# CoFoRD

# Final Report

***ForSite – Critical Biomass removal on Irish Forest Soils***

**DAFM Project Reference No:** 11C208

**Start date:** 1-January 2013

**End Date:** 30-June 2017

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Prof. Julian Aherne, Trent University, Peterborough Ontario Canada
Dr Kenneth A. Byrne, University of Limerick
Dr Liwen Xiao, Trinity College Dublin
Dr Rachel Creamer / Dr David Wall, Teagasc

**Please place *one* "x" below in the appropriate area on the research continuum where you feel this projec fits**

Basic/Fundamental → Applied/Pre Commercial

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | X | | |

**Please specify priority area(s) of research this project relates to from the National Prioritisation Resea Exercise* (NRPE) report;**

| **Priority Area (s)** | **Not applicable** |
|---|---|

Note this plan was published in July 2013, after the project started.

**Key words:** *(max 4)*
forest; biomass; soil; nutrients

## 1. Rationale for Undertaking the Research

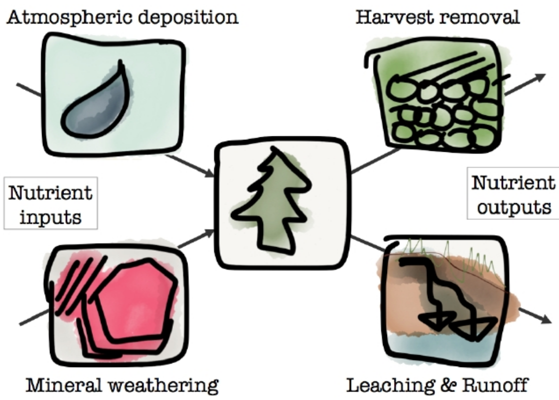
*This section should outline the rationale for carrying out the research and identify the need / problem to be addressed*

We need to reduce the use of fossil fuels, as they give a net input of carbon dioxide to the atmosphere, a driver of climate change. To reduce fossil-fuel use, the Renewable Energy Directive requires EU member states to derive 20% of energy needs from renewables by 2020. Biomass fuels are one renewable alternative, and forest biomass such as branches and foliage currently retained in the forest are a large potential fuel source for generating energy. Removing this additional biomass increases the export of nitrogen and other nutrient elements from the forest, which may impact on future nutrient supply for forest growth. This concern, that increase biomass harvest to provide fuel as a replacement for fossil fuels may impact on nutrient supply for future forest growth, is the rationale for the ForSite project.

Possible approaches to assess the risk of nutrient impact from biomass harvesting are:

- Level 0: assigning risks to soil-type classes
- Level 1: nutrient balance modelling
- Level 1+: ground-based monitoring of nutrient impacts of biomass harvesting, accounting for replacements, complex site nutrient sources, & real-time crop demand

This project takes the Level 1 approach, and uses mass-balance budgeting to assess whether biomass removal gives net nutrient loss, and compares that loss to nutrient supply and reserves. This gives a basis for sustainable soil-nutrient supply for forests, as a support for forest health and forest productivity. New datasets have been compiled of nutrient sources for forests, other than fertiliser or amendment inputs, and of potential nutrient removals in stem, branch and whole-tree biomass.




The concept of nutrient mass-balance in nutrient exchange for a forest ecosystem. Inputs from atmospheric deposition and mineral weathering are compared to outputs in harvesting and drainage (leaching & runoff). Increasing biomass harvest, to include branches and foliage, increases the removal side of the mass balance.

Nutrient mass-balance deficit, where the overall sum of nutrient exchanges is negative, is assessed against nutrient supply in mineral weathering and deposition, and against the soil pools of available nutrients. For potassium, calcium and magnesium, nutrient mass balance is compared to soil cation exchange pool. The number of forest rotations represented by the soil pool is calculated.

In addition to climate change, air pollution has been a concern for forest health since the mid 1980s. Under the UCECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), continuous monitoring of hydrochemical fluxes and concentrations has taken place at three forest plots in Ireland since 1991 in order to understand the cause–effect relationships between air pollution and forest health. These form part of the pan-European ICP Forests Level II network (Integrated Co operative Programme) which supports emissions controls under CLRTAP. This information is used to support annual surveys of forest condition at Level I plots. Today, the assessment of forest condition under the Level I and intensive Level II long-term forest monitoring programmes constitutes one of the world's largest bio-monitoring networks.

In addition to supporting air-quality policy, the Level II forest monitoring supports a sustainable and productive forest sector in Ireland in a number of ways including:

- Provides an understanding of nutrient cycling and biogeochemical processes;
- Supports the assessment of residue removal in Irish forests on nutrient availability e.g. Johnson et al. (2015);
- Contributes to the determination of critical loads of air pollution for forest, water and semi-natural ecosystems e.g. Johnson et al. (2016), Aherne et al. (2014);
- Integrates with other studies of water and soil quality e.g. those related to forest harvesting activities (Hydrofor) and carbon sequestration (CForRep);
- Monitoring in Ireland also contributes to Europe-wide assessments, such as changing deposition (Waldner et al. 2014) or changes in dissolved organic carbon in soil solution (Camino-Serrano et al. 2016).

## 2. Research Approach

*Specify the research methodologies employed, emphasising novel techniques and also outline any modifications from the original approved project proposal*

The research approach of ForSite is to use national-scale datasets of soil physical and chemical characteristics, climate, and national forest inventory, combined with previous and new field sampling as well as long-term records of rain and air quality to construct an ecosytem-scale assessment of increasing nutrient export from managed forests, though an online interface.

Atmospheric deposition has been measured in long-term deposition monitoring plots, part of the ICP Forests and ICP Integrated Monitoring networks. These forest-based measurements are combined with precipitation-chemistry measurements at sites where long-term datasets exist, and the high-density network of Met Éireann rainfall stations. Mapping uses simple kriging for interpolation among stations.

New analysis of mineral-soil materials has been undertaken, with modelling to estimate the input to the biological system of the ecosystem from mineral weathering. (Although physically within the soil, nutrients in minerals only become available to plants following solution.) Samples were available from the Teagasc Irish Soil Information System survey, as well as from the CForRep (ucd.ie/cforrep), SUAS project [link], and BioSoils project [link].

The approach to quantifying outpus in water is to combine overland flow and soil seepage ouputs from the MetHyd model, ascribing precipitation concentrations to overland flow and soil-solution concentrations to soil throughflow.

Estimation of the export of nutrients in biomass varies according to the component of the tree. The stemwood, branches, and remaining foliage have been established as three distinct compartments for this estimation. We have considered harvesting scenarios from a sequence of increasing intensity:

Stem-only harvesting (SOH) of marketable main stems to 7 cm top diameter
Stem–branch harvesting (SBH) with leaves allowed fall, and branches removed
Whole-tree harvesting (WTH) where aboveground biomass is removed in full

While harvest quantities may be calculated, not all of this biomass is mobilisable. Branches used as brash roads to protect soils during extraction will become partly buried. We expect that some branch and foliage material will inevitably remain in the forest, and propose a default deduction of 30%, giving 70% mobilizable biomass.

