WHY THERE ARE (PROBABLY) NO PALAEOECOLOGISTS AT THIS MEETING.

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A key limitation of most studies of pollution impacts is their short-duration. The overwhelming majority of experimental studies are restricted to the duration of a typical research grant, 3 years at most, while only an exceptionally small number of studies span more than a couple of decades. These are very short time-periods in terms of ecosystem change. Alternative approaches involve making a space-for-time substitution in a gradient study or the re-survey of plots over time, but these approaches bring their own problems with complicating co-variables and old data-sets of variable or uncertain quality. In many regions we simply have no ecosystems which have been exposed to no anthropogenic pollution so our ability to judge change from a truly 'natural' baseline is severely compromised. Against this background the use of palaeoecology to gain an improved temporal perspective on pollution impacts is highly attractive. In this talk I explore why palaeoecological studies of pollution-impacts are so rare in terrestrial ecosystems. Key issues include the disciplinary disconnect between palaeoecologists (generally in Geography departments) and ecologists and biogeochemists (generally in Biology or Environmental Science departments) and a methodological disconnect. In modern ecosystems there are a wealth of parameters which can be measured given time, expertise and funding. In palaeoecological studies the number of measurable parameters is much reduced, generally conditioned by the presence of organisms with decay-resistant body-parts. Such organisms are generally over-looked in experimental studies so their pollution sensitivity is poorly characterised and our ability to apply them in palaeoecological studies undermined. The potential importance and relevancy of palaeoecological studies are illustrated with examples of sulphur impacts on peatlands and lake eutrophication. Palaeoecological studies of pollution impacts are not without problems but their potential is vastly under-exploited.

- This paper has DEFRA-policy relevance by suggesting new directions for the scientific investigation of pollution impacts which may improve our knowledge of pollution impacts, particularly at low exposure levels.

THE EFFECTS OF TOTAL NITROGEN LOAD AND THE RATIO OF REDUCED TO OXIDIZED NITROGEN ON BIOGEOCHEMICAL PROCESSES AND SPECIES COMPOSITION OF WET GRASSLANDS.

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In a large mesocosm experiment, the effects of reduced and oxidised N deposition, soil buffering status and total N load on biogeochemistry and vegetation composition were tested. This was done on intact soil cores, including the vegetation, taken from a site on the Isle of Skye with a long history of low N deposition. The selected vegetation was a NVC M25, *Molinia caerulea - Potentilla erecta* mire because of the potential to modify the soil acid neutralizing capacity (ANC). From the field site, cores with similar species composition (~10% *Erica tetralix*, ~25% *Eriophorum angustifolium* and ~10% *Molinia caerulea*) were selected.

The cores were placed in the greenhouse facilities at York University with very low background N deposition (estimated at 1-3 kg N $ha^{-1}yr^{-1}$). N deposition was simulated using artificial rainwater (deionised water with macro- and micro-nutrients at background concentrations) with varying NH_4Cl and $NaNO_3$ concentrations. Five different NH_4^+/NO_3^- ratios in simulated atmospheric deposition were tested (1:9, 1:5, 1:1, 5:1 and 9:1) at two fixed total N deposition loads (16 and 32 kg N $ha^{-1}yr^{-1}$), corresponding to respectively the critical N load and the highest ambient N deposition rates for these ecosystems, together with a control without any added nitrogen. In addition to these treatments, soil ANC was modified in 30 cores which received N deposition at a rate of 32 kg N $ha^{-1}yr^{-1}$ at NH_4^+/NO_3^- ratios of (1:9, 1:5, 1:1, 5:1, 9:1).

Soil pH in cores treated with a high NH_4^+/NO_3^- ratio was lower compared to cores treated with a low NH_4^+/NO_3^- ratio. Lime addition increased the pH slightly but had its most pronounced effect on soil ANC. After four years, cover of the grasses (mainly *Molinia careulea*) was increased in the cores treated with a high NH_4^+/NO_3^- ratio compared to cores with a low NH_4^+/NO_3^- ratio. In addition, some sensitive species and bryophytes declined in cores treated with a high NH_4^+/NO_3^- ratio.

DEFRA Policy relevance:

- The results to date suggest that for this particular NVC community, the benefits of investment in control of reduced N emissions would be greater than control of oxidized N emissions. However, we caution that this conclusion is quite specific to this NVC community, and should not be generalized.
- The work will benefit nature conservation agencies, because it will allow species at high risk from reduced N deposition to be identified, and hence provide an improved evidence base for protection measures.

HEATHLAND RESPONSES TO REDUCED AND OXIDISED NITROGEN APPLICATION WITH VARYING APPLICATION FREQUENCY

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During the last century, inputs of reactive nitrogen (N) to ecosystems have been more than doubled as a result of anthropogenic activities. Increased air-borne N pollution is one of the major threats to the structure and functioning of natural and semi-natural ecosystems. A further increase of up to 70% is predicted for NO_y deposition by 2050 from 1990s levels, while NH_x deposition is predicted to rise by up to 133% over the same period (Galloway *et al.*, 2004).

A number of experiments involving large but relatively infrequent N applications have been undertaken to better understand the effects of increased N deposition on lowland heath ecosystems. There has however been little work on the contrasting effects of atmospheric deposition of reduced (NH_x) versus oxidised (NO_y) nitrogen on healthland ecosystems, and no studies have explicitly investigated the importance of frequency of inputs and ion concentration. So, a study has been conducted to investigate the response of a heathland plant community to different forms of nitrogen (reduced & oxidized) applied at low & frequent vs infrequent and high levels of N additions, keeping the total N deposition constant. Intact heathland turf and soil samples were collected from the burnt area of Thursley Common, Surrey in April 2008 and used to set up experimental mesocosms at Silwood Park (UK). N was applied in the form of ammonium chloride (NH_4Cl) or sodium nitrate ($NaNO_3$) solutions at a rate of 20 kg N ha^{-1} yr^{-1} and responses were compared to controls. Solutions were applied at one of five intervals: weekly, two weekly, monthly, two monthly and four monthly.

After two years of N additions, results reveal significant effects of added N on soil pH which increased in the $NaNO_3$ treatment and decreased in NH_4Cl treated mesocosms. Soil pH was however unaffected by application frequency. Available oxidised nitrogen (TON) concentrations were much higher in the $NaNO_3$ treated mesocosms and NH_4^+ concentrations in NH_4Cl treatments. For both forms of N, small but frequent additions resulted in greater proportional increases in *Calluna vulgaris* shoot growth, compared to high dose, less frequent additions.

