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Terrestrial Umbrella – Effects of Eutrophication and Acidification on Terrestrial Ecosystems

Annual Report

2008

by
UKREATE

.

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Executive Summary

B. A. Emmett

Centre for Ecology and Hydrology Bangor

The Terrestrial Umbrella seeks to provide scientific evidence and support for a series of policy questions regarding recovery from acidification and eutrophication in terrestrial ecosystems. Within the project we have derived specific objectives and deliverables for each policy questions. These are:

Policy question

1. **What is the evidence for the success of policies to reduce emissions of N and S in reducing eutrophication and acidification of terrestrial systems?**

TU objective (WP1): Collate evidence of damage and recovery in the terrestrial systems (soils and vegetation) through data archaeology, re-sampling and analysis of large-scale national or habitat specific surveys

Policy question

2. **Are all forms of atmospheric reactive nitrogen equally damaging to semi-natural habitats and what determines sensitivity to nitrogen?**

TU objective (WP2): Quantify differences between NHy and NOy and dry versus wet deposition impacts through a combination of manipulation experiments and analysis of monitoring data described in WP1

Policy question

3. **What are the most ecological relevant indicators of sensitivity and change**

TU objective (WP3): Analysis of experimental results in combination with spatial surveys to identify most sensitive and ecologically relevant indicators in different habitats and test their robustness.

Policy question

4. **What determines the fate of nitrogen in soils, its short-term and long-term mobilisation, and thus changes in plant species composition?**

TU objective (WP3): Investigate the sensitivity of different soils to N enrichment, and the underlying controls, using a combination of field and experimental studies.

Policy question

5. **What is the likely timing of change in soil chemistry and biodiversity in response to a reduction in N emissions?**

TU objective: Continue to develop ecosystem model chains which link soil biogeochemical models and plant succession and species models.

Policy question

6. **What is the empirical evidence for N impacts and recovery and can models simulate these changes?**

TU objective: Collate data required for testing of linked soil-vegetation model chains involving provision of long-term data from manipulation sites in particular time series data for recovery following cessation of treatments and interaction with management treatments.

Policy question

7. **How will climate change influence the effects of N deposition in terrestrial ecosystems and what are the implications for critical loads?**

TU objective: Investigate the role of climate on N cycling and indicators of N enrichment using two climate change experiments and examine the implications for critical loads using a case study.

Policy issue

8. **Knowledge transfer and Project Management**

TU objective: Support to UK National Focal Centre, response to ad hoc queries from Defra and other agencies, project management including web site, organisation of CAPER conference.

Summary of progress to date is as follows:

There is a large range of activities within this project many of which include data collection, synthesis and modelling. This report describes progress to date after Year 1 and therefore much of the work is not yet at a stage appropriate for communication to a wider audience. However some highlights which have emerged are presented here:

Repeat surveys of moorlands in Scotland have been carried out to identify potential shifts in vegetation composition since the 1960’2 qand 1970’s which may be attributable to air pollution. Preliminary analysis of change shows that there has been an apparent shift in composition of moorlands between the original and new surveys, but that the degree of change varied between moorland types. Blanket bog (which included many high altitude bogs) and high altitude heathlands had the greatest shift, with a smaller change in wet heathland and dry heaths being stable over time. High altitude sites could potentially receive a higher nitrogen loading than those lower down, but this pattern of change could also indicate a role of climate since the shifts in composition appear to be in the direction of more typical mid altitude species and greater *Calluna* dominance.

Data from a unique ammonia enrichment experiment located in a Scottish bog confirms that species of lichens and dwarf shrub species differ in their sensitivity. For example, among the 10 species of *Cladonia* and 4 species of *Sphagnum* on site, only *C. portentosa* and *S capillifolium* appear to be highly sensitive to N deposition, especially as ammonia. *Cladonias* eg *C. chlorophaea* and C. *fimbriata*, which have significantly lower surface area to mass, or *S. fallax* which prefers wetter areas, possibly diluting the ionic strength, are more tolerant. Within the ericoid functional group, only *Calluna* is sensitive to ammonia, not *Empetrum nigrum*, *Vaccinium myrtillus* or *Erica tetralix*.

A preliminary synthesis of results from a range of long term N addition experiments and N gradient studies show that, although the responses to the manipulations are highly varied, some consistent patterns emerge. Of the biogeochemical changes in the vegetation, **foliar %N** generally responded positively and rapidly to the N treatments (within 2 years) especially within mosses. In the heath and moorland surveys foliar %N was also correlated with the level of N deposition. However, in the grasslands experiments there were typically only modest or no significant responses in tissue N content, a feature consistent with a recent UK grassland survey. Experiments that have examined the impact of wet vs dry and oxidised vs reduced N (Whim and Pwllpeiran) indicate these are also important factors in determining foliar N content. If the N deposition treatment was reduced (as seen in Ruabon, also NITREX forest experiments) foliar N also fell quickly. Foliar N may thus be a reasonable indicator of current levels of N deposition, rather than long-term ecosystem N enrichment. The foliar ratio of **N:P** tended to increase with N treatment but across some survey work (lowland heath survey and Countryside Survey) this ratio did not change. A number of other foliar measures have been investigated at some sites but require wider testing to assess their broad value as bioindicators. Some exciting research on moss physiology developed at Wardlow and examined also at Ruabon and Budworth suggests that moss phosphatase (PME) activity and certain other physiological measures may be good indicators. Not enough data exist yet to assess the value of **lichen physiology**, **amino acids**, or **metabolomics** as indicators. Biogeochemical indicators may be used to indicate the level of nitrogen deposition to an ecosystem. At some point the indicator may also show ecosystem level responses and ecologically relevant change. Our research shows that across a wide range of N addition experiments a broad level of consistency emerges in indicator responses. However, the best potential indicators show subtle but important differences between ecosystems and the best approach is likely to make use of a small suite of techniques to indicate both the level of deposition and ecological change due to nitrogen pollution.

Ecological responses observed in these long term N addition experiments are diverse and wide ranging and work is continuing to synthesise these in a theoretical framework. For example, in *Calluna* dominated ecosystems (heathlands, bogs), while wet deposition increases *Calluna* biomass across most experimental sites, most recent work shows considerable damage resulting from dry deposition NH_3. This suggests the lack of decline in NH_3 deposition in the UK may result in continued damage and future reductions in NH_3 emissions appear essential if damage to *Calluna* dominated systems is to be reversed. Most grasslands and heathlands show a good capacity to retain N and only show increased leaching of N at only relatively high N deposition rates. This is an important ecosystem service in the provision of clean groundwater and highlights the importance of preserving these systems in addition to their agricultural, conservation and amenity values. In the grassland systems, severe reductions in forb flowing suggest hindered floristic recovery since seed-banks of important species may be depleted. This is of particular concern since seed-banks of grasslands are short-lived, and suggests the grasslands in areas that have received high N deposition may have a impaired capacity for recovery.

Modelling approaches to predict the effects of nitrogen pollution on plant diversity is being developed by linking soil models with habitat suitability models for > 1000 GB plant species. This model chain is called MAGIC-GBMOVE Previous forecasts using were reasonably accurate when compared to long-term species observations, at least for stable vegetation types. This work package aims to improve the accuracy of predictions of species change in response to interacting drivers, and increase the scope of the model chain to cover vegetation succession as this drives much of ‘natural’ change in species change irrespective of air pollution. One example of a new development is that shows promise is the incorporation of climate variables into the GBMOVE model so climate change and it's interaction with air pollution impacts can be tested.

The 2008 annual project meeting was held at Manchester Metropolitan University and small workshops for specific issues have been organised to ensure good communication between the project partners. An annual organised by the Committee on Air Pollution Effects Research (CAPER) conference was successfully held at the Environment Centre Wales in Bangor. There was > 50 scientists from a wide range of research organisations at the conference to discuss the latest research findings.