Nutrient densities have been assessed from new sampling of biomass tissues, combined with existing datasets. These concentrations are multiplied by tissue mass amounts, quantified using allometric equations derived from UK Forest Research data. This approach is suitable where site-specific stand measurements are available. A less-specific approach has also been taken, computing biomass for mean yield-class by soil type, based on assessment of National Forest Inventory plots using the GROWFOR model. This allows mapping of yield class, and of biomass removal under harvesting scenarios.

Test indicators on the nutrient balance are given:

**Nutrient balance** at ecosystem level—negative balances indicate a loss of that nutrient element to the forest ecosystem under this harvest scenaro;
**Ratio of nutrient balance to inputs** in mineral weathering and deposition—where the ratio is small, uncertainties make it indistinguishable from zero; a relatively large ratio confirms a nutrient loss;
**Ratio of nutrient balance to soil pool**, and computed to show the number of forest rotations to exhaustion; pool reserves of several rotations suggest a loss occurring outside the timeframe of necessary climate-change response.

This assessment does not account for fertilisers, nitrogen fixation, gaseous losses, peat oxidation, or mycorrhizal mediation of N & P nutrition. This knowledge base requires improvement, but that limitation should not be used as an argument to prevent establishment of a biomass industry. Incomplete knowledge is not an excuse for inaction on climate change.

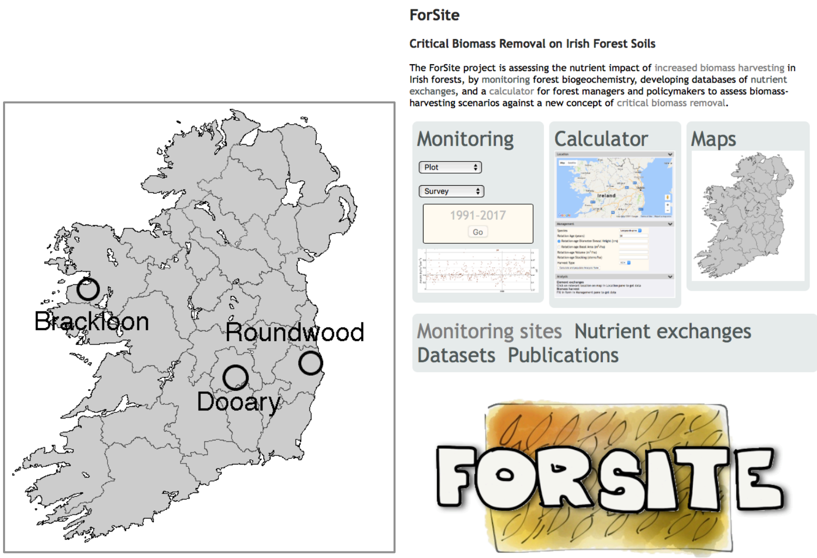
Prescriptive advice cannot be given on the sustainability of biomass harvesting. Where a clear deficit exists, that is of comparable magnitude to the supply from deposition and mineral weathering, and sufficient to exhaust the available supply in one or two rotations, the advice must be to find more information in support of a move to increase biomass harvesting, or restrict harvesting to existing stem-only-harvest practice. To support articulating this condition, the ForSite project has been based on that premise that a "critical biomass removal" can be identified, defined as the quantitative amount of long-term biomass removal below which impacts to site nutrient supply will not occur according to current knowledge.

## 3. Research Achievements/Results

*Outline main results achieved*

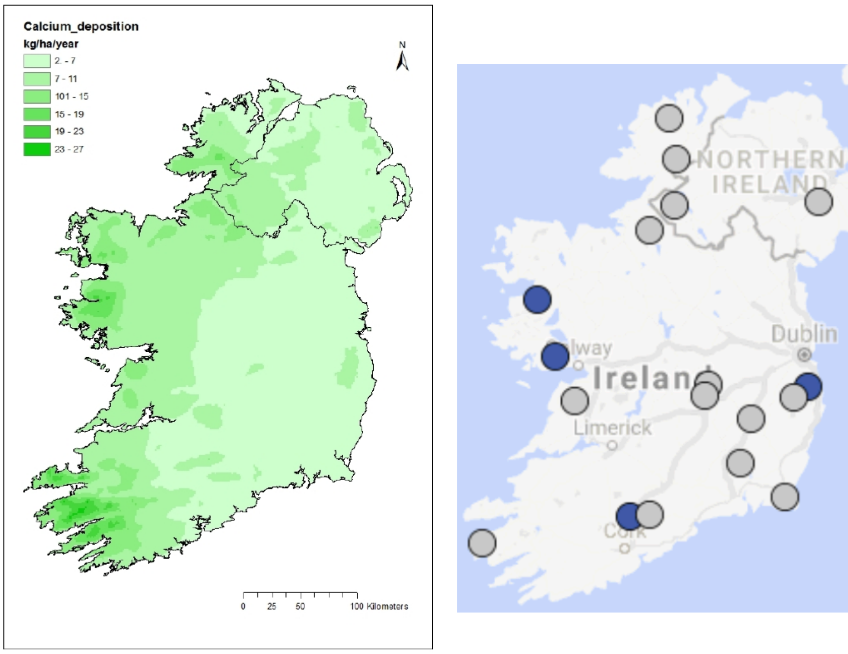
Biogeochemical monitoring in forest ecosytems has been carried out (**Task 1** MONITORING). Sampling of atmospheric deposition (bulk precipitation and throughfall) has been done at the three sites, while sampling of soil solution (at 0 cm and 25 cm depths) has been established at Brackloon and Roundwood. Tensiometers for measuring soil-water tension, as input to soil-water modelling, have been installed at Brackloon and Roundwood. Metorological monitoring has been established, with weather stations, and datalogger stations for soil temperature and soil moisture, at Brackloon and Roundwood.

Hydrochemical sampling has been done twice per month. These samples have been bulked across multiple samplers within each site, and analysed for each collection. This monitoring is the basis for determining deposition, a nutrient input to the forest.



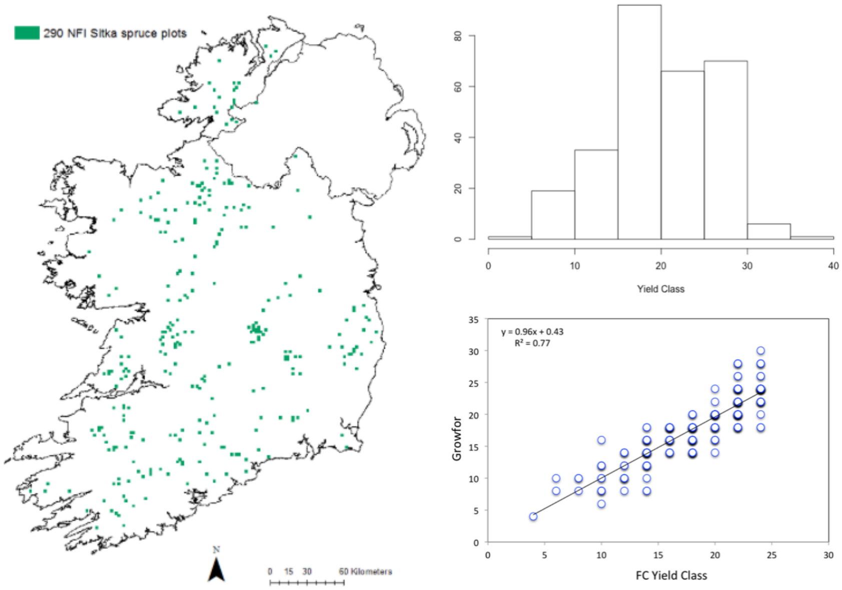

Monitoring site locations; ICP Forests Level II sites monitored under the ForSite project in Ireland. Right: the ForSite website, providing access to monitoring data, and to the ForSite Calculator. [http://forsite.ucd.ie/](http://forsite.ucd.ie/)