Policy relevance:

- Nitrogen deposition effects depend (to some extent) on the form and frequency of inputs. These results provide preliminary evidence that the frequency of experimental additions may also affect the size of vegetation responses to a given N load. This could have implications for setting critical loads on the basis of manipulation experiments.

USING NATIONAL DATA ARCHIVES TO DETECT NITROGEN IMPACTS ON VEGETATION

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Great Britain holds a rich archive of vegetation surveillance data from national monitoring schemes. This project aimed to analyse some of these datasets to see if N deposition signals could be detected.

Results will be presented from four large-scale tetrad and hectad datasets: the Vascular Plant Database, Botanical Society of the British Isles (BSBI) Local Change Survey, British Bryological Society (BBS) Database, and British Lichen Society (BLS) Database. Four semi-natural habitats were selected for analysis: acid grasslands, calcareous grasslands, heathlands, and bogs. All four were analysed separately for uplands and lowlands. Spatial analysis investigating the change in drivers across the gradient of deposition in Great Britain was conducted for all datasets using generalised additive models (GAMs) to assess the impact of N deposition on individual species presence and Ellenberg N scores, taking into consideration other potential drivers.

All of the habitats examined showed signs of nutrient enrichment related to nitrogen deposition. A number of vascular plant, bryophyte and lichen species were identified as showing clear relationships with nitrogen deposition once other potential environmental controls such as climate had been accounted for. All habitats contained species which showed declines in their probability of presence with increasing N deposition.

Relevance for Defra's policy

- Investigated impacts of nitrogen deposition on biodiversity
- Assessed impacts above and below critical loads
- Assessed potential for incorporation into national vegetation monitoring strategies
- Investigated the suitability of CSM for detecting N deposition impacts.

MOSS AND SOIL N AND C CONCENTRATIONS AND RATIOS IN RELATION TO MODELLED NO_x AND NO_2 CONCENTRATIONS IN URBAN FORESTS

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In general, the total N concentration in mosses correlates rather well with EMEP modelled maps for N deposition in background areas. However, Pearson et al. (2000) found no correlation between tissue N and traffic exposure, but a very good positive correlation between traffic exposure and tissue $\delta^{15}N$ indicating contribution of vehicle NO_x emissions on moss N content in urban areas. The lack of increase in moss total N concentration with increasing NO_x concentration was attributed for a variety of probable reasons such as the relative tolerance/susceptibility of a species, growth dilution and the possibility that NO_x emissions from traffic disperse over relatively large distances. Knowing this, *Pleurozium schreberi* and surface soil were sampled from three 10 cm x 10 cm quadrats at 42 sites in *Cladina* and *Calluna* type forests in the Helsinki metropolitan area (60°1'N, 24°57'E) in September 2010. The samples were analysed for total N and C concentrations, and the length and dry biomass of living (green) and dead shoot were recorded. The cover of grasses, forbs, mosses, lichens, dwarf shrubs, litter, bare soil and stones/rock were also assessed from three 1 m x 1 m quadrats at each site.

The modelled annual mean NO_x concentrations reached up to 50 µg m^{-3} and those of NO_2 to 30 µg m^{-3} at the study sites. These pollutant levels seem mainly affect C:N balance of both the above- and below-ground part of the ecosystem. The preliminary analyses show negative correlations between modelled NO_x and NO_2 concentrations and the length of moss green shoot ($p=0.020$ and $p=0.013$), moss C concentration ($p=0.002$ and $p<0.001$) and soil C:N ratio ($p=0.012$ and $p=0.023$). Based on factor analysis, moss biomass and cover are negatively related to cover of grasses, while moss C concentration is also negatively related to moss N concentration. More detailed analyses on the relationships between NO_x and NO_2 concentrations and moss and soil variables will be presented and discussed in the meeting.

Defra policy relevance: The study provides evidence of the impacts of relatively low NO_x and NO_2 emissions on forest ecosystem C:N balance.

THE EFFECTS OF ROADS ON THE COMPOSITION AND FUNCTIONING OF CALCAREOUS GRASSLANDS

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Vehicles emit a cocktail of pollutants from their exhausts which can change the composition of the air. The wear and tear of tyres, brakes and engines can produce particulates and heavy metals. Alkali chemicals can be added to roads to assist salting and road surfaces disrupt natural drainage. These environmental perturbations are likely to affect the plant communities that are growing alongside roads. This may be particularly true of plant species which are adapted to a narrow range of ecological conditions, such as those which are found in calcareous grasslands. I will discuss the results of a year-long study that has monitored nitrogen dioxide concentrations in the air, and the physical and chemical characteristics of the soil, at three calcareous grassland sites. Sites were located close to a low, medium or highly trafficked road. The extent of changes to air and soil quality will be presented and where appropriate the exceedance of established critical levels will be highlighted. The abundance and standing biomass of all plant species was measured at all three sites at different distances from the roadside and relationships with air and soil parameters were identified using mixed effects models. Plant community composition changed nearer the roads, but variability in the cover and productivity of grasses, forbs and mosses were related to different environmental variables. The complex response to both vehicle-derived pollutants and other, unrelated variables may help to explain why previous studies have struggled to find a consistent nitrogen signal when looking at overall plant community responses to roads. Variability in environmental conditions may override the effects of vehicle pollution for some functional groups. Quantifying how different functional groups and individual plant species respond to a suite of environmental changes adds to our understanding of the mechanisms by which roads can change the composition and functioning of ecosystems.

- This study has policy relevance through its quantification of the magnitude of traffic-derived pollution and its effects on roadside plant communities and ecological processes. It will also establish the extent to which critical levels of NO_x have been exceeded at sites of conservation importance across southern England.

ACCUMULATED DOSE RESPONSES FROM UKREATE MANIPULATION SITES: EMERGENT RESPONSES ACROSS ECOSYSTEMS AND IMPACTS OVER TIME

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Defra funds a UK wide network of nine N deposition simulation experiments across a diversity of habitats of conservation value. Many of these experiments are the world's longest running N deposition simulations for their ecosystem type and to date include more than 150 years of treatment application in total. Datasets collected from these experiments provide a unique opportunity to determine the long-term impacts of N deposition, to seek emergent responses common across ecosystems as well as inter-site differences, and to determine how responses change (or "build up") over time with increasing accumulated dose.