Work Package 1:
Collate evidence of damage and recovery in the terrestrial systems (soils and vegetation) through data archaeology, re-sampling and analysis of national surveys or data-rich regions

Task Leader: Simon Smart

Centre for Ecology and Hydrology Lancaster

PIs: Simon Smart[1], Lindsay Maskell[1], Andy Scott[1], Andrea Britton[2], Alison Hester[2], Brian Reynolds[3]

[1]Centre for Ecology and Hydrology Lancaster, [2]MLURI, [3]Centre for Ecology and Hydrology Bangor

Work Package 1 Task Leader: Simon Smart

Milestone October 2008

Task 1.1 – Analysis of spatial and temporal trends of vegetation change at GB scale

Objective

Estimate variation in spatial and temporal abundance in indicator species uniquely explained by drivers (1978-1998 + (2007 if dataset ready)).

Delivery to date

Progress has been delayed by the extraordinary demands of Countryside Survey in the past year. Updated modeled deposition data at 5km sqr scale has recently been received from CEH Edinburgh and has been incorporated into the analysis database. The statistician working on this project has also been developing the new analytical techniques we will use. These are Bayesian analyses that will be executed using the WinBUGS freeware.

Implications

Delivery of results to the October 2009 milestone is not expected to be delayed since much of the effort has gone into preparing response variables and explanatory variables for analysis, as well as in developing the new analysis method.

Task 1.2 – Habitat specific trends: Changes in moorlands and wetlands in Scotland

Objective

Carry out moorland fieldwork, data input and analysis.

Delivery to date

Moorland fieldwork has been completed, with all data input and an initial analysis carried out, more detailed analysis is planned for winter 2008/09. Wetland resurvey was started in 2008 and the work is on schedule.

Methods and results

Task 1.2 focuses on quantification of change in Scottish moorland and wetland systems and attribution of that change between drivers, including land management, climate change and nitrogen deposition. This is being done through a targeted re-survey of sites for which archive vegetation description data (from 1960's and 1970's) are held. The first year has focussed on moorlands. Of 1960 records in the original dataset a subset of 402 were re-visited and re-surveyed, giving wide geographical coverage across Scotland and a representative range of moorland habitats.

Preliminary analysis of moorland species composition by Detrended Correspondence Analysis (DCA – Fig 1) shows that there has been an apparent shift in composition of moorlands between the original and new surveys, but that the degree of change varied between moorland types. Blanket bog (which included many high altitude bogs) and high altitude heathlands had the greatest shift, with a smaller change in wet heathland and dry heaths being stable over time. High altitude sites could potentially receive a higher nitrogen loading than those lower down, but this pattern of change could also indicate a role of climate since the shifts in composition appear to be in the direction of more typical mid altitude species and greater *Calluna* dominance.

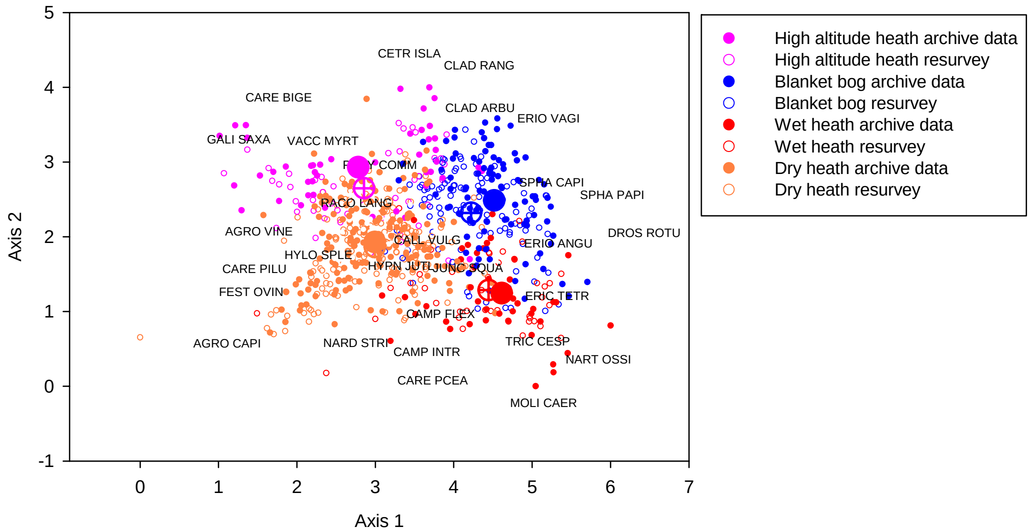


Figure 1 DCA of archive and resurvey moorland composition data. Moorlands were grouped into four types, High altitude heath (at altitudinal *Calluna* limit), Blanket bog, Wet heath and Dry heath. Small symbols show individual plots, large symbols show mean for each group.

Discussion

Further analysis carried out over winter 2008/09 will compare the spatial pattern of change with that of nitrogen deposition and other potential drivers and work on attributing change. The wetland survey was also designed and started this year. From the original data set of 456 plots, 131 plots of two distinct wetland types were selected for survey; upland springs (NVC M32, M33, M37) and lowland *Carex*-dominated swamps (NVC S9-11, S19, S27 & 28). These habitats will provide a contrast between springs, which might be expected to reflect atmospheric inputs, and lowland wetlands, for which surrounding land-use may have a greater impact.

Update on Task 1.3 – Habitat specific trends: Rate of soil enrichment in Woodland National Nature Reserves Sites

Introduction

The main objective of this task is to re-sample soils of 6 woodland nature reserves which were originally surveyed and sampled in the early 1970s. A range of chemical measurements were made on these soils and both the data and soils samples have been preserved at CEH Bangor and CEH Lancaster. This report describes the work undertaken so far on this project. The milestone for delivery of the results is not due until October 2009 but preliminary re-sampling has raised issues that require a progress report and further subsequent discussion within the work package as initial results become available.

Project activity

Site access & management history

Nature reserve managers for all six sites have been identified and contacted with help from Dr Patricia Bruneau of SNH. Permissions for site visits and re-sampling have been obtained. Some difficulties were experienced in making the appropriate contacts as site ownership and management arrangements have changed for some sites since the 1970s. These contacts will be followed up in order to procure information on the management of the sites since the first surveys.

Existing data
Soil data from the 1970s sampling have been digitised into Excel spreadsheets from the original paper reports and some preliminary data analysis has been undertaken. This has revealed considerable variation in chemical properties within and between mapping units and soil types (see eg Figure 1). Accounting for this variation in the interpretation of changes in chemistry over time will present a significant challenge.

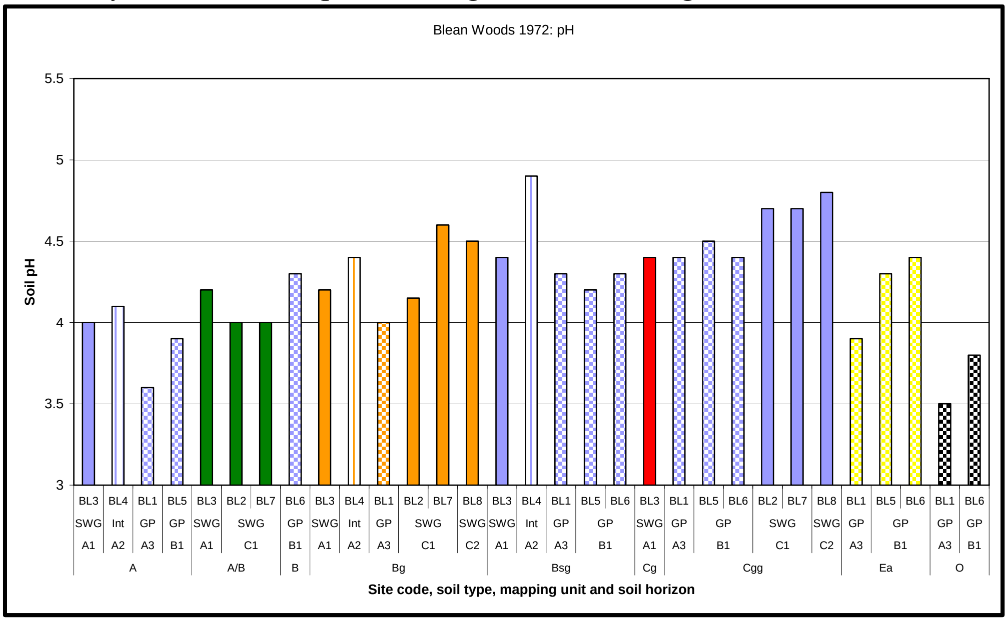


Figure 1. Soil pH for individual sample sites at Blean Woods shown by sample code, soil type, mapping unit and horizon. Soil types: GP = gleyed podzol; SWG = surface water gley; Int = surface water gley / gley podzol intergrade

Sampling and analysis
Soil samples have been collected from Ham Street Woods and Blean Woods during July and August of 2008. The remaining sites will be sampled in the spring of 2009.