Data gathered annually has been submitted to ICP Forests and ICP Integrated Monitoring databases to support Ireland's data-submission obligations under the convention on LRTAP. Access to long-term monitoring data since 1988 has been provided under ForSite, collated and publicly available for the first time. Maps showing deposition of nutrients for Ireland have been prepared, and converted into gridded data coded as database field values for retrieval.



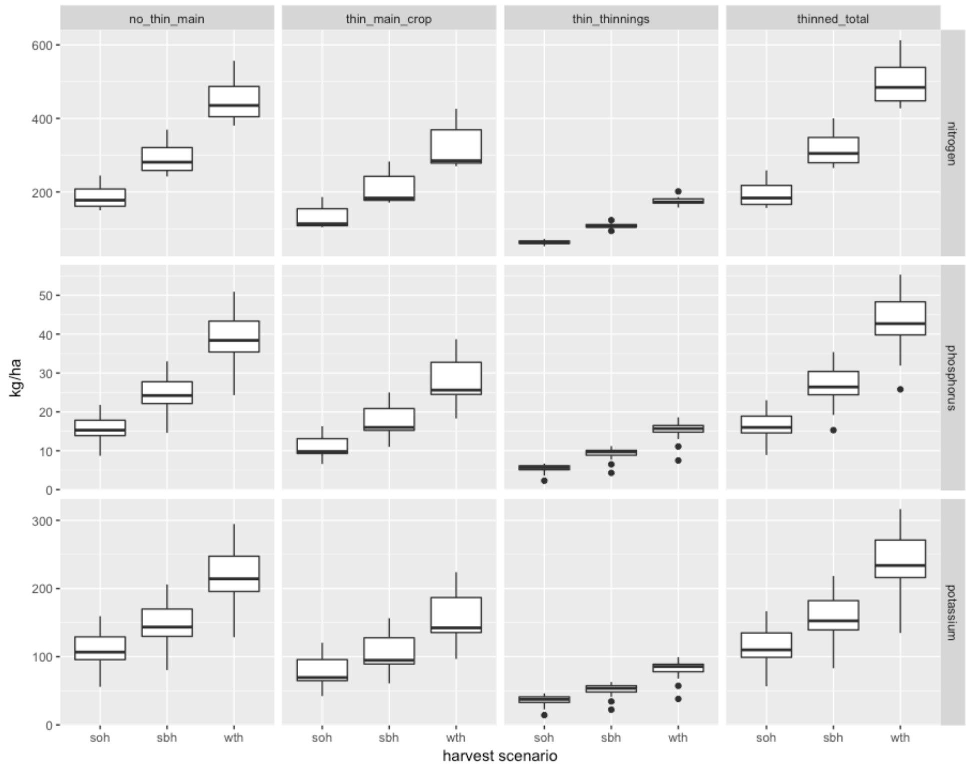

Calcium deposition in Ireland mapped under ForSite (left), using deposition data from eighteen sites (right) including those monitored under ForSite. UCD sites in blue.

Nutrient pools (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) in standing biomass were quantified by combining nutrient concentrations of foliage, stem bark, stem wood, and branches, with estimates of biomass in each compartment (**Task 2** BIOMASS NUTRIENTS). A dataset of nutrient concentrations for the principal commercial tree species and groups has been prepared by literature review combined with field sampling of nutrient concentrations. The nutrient pools of standing, harvestable and mobilisable biomass have been calculated, based on a representative yield class for Sitka spruce by broad soil types, and mapped for Ireland, building on National Forest Inventory data.



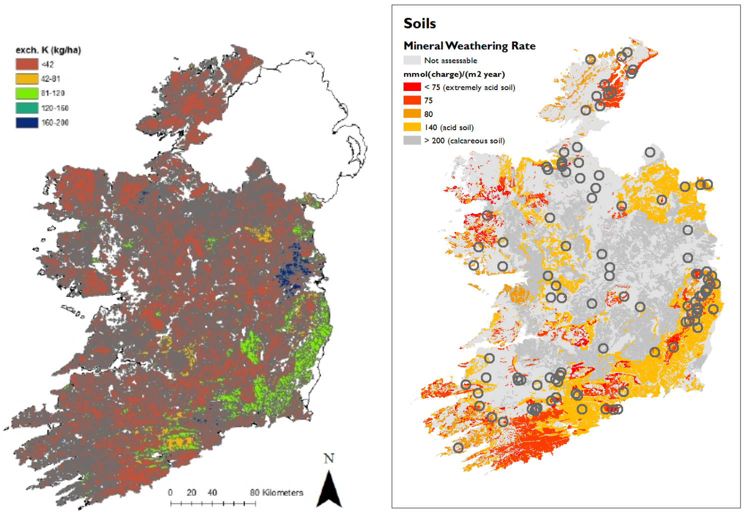

Left, 290 NFI plots assessed. Upper right, yield class for 290 NFI sites, based on plot measurements, using GROWFOR. Lower right, comparison of Yield Class approximated using GROWFOR and the graphical method of Forestry Commission growth curves (maximum YC24), for these 290 plots; the 1:1 line is shown.

Biomass nutrient pools have been assessed for pure Sitka spruce stands, by soil type, with Yield Class and associated rotation age from GROWFOR modelling of NFI plot data. Applying GROWFOR Yield Class by soil group to the Teagasc soil map gave an indicative map of yield class, weighted by the proportion of each soil type within soil associations, as tabulated by Simo et al. 2014.



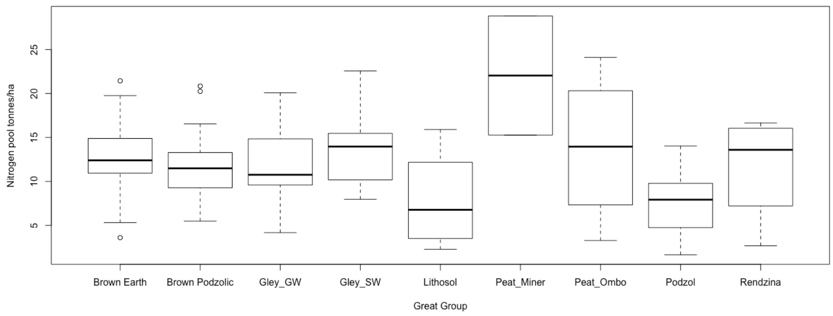

Nitrogen, phosphorus and potassium, kg/ha, in harvested biomass pools for harvest scenarios (stem-only harvest soh, stem–branch harvest sbh, whole-tree harvest wth) for unthinned stands, and for main crop, thinnings and total stand in thinned stands. This estimate is for Sitka spruce Yield Class 20 at rotation age of 35 years.