For emergent responses across ecosystems, particular sensitivity has been observed in lower plants, apparent as a decline in lichens in the heathland and bog sites and a decline in bryophytes in the grasslands. Responses of higher (vascular) plants are less pronounced. N deposition tends to increase growth and/or cover of *Calluna vulgaris* at sites where this dominates, though major changes in higher species richness are not necessarily apparent. At the grassland sites, there is some tendency for community change to follow the pattern of increased graminoid dominance at the expense of forbs, though slow responses at these sites may be a result of P, co-NP or K limitation. Flowering also shows some consistency across sites in response to enhanced N deposition. Assessment of responses with accumulated dose suggest N deposition impacts may build over time as enhanced N deposition rates continue. In particular, declines in diversity and/or cover of lichens and bryophytes supports the idea than even relatively low N deposition rates can (should they continue for extended periods) effect biodiversity. Furthermore, rates of change appear shallower at sites of historically high N deposition. This supports the idea such sites may have already been impacts by ambient deposition and that control plots could therefore already lost sensitive species which may reduce the ability of such studies to detect change in treated plots.

Policy implications:

- Impacts of N deposition in UKREATE sites show continued evidence for damaging effects of N deposition.
- Impacts of flowering raises concerns for provision of seed-banks for ecosystem recovery and for plant-pollinator interactions.
- The accumulated dose work suggests that even relatively low N deposition rates may be damaging if continued over longer periods (and therefore is consistent with reassessment of critical loads downwards).
- Shallower responses at sites of high N deposition suggests these sites may already be damaged from historic N loading.

NITROGEN EFFECTS ON PRISTINE BOG VEGETATION IN PATAGONIA. WHAT'S LOW AND CAN PHOSPHOROUS MITIGATE N-STRESS?

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Defra policy relevance:

- A reference indicating natural conditions can be built from our collection of physiological parameters measured in pristine bog vegetation exposed to outstandingly low nitrogen deposition.
- A discussion to what extent phosphorous can mitigate effects of increased nitrogen availability.

This talk summarises the response of pristine *Sphagnum*-vegetation to a 3-year fertilisation under field conditions in Patagonia. We will focus on stress induced by nitrogen and interactions between nitrogen and phosphorus.

Naturally oligotrophic ecosystems like bogs after increasing nutrient availability. Nitrogen has been largely studied because it imposes stress on moss vegetation: growth inhibition, shading by increased vascular plant cover and damage of the photosynthetic apparatus. Phosphorous may mitigate these negative effects by balancing nutrient ratios and by dilution of nitrogen through stimulated biomass production (Smolders *et al.* 2001).

Nitrogen (4 g N m^{-2} y^{-1}) and phosphorus (1 g P m^{-2} y^{-1}) were applied in a full factorial design to lawns of *Sphagnum magellanicum*. Nutrients were applied evenly 6 times during the growing season. Wet deposition of nitrogen was low (0.1 g N m^{-2} y^{-1}).

Biomass production and photosynthesis were substantially stimulated by adding phosphorous. Any of the nutrients applied changed the morphology of Sphagnum mosses by increasing height increment. Stimulated height increment was correlated with lower densities of mosses (impeded branching), which limited net biomass increase. Lowest densities were found in the combination of both nitrogen and phosphorous.

Mosses receiving extra nitrogen also changed their metabolism indicating stress: tissue concentration of nitrogen doubled, nitrogen-rich amino acids accumulated and photosynthetic efficiency decreased. Surprisingly, applying phosphorous did not interact with these nitrogen effects. Cover of vascular plants and their foliar chemistry remained low in all treatments underlying the poor conditions in Patagonian bogs.

We conclude that the addition of nitrogen imposed physiological stress on Sphagnum plants that can cause long-term damaged. Phosphorous seemed unable to mitigate N-induced stress despite biomass production being limited by phosphorous. In contrast, applying both nutrients seemed to reduce moisture supply to mosses by impeding branching and therefore increasing risk of desiccation.

Our study highlights the importance of long-term experiments that allow integrating important changes on the vegetation-level, the physiological-level and the atmospheric-level (e.g. stochastic droughts).

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TRANS-ATLANTIC COLLABORATION SHOWS GAPS IN NITROGEN KNOWLEDGE; THE TRIPHASIC RESPONSE OF *SPHAGNUM* PEATLANDS TO AIRBORNE NITROGEN REVISITED

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- Effects of airborne nitrogen along a pollution gradient including areas receiving (exceptionally) low inputs of atmospheric N deposition
- Insight into the functioning of peatlands in unpolluted reference areas as compared to areas with low but elevated inputs of airborne nitrogen
- Interactions between nitrogen and carbon sequestration in peatlands
- Effects of nitrogen on peatland plant biodiversity

For *Sphagnum* dominated peatlands, a dose-dependent, triphasic response to atmospheric N deposition has been proposed for European peats (Lamers *et al.* 2000, Berendse *et al.* 2001, Heijmans *et al.* 2002, Tomassen *et al*. 2003): (1) at low rates, N deposition stimulates N-limited *Sphagnum* net primary production, (2) as N deposition increases, N no longer limits *Sphagnum* production and accumulates in growing mosses, and (3) at high N deposition, the living *Sphagnum* layer becomes N-saturated and new inputs of atmospherically deposited inorganic N bypass the living *Sphagnum* filter and leach downward, where they may fuel either vascular plant production or heterotrophic microbial activity.

Recent studies in boreal bogs of Alberta (NW Canada), however, challenge the idea of this triphasic response as N accumulation in peat is substantially greater than the amount of N deposited via atmospheric deposition (Wieder *et al.* 2010). Based on a trans-Atlantic comparison, we will propose an adapted version of the triphasic model to encompass the response of bogs to N deposition within the bounds of the low N deposition gradient. We will postulate the loss of symbiosis between *Sphagnum* and N-fixing microorganisms (cyanobacteria, bacteria) in nitrogen-polluted areas, and indicate its consequences at the species level (trade-off) and ecosystem level (biogeochemistry).

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HOW DO ATMOSPHERIC N DEPOSITION INPUTS AFFECT POST-FIRE COLONISATION AND DEVELOPMENT OF HEATHLAND CRYPTOGAMIC FLORA?

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Thirteen years of experimental research at Thursley Common has demonstrated the high sensitivity of lowland heathland ecosystems to inputs of atmospheric nitrogen deposition. Elevated rates of nitrogen deposition have been seen to drive changes in *Calluna* abundance, phenology and growth as well as alter foliar chemistry and key biogeochemical processes. Detrimental changes to lower plant abundance have also been observed, with treatment differences of up to a 90 % decrease of lichen cover in plots receiving additional nitrogen inputs. As much of the floristic diversity of the lowland heathland habitat is represented by cryptogamic flora, the implicit threats to biodiversity as a result of ongoing N deposition are profound.