A major issue was identified at both sites with re-locating the sampling locations from the 1970s. Once at the site, it became evident that the quality of the original site location data was poorer than the original reports suggested. This situation was made more difficult by changes in physical features at the sites, for example the construction of new footpaths, changes in boundaries etc. Given the heterogeneity in the soils data and the variations seen on the ground during sampling, this will make comparison between the surveys extremely challenging.

Chemical analysis
Samples were returned to CEH Bangor and chemical analyses are currently ongoing. Soil samples from these sites will be retrieved from archive storage at Lancaster. A sub-sample of these will be re-analysed to confirm that the current analytical methods deliver results which are consistent with the earlier data.

Conclusions
Chemical analysis of the Blean and Ham Street Woods will be completed this autumn. The new data will be evaluated to identify whether legitimate comparisons can be made with earlier information. The outcome of this exercise will be used to determine the future direction of this task.

Work Package 2:
Quantify differences between NHy and NOy and dry versus wet deposition impacts through a combination of manipulation experiments and linkage to analysis of monitoring data described in WP1

Task Leader: Lucy Sheppard
Centre for Ecology and Hydrology Edinburgh

PIs: Lucy Sheppard[1], Ian Leith[1], Owen Davies[2], Bridget Emmett[3] Simon Smart[4], A. Vuohelainen, T. Mizunuma and C. Field

[1]Centre for Ecology and Hydrology Edinburgh, [2]ADAS Pwllpeiran, [3]Centre for Ecology and Hydrology Bangor, [4]Centre for Ecology and Hydrology Lancaster, Manchester Metropolitan University

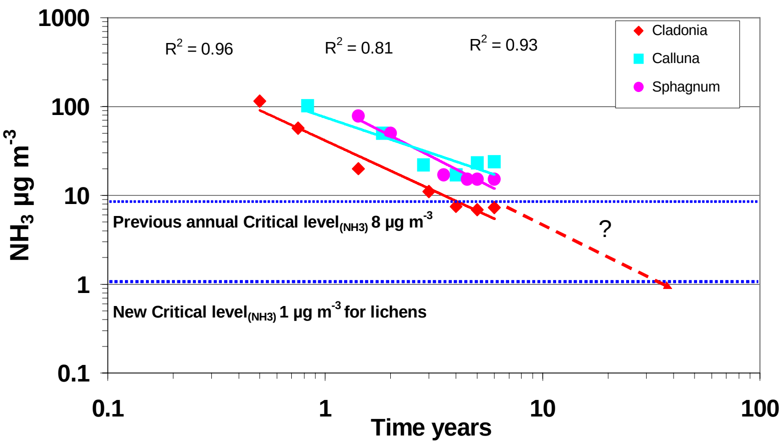
Work package 2 Task Leader: Lucy Sheppard

Objective: Quantifying differences between NHy and NOy and dry versus wet deposition inputs through a combination of manipulation and analysis of monitoring data described in WP1.

Task 2.1 – Differential effects of reduced versus oxidised and wet versus dry N in wetlands. PIs: Lucy Sheppard, Ian Leith (CEH Edinburgh) + Vuohelainen A., Mizunuma T. Field C. (MMU).

Overall deliverable:
Assessment of the relative importance of reduced versus oxidised N (peer reviewed paper on indirect versus direct effects of N deposition by form) and evaluation of long-term ammonia exposure on the CLE_{NH3}.
Milestone: Task 2.1 Oct. 2008
Submission of paper, maintain wet and dry treatment regime and soil and vegetation chemistry evaluations and re-evaluation of long-term species response to ammonia.
Delivery to date: Paper submission has been delayed, in order to maintain continuity in the 18-month data collection, compromised by staffing issues.

1. Observations on the sensitive species, *Cladonia portentosa*, *Sphagnum capillifolium* and *Calluna* growing along the ammonia concentration gradient, suggest they may have reached their damage thresholds for ammonia concentration (see figure). However, meteorological conditions have been extremely favourable over these last 2 years, high rainfall, and it remains likely that drier, more stressful conditions in the future will see the damage threshold $[NH_3]$ reduce further (see extrapolated red dashed line).
2. Quantitative cover analysis confirms that among the 10 species of *Cladonia* and 4 species of *Sphagnum* on site, only *C. portentosa* and *S capillifolium* appear to be highly sensitive to N deposition, especially as ammonia. *Cladonias* eg *C. chlorophaea* and C. *fimbriata*, which have significantly lower surface area to mass, or *S. fallax* which prefers wetter areas, possibly diluting the ionic strength, are more tolerant. Within the ericoid functional group, only *Calluna* is sensitive to ammonia, not *Empetrum nigrum*, *Vaccinium myrtillus* or *Erica tetralix*.
3. Analysis of species cover data using NVC, comparisons with Ellenberg numbers, univariate and multivariate analysis up to 2007 is now complete.
4. Analysis of soil water chemistry sampled at 0-10 cm by suction, confirms that longer runs of data are necessary to identify trends over natural variation. Significant changes in soil pH, C and N stocks are now emerging after 6 years.

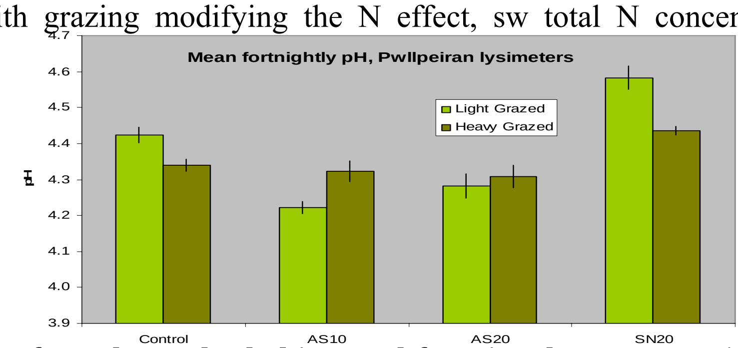


Change in ammonia concentration on an ombrotrophic bog causing loss of >85% of *Cladonia portentosa* (red) , *Calluna* (turquoise) and *Sphagnum capillifolium* (pink)

Task 2.2 Differential effects of reduced versus oxidised N in acid grasslands and the modifying effects of management, grazing. PI: Bridget Emmett (CEH Bangor), Owen Davies (ADAS)

Overall deliverable*:*
Comparison of feedbacks from oxidised versus reduced N mediated changes in soil chemistry on species composition change in acid grassland.
Milestone: Task 2.2 Oct. 2008
Continuation of N applications and repair and testing of soil water (sw) sampling equipment.
Delivery to date:

1. Treatments control (C) and three N treatments of ammonium sulphate, at 10 and 20 kg N ha^{-1} yr^{-1} (AS10 and AS20), and sodium nitrate, at 20 kg N ha^{-1} yr^{-1} (SN20) to duplicated N addition plots, with light and heavy grazing, established in 1996, have been maintained.
2. Zero tension lysimeters have been inserted in the upper organic horizon and leachate samples collected and analysed for pH, NO_3^-, NH_4^+, DON, DOC and cations.
3. Soil N mineralization rates, pH, C and N stocks, exchangeable cations, species change and fungal infection have been evaluated, summer 2008, now awaiting chemical and statistical analysis.
4. Preliminary results indicate: N treatment, oxidised has increased sw pH in contrast to reduced N, with grazing modifying the N effect, sw total N concentration has been increased.