Nutrient supply to forests from mineral weathering has been assessed for mineral soils in Ireland for the first time (**Task 3** MINERAL WEATHERING). Soil samples were analysed for minerals and for mineral proxies, and process-based modelling was used to estimate mineral weathering, which was converted to spatial estimates of mineral weathering using soil data from the Irish Soil Information System. Exchangeable cation pools were calculated from Irish Soil Information System analytical data.




Left, exchangeable potassium pool (kg/ha) of soils, based on Irish Soil Information System data. Right, weathering rate of mineral soils ($mmol_{\pm}/(m^2$ year), based on samples (sites shown as circles), and process-based modelling.

Nutrient pools in soil were calculated, based on Irish Soil Information System data for bulk density corrected for coarse fragments, horizon thinckness, and total N, exchangeable K, Ca and Mg. The plant-available P assessed using Morgan's extract could also be calculated, but is not an indicator that is used for forest nutrition management.

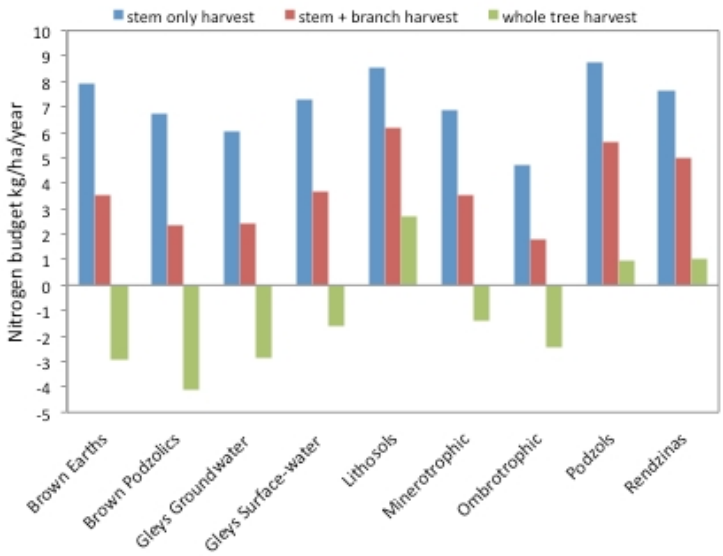



Soil Nitrogen pool, based on Teagasc Irish Soil Information System survey, grouped by soil type. Note that while peats have large pools, the N in all soils is slowly available, perhaps 2% of the pool per year in mineral soils.

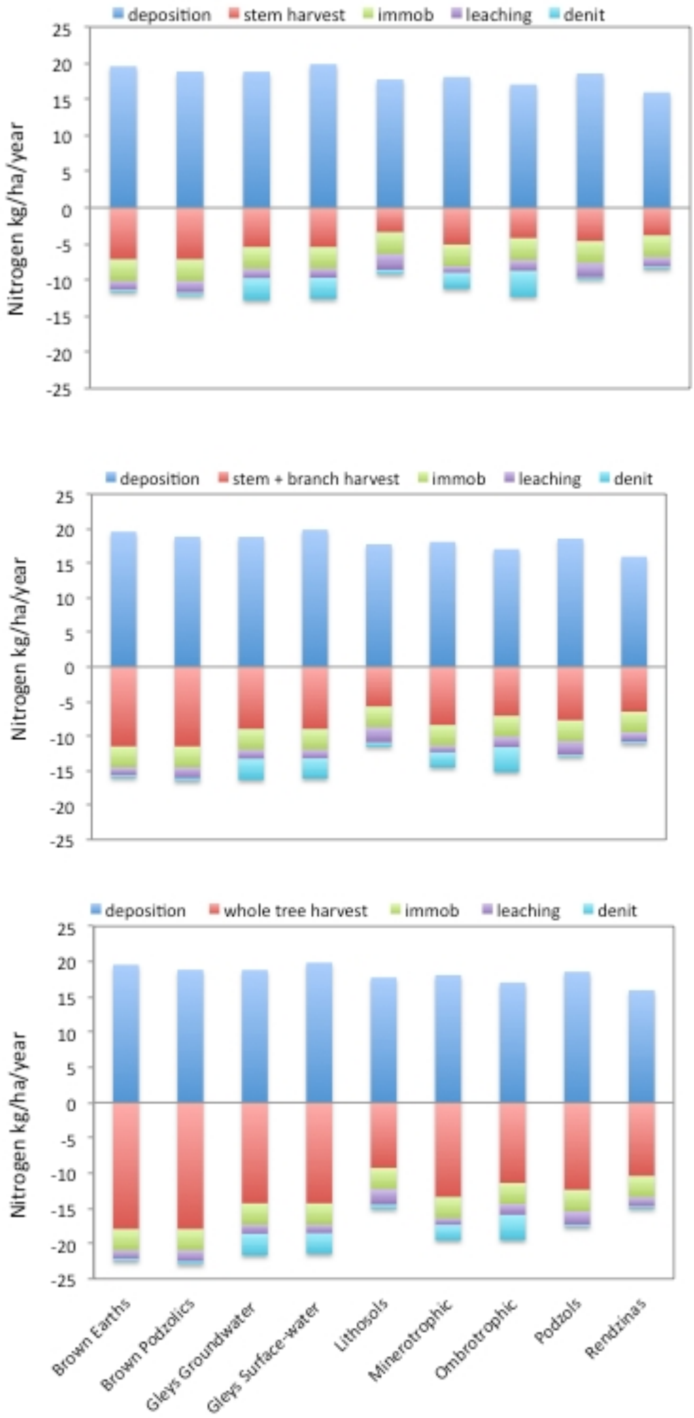
Nutrient losses in drainage, incorporating soil percolation and overland flow, were calculated and mapped for Ireland (**Task 4** SOIL WATER). Nutrient concentrations were taken from deposition monitoring values of bulk precipitation for runoff, and from monitoring of soil solution for soil percolation. Water quantities were modelled using inputs from Met Éireann and site meteorological and soil-hydrological measurements.

Studies were undertaken on nutrients in organic soils, by researchers at Trinity College Dublin (**Task 5** ORGANIC SOILS). Streams in peatland areas were monitored, and the effects of grass buffers on stream margins were assessed. Nutrient losses in drainage water were quantified. Nutrient distribution in biomass compartments, and the change of distribution with decomposition following harvest, were studied, continuing earlier work up to seven years after harvest. Equations were established for nutrient release from decomposing needles, small branches, and larger branches. Such equations could be used to estimate the nutrient removal from biomass pools on organic soils.

Input–output budgets of nutrients in forests under harvesting scenarios have been computed, showing nutrient balances by soil type and harvest type (**Task 6** INPUT–OUTPUT BUDGETS). Biomass calculations were done for 290 National Forest Inventory (NFI) single-species stands of thinning age, based on NFI plot information. Yield class was estimated, and the GROWFOR model was used to predict rotation-age biomass. This use of NFI plot data to estimate yield class is not a sufficient basis for site assessment, but is a means to give an indication of spatial variation at national scale, provided this is not applied to individual sites.