In 2006, a wildfire at Thursley Common burnt through all of the experimental plots, removing all vegetation. Ongoing observations allow us to quantify the nature and rate of recolonising plant species following a severe burn, and determine how N deposition may influence this recovery. To date, experimental observations of lower plant communities have been aggregated into functional type groupings only. The aim of this study is to collect species level data within these functional groupings in order to provide greater insight into how N deposition affects species composition, species richness and reproducive status of heathland cryptogams.

Defra policy relevance:

- Lichen and bryophytes represent an important component of terrestrial ecosystems and contribute to the services that ecosystems provide. They provide vital sinks for deposited N, degradation of which can result in increased nitrate leaching and associated surface water acidification and eutrophication.
- Cryptogamic biomass contributes to the carbon, nitrogen and mineral stocks and cycling within ecosystems.
- Cryptogams provide food, camoflauge and shelter for invetebrate species, and are a valuable nesting material for birds.

BIO-INDICATORS OF NITROGEN DEPOSITION AND EUTROPHICATION

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There is increasing need for reliable and simple indicators to reveal both the level of nitrogen pollutant deposition and any resulting ecological impact at the local habitat scale. Similar information is required over larger areas to confirm predictions of exceedance of pollutant thresholds such as critical loads and levels and to judge the effectiveness of regional and national pollution control strategies. Research to date suggests that one single indicator is unlikely to be reliable enough to give a clear sign of the level of nitrogen deposition or its ecological impact. A more likely approach is to use a combination of measures of N accumulation, biogeochemical responses and observations of significant ecological effects.

This talk will examine these indicator measures through two studies, firstly an analysis of results from the DEFRA-funded Terrestrial Umbrella (UKREATE) long term nitrogen addition experiments across grasslands, heaths, moorlands and bog in England, Scotland and Wales. The well established experiments enable us to examine the relationship between N addition and biogeochemical change in the absence of other significant edaphic, climatic or management influences. Secondly we will examine the results of a multi-habitat botanical survey that was carried out in 2009 as part of the UKREATE project. Over 560 vegetation quadrats (2 x 2 m) were surveyed across 112 sites encompassing upland and lowland heathland, bogs and sand-dunes. We also revisited 23 of the sites surveyed by Stevens *et al.* (2004). In addition to the vegetation data recorded, soil cores, moss tissue and plant tissue were sampled and extensive laboratory analysis encompassing tissue C, N, P, soil C and N, mineralisation potential, moss chlorophyll fluorescence (Fv/Fm) and PME activity was completed.

EFFECTS OF LONG TERM EXPOSURE OF NITROGEN AND AMMONIA DEPOSITION TO EPIPHYTIC TERRESTRIAL ALGAE ON OMBROTROPHIC BOG

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DEFRA Policy Relevance:

- Evidence of the effect of N depositions both in the form or wet of dry towards number of cells of epiphytic terrestrial algae.
- Provide more understanding on algal responses towards oxidised and reduced N.

Algal communities on bogs are typically species-poor. Their species richness is known to decrease in the system of lower pH. Species composition of algae in this study was slightly different between plots treated with gases NH_3 (dry plots) and the one treated with NH_4^+ and NO_3^- (wet plots). Algal cells which received wet treatment contained higher density of algae compared to dry plots. Wet deposition plot was mainly dominated by algae from the division of Chlorophyta. They formed thick greenish layers on the twigs of *Calluna vulgaris*. Besides insignificant number of diatoms, there were 3 main genera in this plot namely *Cylindrocystis* sp., *Desmidium* sp. and *Chroococcus* sp. Species diversity in the dry plot was not much of a different from the wet plot, mainly dominated by algae from the division of Chlorophyta, Bacillariophyta and Euglenophyta. These algae formed a thin layer of gelatinous slimy green patches on soil and moss. Among the dominant species were *Cylindrocystis* sp., *Desmidium* sp. and *Spirogyra* sp. Different algal species has also found to respond differently towards variety of treatment. Number of algal cells was found to increase with induced N, either treated with $NaNO_3$ or NH_4Cl. This study also concluded that oxidised N has been found to be more damaging to algae compared to reduced N. In addition to that, an addition of PK was found to have a damaging effect to the number of algal cells when coupled with $NaNO_3$ treatments. However, the opposite effect was found when PK was added to NH_4Cl treatments, resulting in more algal cells in the plots. Algae was found to significantly increasing in number along NH_3 transect, reaching its peak at 28 m from NH_3 source. After this distance, number of algal cells fluctuates slightly but obviously in lower number than when received higher concentrations of NH_3.

ECOSYSTEM SERVICES – THE GOOD, THE BAD & WHERE DO WE GO NEXT?

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'Ecosystem services' has joined 'biodiversity conservation' and 'sustainable use' as one of the must-have phrases in policy deliberation. It has potential to have a major effect on society's attitudes to environmental management, which is one reason we should not ignore it, but there are considerable difficulties in applying the concept generally.

The ecosystem approach promotes a holistic view of environmental issues and the services idea focuses that the environment has value. One of the more obvious concerns is that ecosystem services concentrate on the human-environment interface, because the measure of value is on the benefit that humans gain. In practice we apply the concept by creating a framework for the study which can be for a place based, habitat based, or service based perspective. The perspectives define the statistical population for data acquisition, so data collected in one study may not be relevant for a study from a different perspective. Two major challenges then face the investigator: how to define the boundaries of the system and how to achieve the correct level of detail – these decisions are never clear-cut, yet they can have a profound influence on the applicability of the work. An important consideration is that the knowledge being used within the ecosystem services assessment has very different levels of uncertainty, which should be correctly reflected in the final outcomes of the study.

To illustrate some of these issues, the talk will draw on examples of both place-based studies linked to long-term ecological monitoring sites and service-based studies looking at the impact of air pollutants.

AIR POLLUTION AND ECOSYSTEM SERVICES – PUTTING A VALUE ON CLEANER AIR

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This study has relevance to Defra policy as:

- There is considerable interest in the use of Ecosystem Services to capture the wider costs and benefits associated with human use of the environment.
- Controlling emissions of air pollutants is costly and the investment required for further emissions reductions achieves diminishing returns.
- Defra wish to test the Ecosystems Services Approach as a means of assessing the value of air pollution controls.

Ecosystem Services are a way of capturing wider information about the benefits (and costs) of services we obtain from the environment, outlined initially in the Millennium Ecosystem Assessment (MA 2005) and the concepts are continually evolving. Defra have developed the Ecosystems Services Approach as a methodology to capture this information within the context of policy questions, such as "What are the costs and benefits associated with controlling air pollution?"