Task 2.3 Analysis of CS data – by habitat and functional type. PI: Simon Smart (CEH Lancaster)

Overall deliverable*:*
Assessment of the relative importance of N form and other key drivers in reported change in vegetation, plant trait groups and soil parameters at the GB scale.
Milestone: Task 2.3 Oct. 2008
Trait database assembly and construction of hypothesised trait-driver relationships
Delivery to date: Progress has been delayed by the extraordinary demands of Countryside Survey in the past year.

1. The trait database is in the process of being checked for gaps in light of the need to add data for 60 taxa newly recorded in the 2007 survey.
2. The growth form, native/non-native status and family fields have all been updated and finalised. The latter is especially important because it allows phylogenetically independent trait analyses to be carried out.
3. We plan to add data on key traits related to both competitive dominance, nutrient acquisition and grazing tolerance over the coming months. These traits will include; canopy height, specific leaf area, life history and clonality.
4. Updated modelled N and S deposition data has been very recently received from CEH Edinburgh and have been incorporated into a database that also includes many other covariates, assembled in preparation for the attribution work scheduled in WP1, which overlaps with delivery of this task. Clarification on use of these new Edinburgh datasets is required before the analysis can progress.

Work Package 3:
Analysis of experimental results in combination with spatial surveys to identify the most sensitive indicators for both N deposition and N enrichment

Task Leaders: Simon Caporn and Nancy Dise
Manchester Metropolitan University

PIs: Bridget Emmett[1], Gareth Phoenix[2], Jonathan Leake[2], Sally Power[3], Jacky Carroll[4], Lucy Sheppard[5], Ian Leith[5], Andrea Britton[6] and Rachel Helliwell[6]
[1]Centre for Ecology and Hydrology Bangor, [2]University of Sheffield, [3]Imperial College London, [4]Manchester Metropolitan University, [5]Centre for Ecology and Hydrology Edinburgh, [6]MLURI.

Work Package 3 Task Leader: Simon Caporn and Nancy Dice

Objective: Analyse experimental results in combination with spatial surveys to identify the most sensitive indicators for both N deposition and N enrichment

Task: Indicators of nitrogen deposition and ecosystem change due to nitrogen saturation

Delivery to date: A preliminary analysis has been carried out and contributed to the ROTAP vegetation chapter meeting (23.10.08). We expect the full dataset meta-analysis to be completed by spring 2009 along with a draft of the paper synthesising indicators from the UKREATE experiments and surveys. The research associate who will carry out the final meta-analysis will be starting on the project in early 2009.

Methods and Results: In year 1 we collated from our partners data on the direction and magnitude of ecosystem change in response to the nine nitrogen manipulation experiments in the UKREATE network. The sites are: moorland (Ruabon), lowland heath (Thursley and Budworth representing warmer, drier and cooler, moist types respectively), montane heath (Culardoch), bog (Whim), acid grassland (Pwllperian, Wardlow) calcareous grassland (Wardlow), sand dune (Newborough). These were augmented with data from the surveys of lowland heath, moorland, dune slacks and forests. Results were classified into:

1. **Vegetation chemical changes (5 categories):** foliar %N, foliar N:P, bryophyte/lichen physiology, amino acids, metabolomics.
2. **Litter chemical changes (3 categories):** %N, extractable NH_4^+ or NO_3^-, exo-enzymes.
3. **Soil chemical changes (4 categories):** %N, C:N, KCl-extractable NH_4^+, KCl-extractable NO_3^-.
4. **Soil process changes (10 categories):** PME activity, NO_3^- leaching, NH_4^+ leaching, DON leaching, base cation depletion, net N mineralisation, net nitrification, microbial immobilisation (^{15}N), denitrification, mineralisable N.

Preliminary results of the data collation show that, although the responses to the manipulations are highly varied, some consistent patterns emerge. Of the vegetation changes, **foliar %N** generally responded positively and rapidly to the N treatments (within 2 years) especially within mosses. In the heath and moorland surveys foliar %N was also correlated with the level of N deposition. However, in the grasslands experiments there were typically only modest or no significant responses in tissue N content, a feature consistent with a recent UK grassland survey. Experiments that have examined the impact of wet vs dry and oxidised vs reduced N (Whim and Pwllpeiran) indicate these are also important factors in determining foliar N content. If the N deposition treatment was reduced (as seen in Ruabon, also NITREX forest experiments) foliar N also fell quickly. Foliar N may thus be a reasonable indicator of current levels of N deposition, rather than long-term ecosystem N enrichment. The foliar ratio of **N:P** tended to increase with N treatment but across some survey work (lowland heath survey and Countryside Survey) this ratio did not change. A number of other foliar measures have been investigated at some sites but require wider testing to assess their broad value as bioindicators. Some exciting research on moss physiology developed at Wardlow and examined also at Ruabon and Budworth suggests that moss phosphatase (PME) activity and certain other physiological measures may be good indicators. Not enough data exist yet to assess the value of **lichen physiology**, **amino acids**, or **metabolomics** as indicators.

In some ecosystems the changes in foliar N following N addition were reflected in increased **litter %N**. Extracellular enzymes such as **phosphatase** (PME) were generally highly active in the litter layer and surface soils and at some of the sites these have been measured. Consistently, PME activity increased with N treatment (measured at Culardoch, Ruabon Wardlow) probably reflecting an increasing ratio of N/P availability. However, the moorland and lowland heath surveys found that the PME was not as strongly related to N deposition as in the experiments - possibly due to varying levels of P availability in the survey sites. Further work in field surveys is needed to assess the potential of PME as a bioindicator.

Extractable NH_4^+ in litter and surface soils often increased after N addition in the experiments, although at some sites this was not significant until the highest N dose and even then was seasonally quite variable. Extractable NH_4^+ dropped quickly after N supply was reduced (Wardlow and Ruabon) and so may be a reasonable indicator of recent deposition. In the moorland survey extractable NH_4^+ was correlated with nitrogen deposition but this was not the case in the lowland heath survey. Other measures of the nitrogen pool in soils such as **C/N ratio** and the **soil %N** are variable across the experiments and surveys.

An increase in **nitrogen leaching** from a site may be seen as a sign of ecosystem N saturation but, in general, the UKREATE experiments show elevated leaching (or increased soil solution concentrations – the potential for leaching) only at the high-N treatments, after several years, or in sites with shallow soils. So, while leaching could be a useful indicator in some situations, typically other indicators appear to be more sensitive markers of change.

For several assays, data is not available across enough sites to allow an overall conclusion, however, rates of both **base cation depletion** and **net N mineralisation** often increased under elevated N treatments. Rates of **nitrification, microbial immobilisation,** and **denitrification** are variable. **Mineralisable N** has recently been developed for use with the Countryside Survey, although not enough data exist yet from the UKREAT sites to assess its value as an indicator.

Discussion: Collation of data from the UKREATE nitrogen addition experiments has enabled us to examine a wide range of potential biogeochemical indicators (at least 20) that may be used to reliably indicate elevated nitrogen deposition and actual or potential ecological change. The ecosystems studied, along with regional surveys of some of these, represent many of the major ecosystem types in the UK. Given the variety, it is not surprising that likely candidate indicators differ across ecosystems. For example, in many of the systems, the simple measure of foliar %N is a reliable marker of N accumulation but this is not consistently true (e.g. grassland plants). However, in all the experiments where phosphatase activity (in soil or moss) was tested its activity has increased in response to N. Probably the best approach will be to adopt a small suite of indicators that can be used over a range of ecosystems.