Nitrogen balance by soil type, for harvest scenarios. The balance is based on calculations at 290 NFI sites, and includes deposition as input, with 70% branch or foliage biomass removal, immobilisation by microbial biomass, leaching and denitrification as outputs. Decomposition of organic matter is not included, either as a long-term source, or as a potential loss following harvesting.




Nitrogen-balance components, by soil type, for harvesting scenarios stem-only harvest (SOH), stem–branch harvest (SBH) and whole-tree harvest (WTH). Outpus are harvest, immobilisation in microbial biomass, leaching (including runoff), and denitrification. Mineralisation of organic matter is not assessed, though it is the main source of N for plant nutrition; increasing negative balances here with increased harvest will be significant where N limitations are already expected.

An online tool was developed to allow computation of nutrient mass balance, and testing against soil nutrient pools (**Task 7** ForSite CALCULATOR). The ForSite Calculator takes user-input location to retrieve values for deposition, mineral weathering and drainage. It can use user-input location to provide default values of biomass nutrients according to harvesting scenario, or use site-specific input and internal conversions to give a more specific estimate. Outputs are nutrient mass balance, and mass-balance defecit compared to soil nutrient reserves.


Management

Analysis

**Element exchanges**
Irish Grid Reference: S 49816 73627
Lat, long: 52.8, -7.3

| | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|
| | | | (kg ha$^{-1}$ year$^{-1}$) | | | |
| Deposition | 22.5 | 0.2 | 2.3 | 3.8 | 4.3 | 6.2 |
| Weathering | - | - | - | - | - | - |
| Drainage | -0.9 | - | -1.3 | -3.3 | -5.8 | -11.8 |
| Harvest | -34.4 | -7.6 | -19.1 | -45.8 | -7.6 | - |
| Nutrient Balance | -12.8 | -7.4 | -18.1 | -45.3 | -9.1 | -5.6 |

Screen-grab of the ForSite Calculator under development, showing the drainage element-exchange, arrow. Note the value for P is assumed zero for mineral soils, and shown as not available.

The outputs of the research, including legacy monitoring datasets, new sampling and spatial datasets, as well as the calculator for assessing nutrient impacts of biomass harvesting, are hosted at http://forsite.ucd.ie/ (**Task 8** DISSEMINATION)

Reference (other than project publications listed below)


Simo, I., R.E. Creamer, L. O'Sullivan, B. Reidy, R.P.O. Schulte and R.M. Fealy 2014. Irish Soil Information System: Soil property maps (2007-S-CD-1-S1) Final Technical Report 18. Prepared for the Environmental Protection Agency by Teagasc.


## 4. Impact of the Research

*A summary of the impact of the research should be provided through the project outputs and outcomes however please provide a synopsis of the benefits / improvements the research has made to the area under investigation. Outline the benefits of the research to end users, e.g. industry, consumers, regulatory authorities, and scientific community etc*

The ForSite datasets show that there are opportunities for sustainably increasing biomass harvest, and that soil types can be shown as varying in their suitability for increased biomass removals. Management expertise in nutrient management is necessary to apply the assessment, and to mediate its nutrient-balance outputs and test indicators, to help inform decision-making. The calculator requires testing and refinement, and could be developed further and improved.

### 4(a) Summary of Research Outcomes

#### (i) Collaborative and Industry links developed during this research

By hosting the ICP Integrated Monitoring meeting in Ireland, which was attended by participants from 12 countries, Ireland has reaffirmed its role in the European forest-ecosystem monitoring community. These contacts were further strengthened by participation in related meetings, expert groups, cooperation on joint papers, and serving as National Focal Point, and as national contact points for working groups for ICP Forests and ICP Integrated Monitoring under CLRTAP.

Cooperation with the Agri-Benchmark project was established in 2016, with the transfer of data on nitrogen deposition from ForSite. This project is innovative in including atmospheric deposition of nitrogen (about 20 kg/(ha year) as an input in farm-based nutrient mass-balance budgeting. Researchers on this project are in UCD, IT Tralee, UCC, and Teagasc. Early results from the Agri-Benchmark project presented in Finland mention the use of atmospheric deposition in future work in this project.

### (ii) Outcomes where new products, technologies and processes were developed and/or adopted

This research provides an exploratory basis for the forest industry to consider the potential effect of nutrient removals that may be caused by increasing harvest to include branches and/or foliage.

The ForSite Calculator is a new information resource combining datasets on nutrient sources in forests, and a means to calculate nutrient mass balances. Subject to support, it can be further developed, and has the potential to be integrated into other systems for nutrient mass-balance budgeting in forestry, agriculture, or other land uses.

### (iii) Outcomes with economic potential

The ForSite outputs are all public domain. They have the potential to contribute to the development of the emerging forest biomass fuel industry, to reducing the burden of fines on Ireland, and to contributing to Ireland's efforts to offset climate change effects.

### (iv) Outcomes with national/policy/social/environmental potential

The mass-balance basis for assessing nutrient budgets in forests is a wholly new approach to assessing environmental impacts on forests, and impacts of forest management. While not assessed in this project, the potential applications of such approaches include examining the mass-balance impact of fertilising, amendment with wastes, and acidification. This is a coarse spatial tool, which does not give insights into processes, but does allow a first estimation of the net exchange of nutrient elements between the forest and its environment.

## 4 (b) Summary of Research Outputs

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

Asam, Z., M. Nieminen, A. Kaila, R. Laiho, S. Sarkkola, M. O'Connor, A. Sana, C. O'Driscoll, M. Rodgers, X. Zhan, L.W. Xiao. 2014. Nutrient and heavy metal dynamics in decaying harvest residue needles on drained blanket peat forests. European Journal of Forest Research. 133 (6): 969–982. Doi: 10.1007/s10342-014-0815-5

Asam, Zaki-ul-Zaman, Mika Nieminen, Connie ODriscoll, Mark OConnor, Sakari Sarkkola, Annu Kaila, Afshan Sana, Michael Rodgers, Xinmin Zhan and Liwen Xiao 2014. Export of phosphorus and nitrogen from lodgepole pine (Pinus contorta) brash windrows on harvested blanket peat forests. Ecological Engineering 64: 161-170. http://www.sciencedirect.com/science/article/pii/S0925857413005144
http://dx.doi.org/10.1016/j.ecoleng.2013.12.014

Camino-Serrano, Marta, Bert Gielen, Sebastiaan Luyssaert, Philippe Ciais, Sara Vicca, Bertrand Guenet, Bruno De Vos, Nathalie Cools, Bernhard Ahrens, M. Altaf Arain, Werner Borken, Nicholas Clarke, Beverley Clarkson, Thomas Cummins, Axel Don, Elisabeth Graf Pannatier, Hjalmar Laudon, Tim Moore, Tiina M. Nieminen, Mats B. Nilsson, Matthias Peichl, Luitgard Schwendenmann, Jan Siemens and Ivan Janssens. 2014. Linking variability in soil solution dissolved organic carbon to climate, soil type, and vegetation type. Global Biogeochemical Cycles 28 (5): 497-509. http://onlinelibrary.wiley.com/doi/10.1002/2013GB004726/full http://dx.doi.org/10.1002/2013GB004726