We outline how the Ecosystem Services Approach has been applied to value impacts of three air pollutants (nitrogen, sulphur and ozone) via their key mechanisms of impact: eutrophication, acidification and direct toxicity. We describe the impact pathway and provide some examples of the valuation chain for selected Ecosystem Services. We also discuss some of the issues involved in conducting this exercise, such as: Can we link observed changes in the environment to the delivery of Ecosystem Services? Do we have evidence of recovery and over what timescales? How do we deal with combinations of pollutants? Does the reality match the arm-waving?

RESULTS FROM THE SOLARDOMES INDICATE THE DETRIMENTAL EFFECTS OF INCREASING BACKGROUND OZONE ON ECOSYSTEM SERVICES

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In the last three years, we have studied the impacts of increasing background ozone concentration on wetland, grassland and tree species in the solardome facility at CEH Bangor. This facility comprises of eight dome shaped greenhouses, each with finely controlled ozone concentrations, providing 8 ozone treatments ranging from pre-industrial to predicted post-2100 concentrations. We provide here a selection of results that are relevant to ozone impacts on ecosystem services. The results are from three Ph.D. studies and from Defra- and CEH-funded research.

The ecosystem services studied so far, and impacted on by ozone:

Provisioning services: Several studies at Bangor have shown shifts in species balance within simulated grassland mesocosms after one or two seasons of exposure, indicating the potential for changes in genetic diversity. Species decreasing in above ground cover with increasing background ozone include the grass *Anthoxanthum odoratum* and the forbs *Leontodon hispidus*, *Ranunculus acris, Campanula rotundifolia* and *Viola riviniana*. Decreases in above ground biomass with increasing background ozone have implications for livestock carrying capacity for the lightly grazed communities we have been studying. Experiments have shown that increasing background ozone increases stomatal conductance in several species. Such an effect would reduce water storage within vegetation leading to increased water vapour in the atmosphere. We have also shown that increasing background ozone impacts on the timing of flowering – an effect that could have consequences for pollinating insects.

Regulating services: We have shown that there is a negative impact of increasing background ozone on root biomass. For some species, this effect occurs even when there are no apparent effects on above ground biomass. Such an effect, seen in several grassland species together with bean and some tree species including birch, indicates that increasing background ozone has the potential to negatively impact on carbon sequestration. Within-canopy measurements have shown that ozone uptake by vegetation is reduced by prolonged exposure to increasing background ozone. Ozone can both increase and decrease methane release from bog mesocosms dependant on accumulated dose. All of these effects would impact on global warming. Implications of ozone-induced reduced root growth for flood control will also be discussed.

Cultural services: A common response to increasing background is enhanced senescence, with thresholds for effects close to the current ambient concentration. By reducing the visual impact of natural grasslands, there is the potential for effects on tourism etc..

Relevance to policy:

This presentation will summarise results from the solardomes that show that important provisioning, regulating and cultural services provided by ecosystems are likely to be compromised in an increasingly ozone rich environment. These effects are highly relevant for policy makers as impacts on ecosystem services are increasingly being used in policy on air pollution and climate change impacts. Several of the results described here are being used in an economic impact assessment for ecosystem services (see paper by Jones et al.).

r ecosystem services (see paper by Jones et al.).

DOES SEASONALITY IMPACT UPON NITROGEN CYCLING IN GRASSLANDS?

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Soils from two permanent grassland sites in N Yorkshire, close to the city of York, have been sampled monthly over a year to examine seasonal effects upon both mineral N species in fresh, field moist soil and mineral N species production or immobilization in soil incubated for 7 days at ambient outdoor temperatures. Surprisingly, very little mineral N was produced in the soils in summer months. It is hypothesised that this is another unrecognized seasonality effect in N cycling. Litter deposited over late autumn and winter months is largely stored in soil at the low winter temperatures. This pool of readily decomposable material starts to be mineralized in spring, but by summer the supply of such material has been greatly reduced. Fresh inputs at his time are also much lower, as plant growth is vigorous, producing little senescent material. This is represented schematically below in Fig. 1. Therefore we suggest that low mineral N input from recent litter in soil is a major factor contributing to the summer minima very often seen in nitrate concentrations in rivers. Previously most scientists have assumed the seasonality simply reflected high nitrate uptake by plants in summer months.

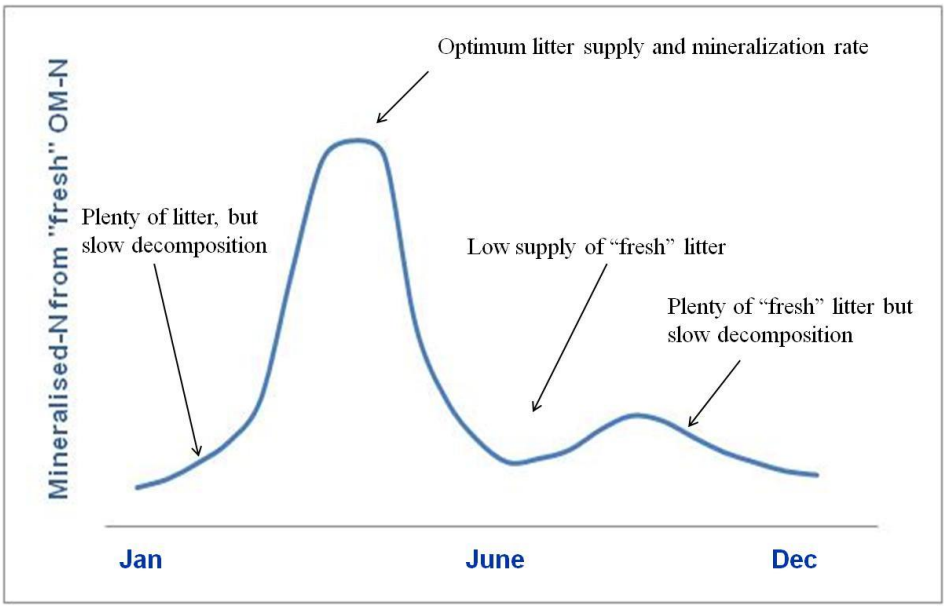

Fig.1. Representation of a mechanism for low mineral N production in soils in summer months.

- The proposed mechanism appears to be in operation at both Hob Moor and the University playing field, and undoubtedly occurs at other sites. It has important policy implications as a mechanism regulating mineral N leaching to surface waters and ground water supplies.