More detailed analysis of the likely indicators will explore their level of change in relation to important aspects of the current experiments that differ from site to site such as the duration, the concentration and the nitrogen form. Further research in this Workpackage in 2009 will test a smaller selection of priority indicators in regional field surveys, relating where possible to known levels of ecological change.

P**olicy Implications** Biogeochemical indicators may be used to indicate the level of nitrogen deposition to an ecosystem. At some point the indicator may also show ecosystem level responses and ecologically relevant change. Research in this Workpackage shows that across a wide range of N addition experiments a broad level of consistency emerges in indicator responses. However, the best potential indicators show subtle but important differences between ecosystems and the best approach is likely to make use of a small suite of techniques to indicate both the level of deposition and ecological change due to nitrogen pollution.

Work Package 4:
Investigate the sensitivity of different soils to N enrichment, and the underlying controls, using a combination of field and experimental studies

Task Leader: Ed Tipping
Centre for Ecology and Hydrology Lancaster

PIs: Bridget Emmett[1], Nick Ostle[2], Steve Hughes[1], Alwyn Sowerby[1], Robert Mills[1]
[1]Centre for Ecology and Hydrology Bangor, [2]Centre for Ecology and Hydrology Lancaster

Work Package 4 Task Leader: Ed Tipping

The research in this Work Package was due to begin in April 2008. The approach proposed in the original submission was to carry out detailed studies of N cycling in four specific soils, and to attempt to define functional soil pools and their dynamic interactions. The results were anticipated to improve understanding of the links between soil C and soil N, and especially to support modelling work in the Dynamic Modelling Umbrella which requires increased knowledge concerning the controls on N immobilisation and release.

However, developments since the proposal was made, especially in the Countryside Survey (CS), suggested a better way to address the issue of how N availability is related to C cycling. We therefore proposed a major variation to WP4, in which CS data and samples, analysed for natural-abundance ^{14}C, would permit a much broader perspective of N:C linkages, more useful in the national-scale assessment required to support policy. This variation has been agreed with the Defra Project Officer.

Task 4.1 – Identifying links between plant and soil type, soil carbon, and nitrogen cycling. PIs: Bridget Emmett (CEH Bangor), Nick Ostle (CEH Lancaster), Rob Mills (PhD student, CEH Bangor)

Milestone

The original WP had a single milestone, which was the delivery of *an assessment of tools available to quantify available carbon and N retention rates in soils*, due in June 2009. The revised deliverable is *quantification of soil organic matter turnover in different plant-soil combinations, related to N cycling.* The same delivery date applies.

Delivery to date

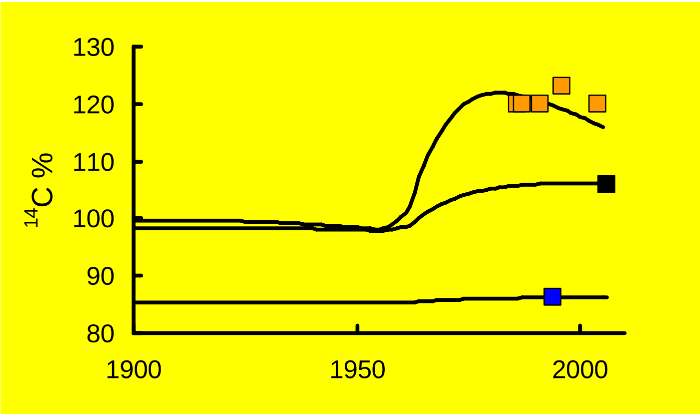
The contract variation has required detailed planning, now completed. We have done this by taking into account CS results, the availability of samples from CS, and defining the analysis strategy. We propose to process soil samples from 55 CS plots, covering Aggregated Vegetation Classes (AVC) 3, 4, 5, 6, 7 and 8. The last five are sensitive to the effects of N deposition, while AVC 3 (fertile grassland) is included to obtain comparative information about organic matter turnover in systems high in N, due to fertiliser and manure applications. There are rather few CS sites for woodland (AVC 5 and 6), but we have other data for UK woodland sites, already analysed for ^{14}C, that can be used. Analysis of the results should produce generally-applicable relationships between soil organic matter turnover and plant-soil combinations, without the need for ^{14}C determinations in further cases.

The practical processing of soil samples, and analysis is about to begin (October 2008). We expect that most of the samples from CS will be delivered to the RCL by December 2008. In addition, we propose to apply the method to all the TU field sites, since knowledge of organic matter turnover rates will be generally useful, and this will make a good link with CS-based survey results. These sites will be sampled early in 2009.

Objectives

The main aim of the revised WP is to determine bulk organic matter turnover times in different plant-soil combinations. Combination of this information with data on bulk soil C:N ratio and determinations of mineralisable nitrogen (measured as part of CS) will provide broad-scale information about spatial variability in soil N cycling, and thereby availability to biota and potential for leaching to surface waters.

The soil organic matter turnover times will be estimated using measurements of soil ^{14}C, which will be carried out using Accelerator Mass Spectrometry at the NERC Radiocarbon Laboratory (RCL), East Kilbride. Combination of the ^{14}C signal with knowledge about the past atmospheric $^{14}CO_2$ content enables the mean residence time (MRT) of soil carbon to be calculated, if it can be assumed that the soil is in steady state with respect to inputs and outputs of carbon. The diagram shows three examples of soils already analysed.



^{14}C contents of three different soils (points), and modelled values, assuming a single C pool. The model takes into account the changing ^{14}C content of the input. The enrichments are due to “bomb carbon” generated around 1960. The fitted MRT values from top to bottom are 34, 138 and 1400 years.

Combination of the MRT value with the soil C pool provides an estimate of the rate of input of carbon to the soil, and this can be combined with C:N ratios to estimate the N input. This will give estimates of the amounts of nitrogen that are being transferred to the stable soil pool, which will be valuable in modelling the soil N cycle. As shown by the results in the figure, MRT values evidently vary considerably among plant-soil combinations – the examples include a forest (fast turnover) a moderately–fertile moorland (MRT 138 years) and a nutrient-poor peaty gley under grass (MRT 1400 years).

Work Package 5:
Continue to develop ecosystem model chains which link biogeochemical models of soil processes and plant succession with species occurrence models

Task Leader: Ed Rowe

Centre for Ecology and Hydrology Bangor

PIs: Simon Smart[1], Lindsay Maskell[1], Salim Belyazid[2], Ed Rowe[3]
[1]Centre for Ecology and Hydrology Lancaster, [2]BCC, Sweden, [3]Centre for Ecology and Hydrology Bangor, [4]Forest Research

Work Package 5 Task Leader : Ed Rowe

Objectives

- To improve a model chain forecasting plant species occurrence from soil chemistry dynamics and pollutant deposition
- To extend this model chain to include:
  a) modules for plant growth and vegetation management and succession
  b) effects of local species pools

Delivery to date

- Three papers submitted to international peer-reviewed journals (see below)

Methods

The effects of nitrogen pollution on plant diversity can be forecast by linking biogeochemical process models with habitat suitability models. Previous forecasts using the GBMOVE species occurrence model driven by the MAGIC soil chemistry model were reasonably accurate when compared to long-term species observations, at least for stable vegetation types. This work package aims to improve the accuracy of predictions of species change in response to interacting drivers, and increase the scope of the model chain to cover vegetation succession. The GBMOVE model will be refined by uncertainty analysis, re-calibration and testing against large spatial datasets, in particular new Countryside Survey 2007 (CS2007) data. An invasibility module will be developed, and a plant growth and vegetation succession module will be incorporated into the model chain. The main development route for this module is to adapt the ForSAFE-VEG model chain for UK habitats, and for non-forest habitats, but stand-alone vegetation modules such as SUMO will also be assessed. Modelling frameworks will also be assessed for their ability to facilitate the integration of models and data.