Camino-Serrano, M., Pannatier, E.G., Vicca, S., Luyssaert, S., Jonard, M., Ciais, P., Guenet, B., Gielen, B., Penuelas, J., Sardans, J., Waldner, P., Etzold, S., Cecchini, G., Clarke, N., Galic, Z., Gandois, L., Hansen, K., Johnson, J., Klinck, U., Lachmanova, Z., Lindroos, A.J., Meesenburg, H., Nieminen, T.M., Sanders, T.G.M., Sawicka, K., Seidling, W., Thimonier, A., Vanguelova, E., Verstraeten, A., Vesterdal, L., Janssens, I.A., 2016. Trends in soil solution dissolved organic carbon (DOC) concentrations across European forests. Biogeosciences 13, 5567-5585. doi:10.5194/bg-13-5567-2016

Johnson, Jim, Thomas Cummins and Julian Aherne. 2016. Critical loads and nitrogen availability under deposition and harvest scenarios for conifer forests in Irealand. Science of the Total Environment 541:319-328. http://dx.doi.org/10.1016/j.scitotenv.2015.08.140

Johnson, Jim, Julian Aherne and Thomas Cummins. 2015. Base cation budgets under residue removal in temperate maritime plantation forests. Forest Ecology and Management 343 (2015) 144–156. http://dx.doi.org/10.1016/j.foreco.2015.01.022

Johnson, J., Verstraeten, A., Meesenburg, H., Vesterdal, L., Hansen, K., Vanguelova, E., Jonard, M., Graf Pannatier, E., Sintermann, J., Nieminen, T.M. et al. Temporal trends in soil solution acidity indicators in European forests. [In preparation.]

Kaila, A., S. Sarkkola, A. Laurén, L. Ukonmaanaho, H. Koivusalo, Xiao L., C. O´Driscoll, Z. Asam, A. Tervahauta, M. Nieminen. 2014. Phosphorus export from drained Scots pine mires after clear-felling and bioenergy harvesting. Forest Ecology and Management 325: 99–107. DOI: 10.1016/j.foreco.2014.03.025

Neumann, M., et al. Carbon in litterfall of European forests - a stable and overlooked contribution to the carbon cycle. [In preparation.]

ODriscoll, Connie, Mark OConnor, Zaki-ul-Zaman Asam, Elvira de Eyto, Russell Poole, Michael Rodgers, Xinmin Zhan, Mika Nieminen and Liwen Xiao 2014. Whole-tree harvesting and grass seeding as potential mitigation methods for phosphorus export in peatland catchments. Forest Ecology and Management 319 (0): 176-185. http://www.sciencedirect.com/science/article/pii/S0378112714001066
*http://dx.doi.org/10.1016/j.foreco.2014.02.011*

## (ii) Popular non-scientific publications and abstracts including those presented at conferences

Cummins, Thomas 2014. Forestry Overview : ICP-IM field trip, 9-May 2014. Presentation to field-trip group for ICP Integrated Monitoring visit to Burrishoole catchment.

## (iii) National Report

## (iv) Workshops/seminars at which results were presented

Aherne, Julian, Johnson, Jim, Farrell, E.P., Bowman, J. and others not named. 2014. Acidification and Recovery [of Irish Ecosystems]: observations from EMEP and ICP sites in Ireland. Presentation at the ICP-Integrated Monitoring Workshop on data assessments and evaluation methods for IM data Westport, 7-May 2014. http://www.syke.fi/download/noname/{F3B78EE0-F9B2-4040-AFB7-37BDFA4E16EA}/99431

Byrne, Kenneth A. 2016. Research and policy context of forest biomass use in Ireland. Research Perspectives on the Optimal Use of Forest Biomass, workshop held at University of Limerick, 28-September 2016.

Cummins, Thomas. 2016. Impact of biomass removals on nutrient balance. Research Perspectives on the Optimal Use of Forest Biomass, workshop held at University of Limerick, 28-September 2016.

Cummins, Thomas. 2016. Nutrient exchanges under increased forest biomass harvesting. Environ 2016, 22-24 March 2016, University of Limerick. [presentation from ForSite]

Farrell, Edward P. 2014. Twenty Years of Forest Monitoring in Ireland. Presentation at the ICP-Integrated Monitoring Workshop on data assessments and evaluation methods for IM data Westport, 7-May 2014. http://www.syke.fi/download/noname/{248110D4-1A18-4910-9771-5A15D95ED520}/99435

Johnson, Jim and Thomas Cummins. 2016. Nutrient cycling in conifer forests in Ireland and implications of management and disturbance on their sustainability. Environ 2016, 22-24 March 2016, University of Limerick. [abstract from ForSite]

Johnson, Jim, Julian Aherne, Thomas Cummins and Pat Neville. 2014. Assessing the Implications of Atmospheric Deposition and Harvest-residue Removal on Nitrogen Budgets in Irish Forests. ICP Forests 3rd Scientific Conference, Athens, Greece, 26-May 2014. [pdf from forsite] [pdf from ICP Forests] [abstract from researchgate] [presentation from ForSite].

Johnson, Jim, Thomas Cummins and Julian Aherne. 2014. Modelling Soil Acidity and Soil Carbon and Nitrogen Pools in Irish Forests under Nitrogen Deposition and Forest Harvesting Scenarios. Poster at Biogeomon, Bayreuth, 2014. [pdf from forsite] [abstract from Biogeomon]

Johnson, Jim, Arne Verstraeten, Nenning Meesenburg, Lars Vesterdal, Karin Hansen, Elena Vanguelova, Mathieu Jonard, Elisabeth Graf Pannatier, Jörg Sinterman, Tiina M. Nieminen, Stefano Carnicelli, Guia Cecchini, and Nicholas Clarke. 2016. Temporal trends in soil solution acidity indicators in European forests. In: Tracing Air Pollution and Climate Change Effects on Forest Ecosystems: Trends and Risk Assessments, 5th ICP Forests Scientific Conference, 10-12 May 2016, Luxembourg. Walter Seidling and Marco Ferretti eds. [pdf from luke.fi]

Johnson, Jim, Arne Verstraeten, Nenning Meesenburg, Lars Vesterdal, Karin Hansen, Elena Vanguelova, Mathieu Jonard, Elisabeth Graf Pannatier, Jörg Sinterman, Tiina M. Nieminen, Stefano Carnicelli, Guia Cecchini, and Nicholas Clarke. 2016. Temporal trends in soil solution acidity indicators in European forests. In: Tracing Air Pollution and Climate Change Effects on Forest Ecosystems: Trends and Risk Assessments, 5th ICP Forests Scientific Conference, 10-12 May 2016, Luxembourg. Walter Seidling and Marco Ferretti eds. [pdf from luke.fi]

Shortle, Thomas, Thomas Cummins and Julian Aherne, 2014. Mineral weathering rates for Irish forest soils using the models PROFILE and A2M. Environ 2014, Trinity College Dublin, 26th-28th February, 2014. Environmental Sciences Association of Ireland.