HOW DOES NITROGEN DEPOSITION AFFECT HEATHLAND RECOVERY FOLLOWING A MAJOR FIRE?

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Climate change is predicted to increase the frequency and severity of summer fires in the UK. However, the effects of fire on ecosystem processes are likely to depend on pre-burn vegetation characteristics, soil chemistry and microbiology, all of which are known to be affected by changes in nitrogen (N) deposition. Long term N addition experiments at a lowland heathland (Thursley Common National Nature Reserve, Surrey) have established the mechanisms by which nutrient loading drives above- and belowground ecosystem change, and resulted in many treatment-related differences in plant and soil characteristics. The occurrence of a severe summer fire at the site in 2006, therefore, provided the opportunity to evaluate the impact of a major perturbation on nutrient and microbial dynamics in soils of contrasting chemistry and microbiology. . We specifically quantified a) the availability and dynamics of soil nutrients; b) the composition and dynamics of the soil microbial community; and c) the post-fire vegetation re-growth for a 12 month period following the fire.

Results indicate that the fire significantly reduced the size of soil nutrient stores, although pre-existing differences in N and P availability between control and N-treated plots remained. Temporal variation in nutrient availability and leaching was high, reflecting patterns in microbial activity and climate. Microbial community composition was dynamic, with clear differences apparent between both unburnt and burnt areas, and control and N-treated plots. The persistence of clear N treatment-related differences in community structure following a high impact, high temperature fire was surprising, and suggests that below-ground effects of N deposition are likely to be highly persistent. Vegetation recovery following fire showed clear effects of N treatment, reflecting patterns in both nutrient availability and microbial community composition. Evidence from the study to date indicates that, although severe summer fires have the potential to remove a proportion of accumulated soil nutrient stores, deposition-driven differences in nutrient availability, microbial community composition and vegetation performance remain, at least in the short term.

Policy implications:
This study provides a quantitative evaluation of the consequences of two major global change phenomena for soil biodiversity, nutrient cycling and vegetation dynamics. Information on the relationships between above and belowground processes, and ecosystem resilience to a major perturbation, will contribute to an improved understanding of anthropogenic effects on ecosystem processes and, ultimately, earth's life support system.

FATE AND IMPACTS OF ACUTE ATMOSPHERIC NITROGEN DEPOSITION ON PLANTS AND MICROBIAL COMMUNITIES IN THE HIGH ARCTIC TUNDRA

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Arctic tundra ecosystems that historically received very low rates of atmospheric N depositions have been shown to have some sensitivity to increases in N inputs. However, chronic rates of N deposition in the Arctic are low. Instead, a greater threat arises from acute N deposition events where ~ 40% (perhaps reaching 80%) of annual atmospheric N input can be deposited as acidic rainfall (pH 4) in less than a week. These events result from polluted air masses from Europe travelling to the Arctic with minimal dispersal. The aim of our research is to investigate the fate and impacts of acute atmospheric nitrogen deposition upon plants, microorganisms and soil biogeochemical processes in the high Arctic tundra. This research is part of a multidisciplinary EU project "NSINK" (http://nsinkproject.group.shef.ac.uk/NSINK/Home.html), studying the impact of atmospheric N deposition on N cycling in the high Arctic.

In this study, acute N deposition events have been simulated since summer 2009 using a plot scale N-addition experiment on tundra at Ny-Ålesund, Svalbard (78º55'N; 11º56'E). The vegetation is dominated by bryophytes and *Salix polaris*. ^{15}N-labelled amendments were made with $^{15}NH_4{}^{15}NO_3$ during 2010 at rates of 0.4, 4 and 12 kg N ha^{-1} yr^{-1}. The fate of different species of reactive N, such as NO_3^- and NH_4^+, was also assessed by N-addition of $Na^{15}NO_3$ and $^{15}NH_4Cl$ (4 kg N ha^{-1} yr^{-1}). Soil and plant samples (10×10 cm^2 monolith) and soil leachate were sampled through the summer. Extensive laboratory analyses encompassing ^{15}N, C, N for plants (above and below ground), and soil; soil pH; soil inorganic N, microbial N, leachate ^{15}N have been undertaken. Initial plant surveys have been completed in summer 2010 along with assessment of photosynthetic activity response of *Salix polaris* using chlorophyll fluorescence (Fv/Fm). Impacts of acute N deposition upon microbial (archaeal and bacterial) community structure is being investigated using molecular (DNA)-based approaches such as Terminal Restriction Fragment Length Polymorphism (T-RFLP).

Salix polaris showed immediate (3 days after N-application) positive fluorescence response to 12 kg N ha^{-1} input. 10 days after the application, plants treated with 4 and 12 kg N ha^{-1} responded positively to the treatment showing 21% and 15% increases, respectively in F_v/F_m ratios as compared to controls. Between the N species, plants treated with $NaNO_3^-$ responded positively to the N treatment showing 17% higher photosynthetic capacity than controls. Archaeal and bacterial communities structure revealed significant (P = 0.001) differences between the organic and the mineral soil horizons. Archaeal community structure showed significant (P = 0.004) changes over time in the mineral horizon only; whilst the bacterial structure did not change over time. The N-addition (12 kg N ha^{-1} yr^{-1}) had a significant effect (P = 0.048) only on the bacterial community structure of the mineral horizon one day after the N-addition. Thus, our data suggest that even if such N deposition events are short lived, they can improve the photosynthetic capacity of the high Arctic plants by 15-20%, and can have rapid impacts on the bacterial community structure.

- Our work will inform Defra policy as to how N emissions from the UK can impact on remote and pristine ecosystems of exceptional conservation value.
- It will inform how these impacts may influence ecosystem functioning that may feedback to global climate (e.g. ecosystem carbon balance) and hence the UK climate also.

A FLUX-BASED ANALYSIS OF THE EFFECTS OF OZONE POLLUTION ON FOOD SECURITY

Gina Mills[1*], Felicity Hayes[1], David Norris[1], Mhairi Coyle[2], Howard Cambridge[3], Steve Cinderby[3], David Simpson[4], Tim Murrells[5], John Abbott[5], Sally Cooke[5] and colleagues in the ICP Vegetation.
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With the world population predicted to increase to 9 billion people by 2050, security of food supplies is one of the most important challenges for this century. Food security may be usefully conceptually divided into three major components: Food availability (production, distribution, and exchange), food access (affordability, allocation, and preference), and food utilization (nutritional value, social value, and food safety). The FAO (and others) also explicitly include stability as a fourth component, to acknowledge that food security varies seasonally and inter-annually in many places. The key components of the food system that ozone pollution interferes with are the productivity of crops, the nutritional value and the stability of food supplies, and it is these effects that are being quantified in this Defra-funded project at both the national and European scale.