Results and Discussion

The GBMOVE models will be refitted when CS2007 data have been collated. This will not require re-fitting of all the species models since these are predicted from mean "Ellenberg" scores; only the relationship between mean Ellenberg score and abiotic variables will be re-fitted. A new assay for mineralisable nitrogen was applied to 700 cores from those CS2007 "X" plots for which data are available since 1978. An analysis of data from the CS2007 pilot study showed that this assay is likely to improve predictions of mean "Ellenberg" fertility (Figure). **a)** **b)**

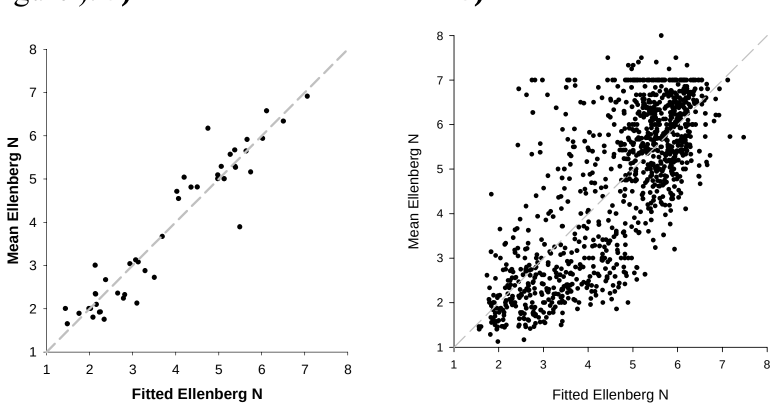


Figure 1. Measured mean Ellenberg N for Countryside Survey plots, compared with mean Ellenberg N predicted using: a) C/N ratio for all plots (R^2 = 0.59); and b) N/C ratio, pH, moisture content and mineralisable N as co-predictors for the subset of plots sampled in the pilot study (R^2 = 0.91). Submitted to Journal of Vegetation Science.

Uncertainty analyses of the VSD-GBMOVE model chain will be carried out using methods being developed in ongoing projects analysing uncertainties in VSD and MAGIC. Testing of CliMOVE, the version of GBMOVE in which three climatic parameters are fitted as well as the other abiotic parameters, has focussed on predicting change in habitat suitability for heather in the CLIMOOR droughting and warming experiment (Figure 2).

To develop capacity to predict changes in vegetation type, the ForSAFE-VEG model is being adapted for UK species and for non-forested ecosystems. This work has three main aspects:

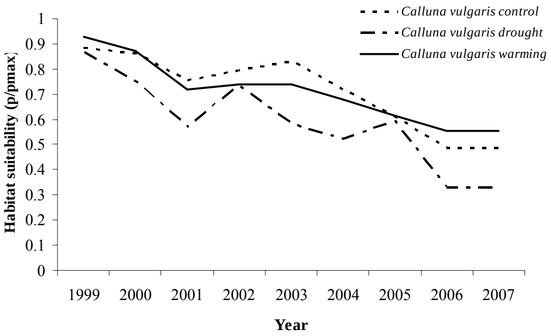


Figure 2. Predicted change in habitat suitability for heather (Calluna vulgaris) in the Climoor experiment control, droughted and warmed treatments.

a) selection and model set up for ICP2 forest plots, to evaluate data availability and the model's biogeochemical performance; b) implementation of a simplified growth module accounting for carbon and nutrient cycles in ground vegetation, enabling simulation of non-forest sites; and c) parameterisation of VEG to simulate changes in the ground vegetation for UK terrestrial ecosystems. Ten ICP2 forest sites have been selected for modelling with ForSAFE-Veg, and data on forest characteristics, management and soil properties including mineralogy have been collated. To simulate competition for light, nutrient elements and water, seven plant functional types (PFTs) have been identified. All plant species will be assigned to one of these PFTs. The relative dominance of the PFTs will depend on the composition of the ground vegetation as predicted by the VEG model. The PFT model will thus be driven by species composition as predicted from the effects of abiotic factors on individual species.

The VEG module dynamically simulates interactions between species on the basis of their competitive strength. Competitive strength is in turn calculated according to the environmental conditions using a set of response functions. In the UK, the GBMOVE set of models provides an empirical basis for assigning environmental thresholds and optima for individual species. We have developed methods for deriving VEG parameters from the GBMOVE models, allowing VEG to be applied to the majority of the UK flora using a consistent and empirical approach.

Modelling frameworks aim to ease the technical challenges of interfacing models and databases, and thereby focus attention on the scientific issues. Criteria for assessing modelling frameworks have been outlined and potential frameworks assessed.

Implications

Development of modules to be used in the TU model chain will continue in FORTRAN. Methods for re-implementing GBMOVE either in FORTRAN or as a compiled object will be explored. Links among modules and databases will initially be developed in FORTRAN. Links among compiled modules will also be developed using OpenMI and Visual Basic. The final choice of framework used to schedule the entire TU model chain will be made by Oct 2009.

Publications and talks

Rowe EC, et al. (submitted) Mineralisable nitrogen and other soil measurements as predictors of mean Ellenberg nutrient indicator value. Journal of Vegetation Science.

Smart, S.M., *et al.* (submitted) Empirical realized niche models for British higher and lower plants - development and preliminary testing. Ecological Modelling.
de Vries, W., *et al*. (submitted) Use of dynamic soil-vegetation models to assess impacts of nitrogen deposition on plant species composition and to estimate critical loads: an overview. Ecological Applications.

Milestones for Oct 08

5.1 Bayesian calibration approach applied to current Ellenberg versus soil variable regression models. **Not met**, due to prioritisation of CS2007 reporting, and in anticipation of a potentially more rigorous and sensitive signal attribution capability using Bayesian methods that is currently being developed in WP1. Delivery: March 2009.

5.2 Assembly of trait databases, BRC 10km square species pool data and computation of estimated abundance for invasives and native potential dominants. **Not met**, due to prioritisation of Countryside Survey 2007 reporting. Delivery: March 2009.

5.3 Review available existing modelling tools and investigate their compatibility. **Met.**

Task 5.1 – Analysis of large spatial datasets to identify relationship between species presence and a range of abiotic variables including climate change and soil chemistry and thus create multi-dimension species response functions

Task 5.2 – Development of plant species pools to develop an invisibility module

Task 5.3 – Development of plant growth and composition modules through modification of existing modules for non-forest systems

Task 5.4 – Evaluation of modelling frameworks

Work Package 6:

Collate data required for testing of linked soil-vegetation model chains from long-term manipulation sites, in particular time series data for recovery following cessation of treatments and interaction with management treatments. Interpret findings to understanding of impacts, rate of recovery and modifying factors

Task Leader: Gareth Phoenix[1] and Bridget Emmett[2]
[1]University of Sheffield
[2]Centre for Ecology and Hydrology Bangor

PIs: Elena Vanguelova[1], Simon Caporn[2], Jacky Carroll[2], Nancy Dise[2], Jonathan Leake[3], Gareth Phoenix[3], Sally Power[4], Lucy Sheppard[5], Ian Leith[5], Alwyn Sowerby[6], Andrea Britton[7], Rachael Helliwell[7]
[1]Forest Research, [2]Manchester Metropolitan University, [3]University of Sheffield, [4]ImperialCollege London, [5]Centre for Ecology and Hydrology Edinburgh, [6]Centre for Ecology and Hydrology Bangor, [7]MLURI

Work Package 6 Task Leader: Gareth Phoenix and Bridget Emmett

Objectives:
(1) Provision of data sets for the testing and development of linked soil-vegetation ecosystem models (WP5)
(2) Interpret findings to increase understanding of impacts, rate of recovery and modifying factors.
(3) Produce a synthesis paper reviewing the current understanding of ecosystem responses to N (based on UKREATE sites) drawing out the most important unifying responses.