Waldner, P., Marchetto, A., Thimonier, A., Schmitt, M., Rogora, M., Granke, O., Mues, V., Hansen, K., Pihl Karlsson, G., Žlindra, D., Clarke, N., Verstraeten, A., Lazdins, A., Bardulis, A., Schimming, C., Iacoban, C., Lindroos, A.J., Vanguelova, E., Benham, S., Meesenburg, H., Nicolas, M., Kowalska, A., Apuhtin, V., Napa, U., Lachmanová, Z., Kristoefel, F., Bleeker, A., Ingerslev, M., Vesterdal, L., Minaya, M., de la Cruz, A., Molina, J., Fischer, U., Seidling, W., Jonard, M., O'Dea, P., Johnson, J.A., Fischer, R., Balestrini, R., Lorenz, M., 2016. Plot wise aggregated deposition data compiled by the Expert Panel on Deposition, ICP Forests.

## (v) Intellectual Property applications/licences/patents

None.

## (vi) Other

Waldner, P., Marchetto, A., Thimonier, A., Schmitt, M;, Rogora, M., Granke, O., Mues, V., Hansen, K., Pihl Karlsson, G., ~Zlindra, D., Clarke, N., Verstraeten, A., Lazdins, A., Bardulis, A., Schimming, C., Iacoban, C., Lindroos, A.J., Vanguelova, E., Benham, S., Meesenburg, H., Nicolas, M., Kowalska, A., Apuhtin, V., Napa, U., Lachmanová, Z., Kristoefel, F., Bleeker, A., Ingerslev, M., Vesterdal, L., Fischer, R., Balestrini, R., Lorenz, M., 2016. Plot wise aggregated deposition data compiled by the Expert Panel on Deposition, ICP Forests.

The ForSite website, http://forsite.ucd.ie/ documents the substance of the monitoring work and nutrient mass-balance study undertaken as the ForSite project. The website builds on the project structure to give nutrient-exchange datasets, and record the specifications for developing those datasets.

## 5. Scientists trained by Project

Total Number of PhD theses: _____

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Total Number of Masters theses: 2

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

*Ros Mangrinan, Eva. University of Limerick. Nutrient pools in Sitka spruce and lodgepole pine forest biomass. Submitted May 2015.*

*Shortle, Tom. University College Dublin. Mineral Weathering Rates for Irish Forest Soils. Submitted January 2016.*

*Masters minor theses were completed by five students at UCD (Caoimhe Saunderson, Paul Keane, Peter Murphy, Mandy Nsofor, Richard Boakye).*

## 6. Permanent Researchers

| Institution Name | Number of Permanent staff contributing to project | Total Time contribution (person years) |
|---|---|---|
| UCD | 1 | 0.45 |
| UL | 1 | 0.25 |
| TCD | 1 | 0.45 |
| Teagasc | 2 | 0.045 |
| **Total** | | **1.195** |

## 7. Researchers Funded by DAFM

| Type of Researcher | Number | Total Time contribution (person years) |
|---|---|---|
| Post Doctorates/Contract Researchers | [check No.] | Jim Johnson: 3.822<br>Connie O'Driscoll: 1.00<br>Zaki-UlZaman Asam: 1.00<br>Mohammad Askari: 0.623<br>Brian Doyle: 2.364<br>Desmond Hynes: 0.032<br>Kieron Cushen: 0.056<br>Antonio Cachinero: 0.769<br>Philip Murphy: 0.118<br>Philip Fanning: 0.491<br>Eva Ros Mangrinan: 0.300 |
| PhD students | 0 | |
| Masters students | 3 | Eva Ros Mangrinan: 1.177<br>Tom Shortle: 1.743<br>Mark O'Connor: 2.0 |
| Temporary researchers | | |
| Other | | Ricardo Filho: 0.10 |
| **Total** | | |

## 8. Involvement in Agri Food Graduate Development Programme

This programme began in 2015, two years after the project began.

| Name of Postgraduate / contract researcher | Names and Dates of modules attended |
|---|---|
| | |

## 9. Project Expenditure

Total expenditure of the project: €805,191

Total Award by DAFM: €809,295

Other sources of funding including benefit in kind and/or cash contribution(specify): € 0

Breakdown of Total Expenditure

| Category | UCD | UL | TCD | Teagasc | Total |
|---|---|---|---|---|---|
| Contract staff | 2,363 | 3963 | 0 | 0 | 6,326 |
| Temporary staff | 70270 | 0 | 0 | 0 | 70,270 |
| Post doctorates | 169876 | 0 | 88517 | 0 | 258,392 |
| Post graduates | 39,196 | 33537 | 51667 | 0 | 124,399 |
| Consumables | 30,687 | 281 | 6694 | 2716 | 40,378 |
| Travel and subsistence | 22,190 | 1258 | 4559 | 0 | 28,007 |
| Sub total | 334,581 | 39039 | 151436 | 2716 | 527,772 |
| Durable equipment | 2263 | 0 | 2329 | 0 | 4,592 |
| Other | 147,402 | 0 | 3020 | 0 | 150,422 |
| Overheads | 64447 | 11712 | 45431 | 815 | 122,405 |
| **Total** | **548693** | **50751** | **202217** | **3531** | **805,191** |

## 10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources i.e. Additional Staff, National/EU funding secured, EI Commercialisation Fund

**€2399 was awarded from EPA under STRIVE Event support** to support hosting the 2014 ICP Integrated Monitoring meeting, held in Westport, 7–9 May 2014. This was an opportunity to present the ForSite concept, which was done at the Marine Institute, Furnace, Newport, during the field trip of the group. ForSite Task 1 Monitoring provides data that is compatible with the ICP IM monitoring protocols. The meeting identified a duplicate site with the potential to parallel the Brackloon site for future monitoring.

**€1500 was awarded as a Royal Irish Academy Charlemont Travel Grant 2016** to support a research visit by Jim Johnson to the Catholic University of Louvain (UCL), Louvain-la-Neuve, Belgium, to work with Dr. Mathieu Jonard, 11–28 April, 2016. The activity was titled "Response of soil solution acidity in European forests to reductions in air pollution". The central objective was to apply linear mixed models to the ICP forests soil-solution dataset to identify long-term temporal trends and to identify continental, regional and local factors associated with these trends. The work was presented at the ICP Forests Conference in Luxembourg in May 2016. A draft manuscript to be submitted to Global Biogeochemical Cycles is also in preparation. The results also appeared in the ICP Forests 2016 Technical Report.

## 11. Future Strategies

*Outline development plans for the results of the research.*

The approach of ForSite, building on and extending national datasets, is applicable at the resolution of soil types rather than of individual forest sites. It is not a sufficient basis for prescription in site-specific forest management, but is suited as an exploratory mechanism for investigating the possible significance of nutrient exports on mass-balance budgets. Further developments will draw on continued monitoring of deposition and soil solution, through continuation of ICP Forests monitoring. The sample basis of mineral-weathering assessment could be extended though analysis of a topsoil sample archive from the National Grassland Survey (focussing on semi-natural grasslands). Assessment of mobilizable biomass from commercial harvesting can improve the quantification of biomass and nutrient exports, accounting for harvest methods, and for the retention of unmobilizable biomass on site. Further experience in the management of forests under biomass harvesting, and monitoring of the direct site-specific impacts, would contribute to evaluation of the approach, identifying priorities for investigation, and establishing sustainability limits for the biomass-removal potential of forest ecosystems.

