Strategies**

The research has led to the realistic prospect of developing a forest nutrient model for use by forest managers and policymakers, for evaluating management scenarios on a site-by-site basis. A proposal has been submitted to DAFM to pursue this opportunity.

Ammonia monitoring has been consolidated for the only long-term ambient atmospheric ammonia network for Ireland. A paper is in development based on this, and a proposal is in preparation for a current EPA call on assessing ammonium deposition for Ireland.

12. **Industry Collaboration**

Coillte collaborated in the project, providing a physical context for monitoring and surveys in managed forests, operating the network of monitoring sites with forest-health and intensive biogeochemical monitoring throughout the project, and contributing to the scientific assessment of the findings.