Task: What is the empirical evidence for N impacts and recovery and can models simulate these changes?

Delivery of objectives to date
A considerable body of existing data from the UKREATE field sites has been submit to the UKREATE database (*Objective 1*), though some partners have experienced delays: Manchester Metropolitan University are awaiting appointment of a research assistant to undertake this task, CEH Edinburgh are delayed due to staff shortages. The Forest and Peaknaze datasets are compiled and are about to be submit to the database. A summary of the considerable amount and diversity of data submitted to date, and progress on data submission by each site is provided in Table 6.1 below. Collection of new data required to improve existing model runs has begun at all sites (*Objective 1*). The specific task of initiating collection an 18 month time series of soil solution chemistry, pH and soil moisture has also been started by all partners. However the University of Sheffield and Imperial College London have both just started this now (delay caused by delayed contract and the need to await appointment of a PhD student to undertake this work) so on the delivery date of Oct 2009, these partners will provide a 12 month dataset (with the remaining 6 months to follow) while the other partners will provide the full 18 months' data.

Completion of Milestones
Milestone 43, "*Start new data collection and provision of site data*" Deliverable by Oct 2008: Mostly complete by all partners barring the delay in data submission from some partners and initiation of 18 month datasets at two sites as detailed above. Milestone 44, "*Continued data collection and provision of essential datasets*" Deliverable by Oct 2009: This is ongoing and all sites anticipate completion by the deadline (bar the partial completion of the 18 month dataset at the sites mentioned above). Milestone 45 and 46: Not currently applicable.

Objectives 2 and 3 are progressing as scheduled with the production of the first draft text of the review paper completed from review text submitted by each partner. This text is also contributing to the RoTAP review, and this information was fed into the RoRAP vegetation chapter meeting (23.10.08). Manuscript development will now move to drawing out unifying responses across sites.

Methods and Results
Current activities at the UKREATE sites are too numerous and diverse to describe in detail since each site's main activities are largely dependant on which datasets are being collected. However, a brief overview is provided here. At Thursley, annual assessment of species abundance and *Calluna* performance has revealed a significant effect of on-going N additions on bud burst, growth and flowering more than a year after the intense summer fire in July 2006. Interestingly, N deposition has more than doubled post-fire bryophyte cover and significantly decreased lichen abundance. Recent soil microbial analyses show major effects on microbial community composition. At Whim bog, Cover assessments have been evaluated for NVC along with analyses of Ellenberg indicators, diversity indices and functional groups. There remains no significant wet N driven cover change for *Calluna*, in contrast to the clear significant reductions with ammonia. After 6 years soil C has significantly increased with N additions, with different effects of N form and dose. At Wardlow, soil solution sampling has been re-started using new rhizon samplers. Recent vegetation surveys show considerable impact on flowering which appear to magnify species change in vegetative

cover. In recovery plots, despite considerable recovery of soil N status, reduced soil P and plant P stress remains showing that impacts on P status are slower to recover than impacts on N status. At Culardoch, new data on soil mineralization and nitrification is being collated. New analyses reveal that N and burning treatments have resulted in rapid N leaching and soil acidification. Reductions in lichen species richness and cover with N addition have continued. N continues to stimulate growth and flowering in *Calluna*. At the Forest sites, national chemical trends are indicative of recovery from sulphur deposition and acidification. The recovery is confirmed by pH increase and sulphate, aluminium and manganese decrease in the soil solution at most sites. At Climoor and Peaknaze vegetation measurements have recently been undertaken and analysis of that data is underway. Soil water chemistry measurements are ongoing.

Policy implications

For *Calluna* dominated ecosystems (heathlands, bogs), while wet deposition increases *Calluna* biomass across most sites, most recent work shows considerable damage resulting from dry deposition NH_3. This suggests the lack of decline in NH_3 deposition in the UK may result in continued damage and future reductions in NH_3 emissions appear essential if damage to *Calluna* dominated systems is to be reversed. Most grasslands and heathlands show a good capacity to retain N and only show increased leaching of N at only relatively high N deposition rates. This is an important ecosystem service in the provision of clean groundwater and highlights the importance of preserving these systems in addition to their agricultural, conservation and amenity values. In the grassland systems, severe reductions in forb flowing suggest hindered floristic recovery since seed-banks of important species may be depleted. This is of particular concern since seed-banks of grasslands are short-lived, and suggests the grasslands in areas that have received high N deposition may have a impaired capacity for recovery.

TABLE 6.1: Progress on data submission by site

	T	W	R	B	Wa	Wc	P	C	F	Cl	Pk
Vegetation surveys	√	d	d	d	√	√		√	d	√	d
Biomass or shoot growth	√	d	d	d	√	√		√	d	√	d
Plant chemistry	√	d	d	d	√	√		√	d	√	d
Soil extractable NO_3^-, NH_4^+	√		d	d	√	√				√	d
Soil sol^n or leached NO_3^-, NH_4^+		d	d	d	√	√		√		√	d
Leached organic N			d	d	√	√		√	d	√	d
Soil pH	√	d	d	d	√	√		√	d	√	d
Soil moisture		d	d	d				√	d	√	d
Soil total N	√	d	d	d	√	√		√	d	√	d
Soil total C	√	d	d	d	√	√		√	d	√	d
N mineralization rates	√		d	d	√	√		√		√	d
Nitrification	√		d	d	√	√		√		√	d
N_2O production	√	d			√	√				√	d
Respiration		d	d	d						√	d
Extractable base cations	√				√	√		√	d	√	d
Total base cations					√	√		√	d	√	d
Extractable non-bases (Al, Fe, Mn)					√	√			d	√	d
Total non-bases (Al, Fe, Mn)					√	√		√	d	√	d
Usefull additional data: CEC; DOC, DON, SO_4^- Cl, Ca, Mg, K, Na; Litterfall C,N,P		d	d					√	d		
PME activity	√	d	d		√	√					
Soil extractable PO_4^-	√	d	d		√	√					
Drought injury	√	d	d								

√ = data submitted. d = data available but submission delayed (see text for details). Sites are T=Thursley, W=Whim, R=Ruabon, B=Budworth, Wa=Wardlow acidic, Wc=Wardlow calcareous, P=Pwllpeiran, C= Culardoch, F= ICP Forests, Cl= Climoor, Pk=Peaknaze.

Work Package 7:
Investigate role of climate change N cycling and indicators of N enrichment using two established climate change experiments

Task Leader: Alwyn Sowerby

Centre for Ecology and Hydrology Bangor

PIs: Alwyn Sowerby[1], Bridget Emmett[1] and Elena Vanguelova[2]
[1]Centre for Ecology and Hydrology Bangor, [2]Forest Research

Work Package 7 Task Leader: Alwyn Sowerby

Objective:
The aim of this work package is consider the impact of climate change on the flow and uptake of N through terrestrial ecosystems, as well as the impact of potential change in location of receptor (i.e tree species). There are two tasks within the work package, Task 7.1 uses two established climate change experiments to identify the impact of warming and repeated summer drought on the N cycle and indicators of N enrichment. Task 7.2 aims to identify the potential importance of change of location of receptor as a result of changing forestry policy and adaptation measures designed to address the threats of climate change, on the uptake of N and nutrients and the implication to Critical Load for acidity and N for woodland.

Task 7.1 – The influence of climate change on the N cycle and indicators of N enrichment in upland heathland and grassland PI: Alwyn Sowerby (CEH)

Milestone - Delivery to date
The deliverable milestone for Task 7.1 during this reporting period was maintenance of experimental sites, and all climate change treatments have been operational throughout 2007-2008. In Task 7.2, in line with the deliverable milestone for the task, current maps of tree species for the two sites have been generated from FC sub compartment database.