Ireland's contribution under the UNECE Convention on Long-Range Transboundary Air Pollution has been supported by this project, until the end of monitoring in June 2017. Future monitoring of this type may contribute to new obligations under the revised National Emission Ceilings Directive, Article 9 and Annex V, which requires that the effects of air pollution be monitored in a representative, risk-based and cost-effective national network of terrestrial ecosystems. The Directive identifies ICP Forests methods as being potentially suitable for this purpose. Ireland is required to submit details of monitoring locations by July 2018, and to submit monitoring data by July 2019 and on a four-year cycle thereafter. The plots, infrastructure, methods, skills and data timeseries stewarded and further developed under ForSite are a basis for this work, building on monitoring since 1991.

## 12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels

I consent to this report being made available to the public, through the Department's website and other dissemination channels. *

Yes ☑ No ☐

## 13. Declaration

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed:
Thomas Cummins, Project Coordinator

Date: 5-December 2017, World Soil Day

*IPR sensitive information that the coordinator does not wish to make public should be highlighted in red font. All text in red font in this report will not be made publicly available by DAFM.

**Guidelines for the Completion of Final Report**

The attached Final Report Template should be completed for DAFM projects funded under the **2006, 2007**, **2008, 2010 and 2011** Calls.

The aim of the final report is to provide a summary of all aspects of the research project. A final report is required for all projects and a percentage of the grant award will be withheld until it is submitted and deemed satisfactory.

Please note that the Department of Agriculture, Fisheries and the Marine may publicise information included in the Final Report. ***All sections of the report must be completed.*** Incomplete reports will not be accepted by DAFM and will be returned to the project coordinator for completion.

**Two copies of the final report are required, 1) a signed hard copy and 2) an electronic copy.**

**A guideline of up to 400 words per relevant section is recommended.**

**Project Details**
The project title, project reference number and actual start and actual finish date should be noted. Indicate on the research continuum from basic/fundamental research to applied/pre-commercial research where you feel the research project fits by placing '**x**' in the most appropriate box. Indicate in the section provided **the priority area of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report**, There are 14 priority areas of Research as follows;

| | |
|---|---|
| A Future Networks & Communications | H Food for Health |
| B Data Analytics Management, Security & Privacy | I Sustainable Food Production and Processing |
| C Digital Platforms, Content & Applications | J Marine Renewable Energy |
| D Connected Health & Independent Living | K Smart Grids & Smart Cities |
| E Medical Devices | L Manufacturing Competitiveness |
| F Diagnostics | M Processing Technologies and Novel Materials |

In addition, key words relating to the project should be included in this section.

***http://www.agriculture.gov.ie/research/researchpolicy/14researchprioritisationactionplans**

**1. Rationale for Undertaking the Research**

This section of the final report should provide background information on why the research was needed. It should clearly outline the reason for carrying out the research and identify the problem / knowledge gap that needed to be addressed. It should address the question '**why was this research needed?**

**2. Research Approach**

Information provided on research approach should address the questions **'how the research was carried out?'** Details should include work carried out and research methodologies used to address the issues identified in the 'rationale for undertaking the research'. Emphasis should be placed on novel techniques, materials, technology and equipment used. Scientific or technical difficulties encountered in the research and any significant modifications from the original proposal must be noted. Please note that this section does not require fine scientific detail, but is designed to give the reader an overall view of the research methods employed.

**3. Research Achievements/Results**

This section is simply designed to address the question **'what are the results of the research'.** Emphasis should be placed on novelty and innovation. Tabulated scientific results are not required but a succinct summary of results obtained from each task should be illustrated.

**4. Impact of the Research**

A summary of the impact of the research should be provided through the project outputs and outcomes. The benefits / improvements the research has made to the area under investigation should be elucidated. Specifically, describe how the outcomes of the research have benefited the end users such as industry, consumers, regulatory authorities, policy makers and the scientific community.

**4(a). Summary of Research Outcomes**

The outcomes reported must detail the wider effect of the project from a sectoral or national perspective; these may be in the medium or long term. The summary of research outcomes is a critical component of the final report. It is imperative that this section is completed fully and precisely, as DAFM is required to report on the outcomes of all research projects. In addition, this data is essential to DAFM in justifying value for money of its research programmes and in securing future funding. Therefore, please ensure that information in this section is accurately reported.

**4(b). Summary of Research Outputs**

Research Outputs are what are produced by the project in terms of activities, events, services that reach people. The summary of research outputs is a critical component of the final report as it provides quantitative data on the research. It is imperative that this section is completed fully and precisely, as DAFM is required to report on the outputs of all research projects. In addition, this data is essential to DAFM in justifying value for money of its research programmes and in securing future funding. Therefore, please ensure that information in this section is accurately reported.

### 5. Scientists trained by the project

The total number of PhD and MSc theses produced as a direct result of work carried out on this DAFM project should be noted. In addition, the authors, institutions and titles of the theses and submission dates should be specified. If theses have not been submitted before completion of the final report, please give details including the anticipated submission date.

### 6. Permanent Researchers

The number of permanent research staff who contributed to the project (on a cost neutral basis) per institution and associated time contribution must be captured.

### 7. Researchers Funded by DAFM

Details of numbers, total time contribution (in months) and of all, post doctorates (PD) &contract researchers; PhD students; Masters students; temporary researchers and other staff funded by DAFM should be included.

### 8. Involvement in Agri Food Graduate Development Programme

The names of students / researchers that participated in the Agri Food Graduate Development Programme should be included in addition to the names and dates of modules undertaken.

### 9. Project Expenditure

The aim of this section is to provide a summary of expenditure during the lifetime of the project. Please note that it is imperative that all figures included in this section correspond to figures included in the last progress report submitted and evaluated by DAFM. The names of the institutions involved must be included in the tables provided.

### 10. Leveraging

The aim of this section is to summarise any additional resources'/funding leveraged from this award from other sources e.g. Additional Staff (type of staff, value of staff secured), National/EU funding secured, EI Commercialisation Fund

### 11. Future Strategies

Future strategies to further develop the outputs of the research should be indicated. If the outputs of the research have not been taken up by end users, explain why this is the case. What further advances / work is required in your area of research in order for the outputs to taken up by industry / consumers / end users? What follow-on research is required in this area to realise an end product? If further funding is required for research in this area, where do you intend to apply for funding e.g. Enterprise Ireland?

**12. Consent to Publish Final Report on DAFM Website**

The coordinator should indicate whether or not they consent to the publication of this final report on the DAFM website and/or through other dissemination sources. IPR sensitive material will not be published. The coordinator must indicate sensitive material by highlighting the text in red font where appropriate in the final report.

**13.Declaration**

The project coordinator must sign and date the report. Unsigned reports will be deemed incomplete and will not be accepted. The coordinator must also indicate their consent to the publication of this final report.