In this presentation, we will describe quantification of the impacts of ozone yield quantity and quality using flux-based response functions. These functions relate effects to the accumulated uptake of ozone determined using models of the effects of climate (temperature, humidity, light), soil moisture and growth stage on stomatal conductance (the phytotoxic ozone dose, POD). The flux-approach has greater biological relevance than the previously used concentration-based methods which used the accumulated ozone concentration above 40 ppb as the dose metric.

Unfortunately we are unable to include results in this abstract as the analysis will not be completed until mid-March. For the European study, we will present maps indicating where the largest impacts on wheat and tomato are predicted for 2000 and for various precursor control scenarios for 2020. We will also include an economic impact assessment using production data on a 50 x 50 km grid. For the UK study, we will show the areas where economic impacts are expected for wheat, potato, oil seed rape and pasture using a 10 x 10km grid for two contrasting ozone years: 2006 and 2008. Examples will be presented showing how flux-based predictions differ from those using the earlier AOT40-based methods. Lastly, we will provide a first indication of the potential impact of ozone episodes on the horticultural industry, focussing on the impacts of ozone injury on the ready-to-eat salad leaf industry.

Policy relevance:

- This study is quantifying effects of ozone pollution for use by the LRTAP Convention in the development of strategies for pollution control in Europe.

- The more detailed UK study has been commissioned to provide an indication to Defra of the current and future economic impacts of ozone on food production and to recommend future research priorities.

LONG-TERM EFFECTS OF OZONE ON CARBON FLUXES IN MIRE MESOCOSMS

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Tropospheric ozone poses a significant threat to crop yield and forest productivity of sensitive species, and to ecosystem carbon storage at current levels in Europe, while northern hemisphere background ozone concentrations are expected to increase further during the next decades. Risk assessment of ozone impacts on mires is essential, because (1) knowledge to date on the effects of ozone on mires, and ecosystem functioning in general is limited, (2) mires are a significant store of carbon and an important source of methane (CH_4), and (3) mires are of conservation importance in the UK. The aims of this study are to assess effects of ozone on CH_4 and CO_2 fluxes in peatlands, and to identify the underlying plant, soil and microbial processes.

Mesocosms from a wet heath (Isle of Skye, Scotland) with vegetation dominated by the sedge *Schoenus nigricans* (NVC: M15) and the peat moss *Sphagnum papillosum* were exposed for 2.5 years to control and elevated levels of ozone in open-top chambers. The control treatment received non-filtered air, whereas the elevated ozone treatments consisted of non-filtered air (NFA) plus 10, 25 and 40/10 ppb. The highest ozone treatment had a target concentration of NFA+40 ppb for 8 hours during the summer and NFA + 10 ppb for 8h per day during winter. In the two intermediate treatments, ozone was elevated for 24h per day in both summer and winter.

Methane emissions were reduced by elevated ozone from the end of the first growing season onwards. Methane oxidation potentials measured in the top 5 cm of the *Sphagnum* layer (largely living *Sphagnum*) and CH_4 production potentials deeper down the peat profile were affected by ozone, but could not fully elucidate the processes underlying the observed CH_4 emission reduction in response to ozone. Results of a $^{13}CO_2$ labelling experiment assessing the effect of elevated ozone on the contribution of recent photosynthates to CH_4 emission will also be presented. Ecosystem respiration was enhanced by elevated ozone from the second growing season, while gross photosynthesis was increased by elevated ozone from the onset of the experiment. The latter was largely caused by enhanced respiration of the sedges at elevated ozone. Above and belowground sedge growth was not affected by ozone, while *Sphagnum* biomass production was higher at elevated ozone. Overall effects of ozone on the C and CO_2 equivalent budgets of the mire mesocosms will be discussed.

ESTIMATING OZONE (O_3) FLUX INTO CROPS GROWN IN INDIA

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High concentrations of O_3 (as high as 70 ppb-7 hour means) have been reported in the Indo-Gangetic plains, the most important crop growing region in India. Experimental studies have reported that the current day surface O_3 concentrations in this region frequently result in yield losses of up to 30% for sensitive crops (e.g., wheat, rice, legumes). Future global emission projections suggest that, even with implementation of current emission reduction legislation, this region may become one of the most O_3 polluted regions of the world. This suggests that O_3 may pose a potential threat to future food security in India which is home to ~ $1/6^{th}$ of the world's population.

A modelling study using concentration based risk assessment methods was conducted for the year 2000 for four staple crops (rice, wheat, potato and soybean). This estimated that ground level ozone could be causing high yield losses (e.g. ~10% loss in wheat and 7% for rice) across the South Asian region which translate, at current world market producer price, into economic losses in the region of 3.5 billion US$ (Jamir *et al.,* in prep). Assessing the socio-economic implications of these results show that these effects are felt disproportionately by producers (farmers) and consumers.

However, the effect of O_3 on crops is strongly influenced by dose modifying factors that are known to affect plant sensitivity through mediation of O_3 uptake (e.g. species type, phenology and environmental conditions). To accommodate these factors new flux-based risk assessment methods have been developed in Europe. The European stomatal O_3 flux model for wheat has been re-parameterised for Indian conditions to estimate stomatal O_3 flux across India.

Provisional results suggest that growing season stomatal ozone fluxes vary between 0.75 and 13.5 mol PLA m^{-2} which would translate into yield losses of between 5 and 65% if we were to assume that the European flux response relationships are valid under Indian conditions. Our results are presented in relation to the different agro-climatic regions in which wheat is grown in India.

The results reflect the importance of considering spatial variation in the meteorological conditions and crop phenology in relation to influencing O_3 sensitivity of crops in India.

- This would aid Defra's participation in the Global Science and Innovation Forum (GSIF), as a part of the strategic framework to improve the coordination of the UK's engagement in international science and innovation.

OZONE AND DROUGHT STRESS INTERACTIONS IN BEAN AND GRASSLAND SPECIES

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This study has relevance to Defra policy as:

- The interaction between ozone and drought may cause alterations in carbon sequestration of unimproved grasslands.
- Ozone driven disruption of stomatal functioning reduces the ability of plants to respond to drought.