Methods
The Climoor and Peaknaze experimental sites utilise automated roof technology to produce warming and summer drought treatments (Beier *et al*. 2004). In conjunction with funding from the Nitroeurope project (www.nitroeurope.eu), routine measurements of key fluxes and indicators of N enrichment are continuing.

Results and Discussion
All data collection is on track by the next milestone (Oct 2009) we will have a complete 18 month data set of the key biogeochemical and vegetation measurements for both sites, including NO_3 and NH_4 leaching, N_2O flux as well as other fluxes related to the C cycle (e.g. soil respiration). We will also have meterological and abiotic data for the site, as well as plant diversity, biomass and foliar-N concentrations for the dominant species at the sites.

Implications
Work in this task will assess the magnitude of change and response of critical N processes in response to climate change (warming and drought) and how this compares to natural variability.

Task 7.2 An assessment how climate change may affect critical loads for woodlands
PI: Elena Vanguelova (Forest Research)

Methods
A GIS approach using also Ecological Site Classification (ESC, Pyatt *et al*., 2001) are used to bring together predicted changes in species, flows and uptake for a selected woodland to identify the relative magnitude of climate change on critical load exceedance.

References - Beier, C., Emmett, B.A., Gundersen, P., Tietema, A., Penuelas, J., Estiarte, M., Gordon, C., Gorrison, A., Llorens, L., Roda, F., Williams, D. (2004) Novel approaches to study climate change effects of terrestrial ecosystems in the field – drought and passive night time warming. Ecosystems, 7(6), 583-597.

Results and Discussion

To date, current maps of tree species for the two sites have been generated from FC sub compartment database. Areas for each main tree species are extracted from the maps and are shown in Figure 1. Maps only for the main forest types (e.g. coniferous, broadleaves and mixed woodland) are shown in Figures 2.

Implications

The work under this task will be put into context to enable better predictions of the woodland areas endangered by pollution in the fate of changing climate. If impacts are shown to be marked, the results will also provide the evidence base to support and guide Defra in bringing about the necessary change in future emission control to protect England’s woodlands.

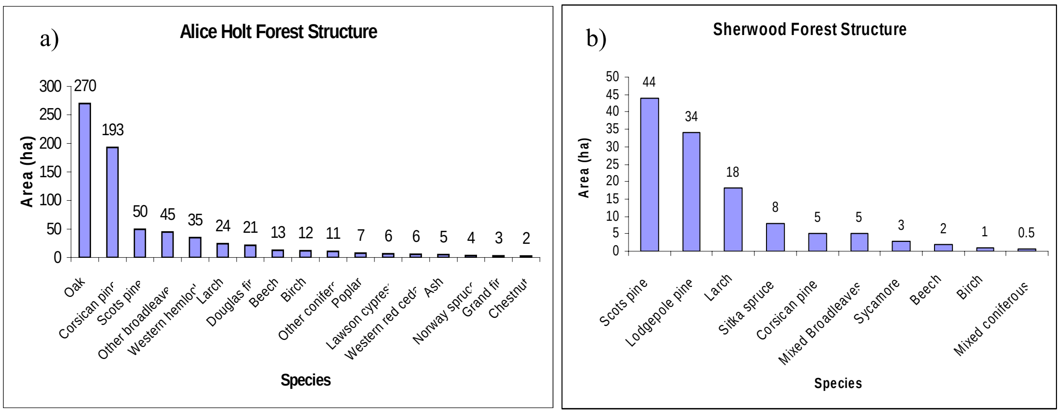


Figure 1. Areas of tree species in a) Alice Holt Forest and b) Sherwood Forest, estimated from FC sub-compartment database maps

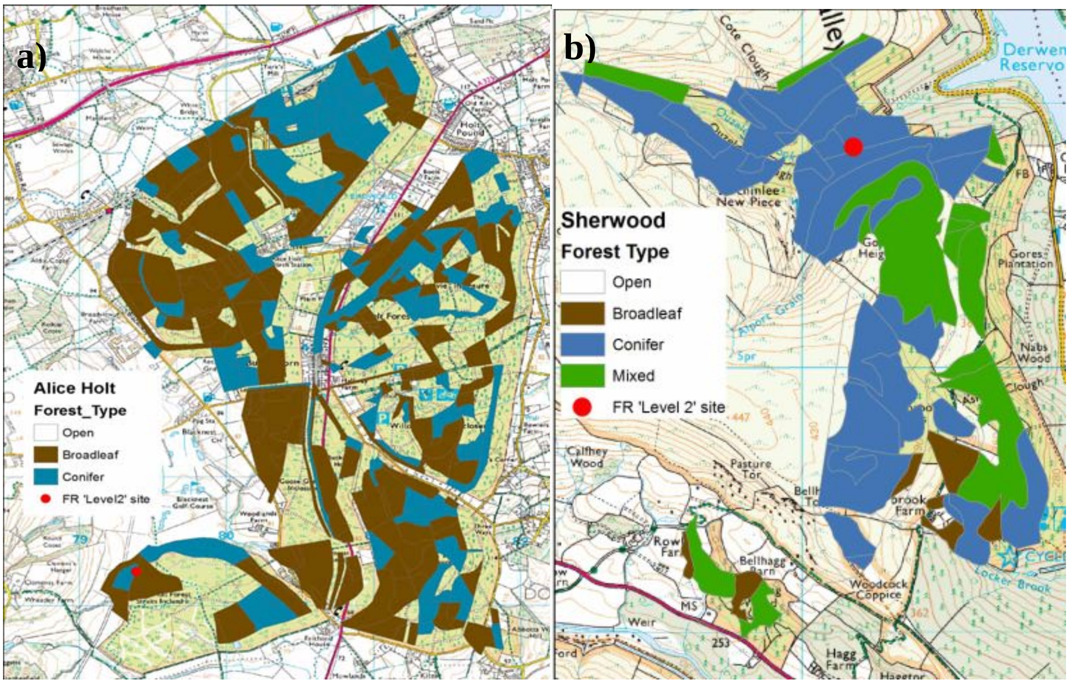


Figure 2. Mapped main forest types for the two study sites: a) Alice Holt forest and b) Sherwood forest. The locations of the Level II sites in both forests are also shown.

References - Pyatt, G., Ray, D. and Fletcher, J. (2001). An Ecological Site Classification for Forestry in Great Britain. Bulletin 124. Forestry Commission, ISBN 0 85538 418 2.

Work Package 8: Provision of management, advice and support on an ad hoc basis, support of CAPER conference

Task Leader: Bridget Emmett

Centre for Ecology and Hydrology Bangor

PIs: B. Emmett[1], Lucy Sheppard[2] and Mike Ashmore[3]
[1]Centre for Ecology and Hydrology Bangor, [2]Centre for Ecology and Hydrology Edinburgh, [3]University of York

Work package 8 Task Leader: Bridget Emmett

Task 8.1 – Management support and knowledge transfer

A start-up meeting was organised at MMU and focussed on synthesis talks bringing together the existing data and knowledge. This has enabled the UKREATE team to present our findings to a series of RoTAP meetings and provide written text for the RoTAP report. Planned activities for all WPs was also reviewed and timetables and responsibilities checked and agreed. A report to the project manager was submitted.

A series of meetings to develop the variation to the contract regarding the role of historical has more recently been organised with the PI taking the lead in finding the additional staff resource to fulfil this need.

A 2nd annual meeting will be organised for Oct 2009.

Task 8.2 – Organisation of CAPER conference

A highly successful CAPER conference was organised at CEH Bangor. There was over subscription for places demonstrating the high regard with which this meeting is held.

Task 8.3 – Assessment of the validity of mapping values of empirical loads in the UK

This is in progress