Two characteristic temperate grassland species *Dactylis glomerata* and *Ranunculus acris*, grown in competition, and the ozone-sensitive (strain S156) and ozone-resistant (strain R123) lines of *Phaseolus vulgaris* used in the ICP Vegetation experiments, were exposed to well- and reduced-watered conditions together with increasing background ozone concentrations for between 5 to 20 weeks. Experiments were carried out in the CEH-Bangor ozone exposure facilities and the mean 24 hr ozone concentration in the 8 solardomes ranged from pre-industrial to predicted 2100 values (ca. 15 to 95 ppb).

There was a significant ozone effect on below ground biomass in *D. glomerata*, *R. acris* and *P. vulgaris*, with the watering treatment - ozone interaction being a strong modifier of response. However, for all species above ground biomass was not significantly altered despite there being a significant increase in rates of foliar injury and senescence under increasing ozone concentrations.

Stomatal conductance measurements were obtained throughout the exposures, under similar climatic conditions, using a Delta-T (AP4) porometer. The combined effects of increasing ozone and drought appear to have a direct effect on stomatal conductance with increasing ozone reducing the ability of plants to close their stomata under stress conditions. This trend was more apparent in *D. glomerata* and *P. vulgaris* than *R. acris.*

Impairment of stomatal functioning, due to disruption of abscisic acid (ABA, the so-called “drought hormone”) signalling, is a reported response of some plant species to ozone toxicity. ABA bioassay studies for *P. vulgaris* showed that after 7 days ozone exposure detached leaves were able to close their stomata in response to exogenously supplied 3µm ABA solution, whereas in the control treatment rates of transpiration significantly increased with increasing ozone concentrations. This trend was still evident after 14 days ozone exposure in the ozone resistant cultivar but there was a significant increase in transpiration rates with increasing ozone in ABA treated ozone-sensitive plants. This finding suggesting that ABA signalling is being disrupted in the ozone sensitive cultivar and that disruption of stomatal functioning may potentially reduce the ability of plants to respond to drought.

Exogenous application of ABA would be anticipated to close the stomata, thereby reducing the influx of ozone into the plant and consequently reducing rates of foliar damage associated with enhanced ozone. Response of *P. vulgaris* cultivars to 10µm ABA foliar spray resulted in a significant decrease in rates of ozone injury in the ozone resistant cultivar across all the ozone concentrations in comparison to the control, however there was no change in rates of injury with ABA application in the ozone sensitive strain.

SHORT TERM EXPOSURE TO O_3 AND N DOES NOT AFFECT CARBON ALLOCATION IN *DACTYLIS GLOMERATA*

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This study has relevance to Defra policy as:

- Background ozone concentrations continue to rise, while nitrogen deposition remains largely unchanged.
- Ozone and nitrogen pollution both alter C allocation patterns in vegetation.
- There is potential for the combined effects of these pollutants to reduce root biomass, and change carbon turnover rates and carbon sequestration in grasslands.
- The mechanisms behind these changes require further investigation in order to inform policy on the timing and severity of O_3 and N effects on (semi-) natural vegetation.

Tropospheric ozone (O_3) and nitrogen deposition (N) have the potential to change the quantity of C stored in plant biomass, and reduce soil C sequestration in crops and (semi-) natural grassland. The combined effects of these pollutants on C partitioning are yet to be clearly identified. This study aimed to provide a complete C budget for the plant-soil system exposed to O_3 and N, using ^{14}C pulse labelling in a common grassland species *Dactylis glomerata*. Plants were exposed for 3 weeks in a closed chamber O_3-fumigation system to one of two environmentally relevant concentrations of O_3 (ambient 10 ppb and elevated 80 ppb) and N additions of 0 kg/ha/yr or 50 kg/ha/yr. Below-ground respiration and soil solution ^{14}C were measured every 24 h after pulse addition to record C-flux dynamics of in these pools, and the fate of ^{14}C labelled photosynthate was determined in 8 C pools after 8 d. There was a limited effect of O_3 and N on C allocation in *D. glomerata* biomass. High N induced a 19.8% reduction in below-ground respired $^{14}CO_2$ (p<0.05) and a significant interaction between O_3 and N effects on soil microbial ^{14}C was evident (p<0.05). C sequestration may initially increase due to reduced respiration, but this trend is likely to reverse as pollution exposure continues due to decreasing photosynthetic capacity.

KEENLEY FELL –OZONE FIELD FUMIGATION EXPERIMENT

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The effects of ozone on agricultural crops and forests have been extensively studied and the impacts quantifed. However natural and semi-natural ecosystems are also exposed to significant amounts of ozone and there have been few field studies of potential impacts. In 2006 Defra commissioned a project to release ozone across an upland mesotrophic grassland, simulating 2030 concentrations. The grassland is being managed to enhance biodiversity under the Higher Level Stewardship Scheme (HLS). The site was setup in 2007 with 3 exposure transects where ozone is released from a line source, giving a decreasing concentration enhancement downwind of the release manifolds. Several plots were designated for studies of impacts on the vegetation. Measurements of basic meteorology, soil temperature and water content and micrometeorological $CO_2/H_2O/O_3$ fluxes have also been made. The site experiences weather typical of an upland habitat in the UK, essentially wet and windy. The data coverage and exposure periods vary from year to year due to initial teething problems, changes in instrumentation and other issues.

Although no changes in total above ground biomass have been detected, some effects have been seen on species composition. There has been a general increase in forbs across the site since 2007, but this has been less for some species (e.g. Ranunculaceae) in the ozone-treated plots than in the control plots, with significant relative reductions in above-ground biomass. Conversely, biomass of some grass species has been greater under the influence of ozone. Of perhaps greatest interest relevant to improving biodiversity, the hemi-parasite hay rattle (*Rhinanthus minor*), which preferentially affects grasses, was also adversely affected by ozone in 2009 and may partly explain the shift between forbs and grasses as an indirect effect of ozone. The ozone concentrations applied during this experiment fell short of the target exposures; significant effects have therefore been seen at enhancements of only a few ppb above ambient, at concentrations that might well be achieved within the decade given current rates of increase in background ozone concentrations across the northern hemisphere.

EFFECTS OF OZONE ON MESOTROPHIC GRASSLAND COMMUNITIES UNDER CLIMATE CHANGE

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Future climate scenarios include an increase in factors that contribute to tropospheric ozone formation and an increased likelihood of prolonged summer drought. Individually, these stresses reduce plant productivity and growth, while inter-specific differences in sensitivities to ozone and low soil water availability can lead to changes in plant community composition and biodiversity loss. However, little is known about the combined effects of these two important global change drivers at either the species or the community level.

An experiment was therefore carried out exposing model mesotrophic grassland communities to differing levels of ozone, under two levels of simulated rainfall. Mesocosm communities were established in spring 2009 by planting equal biomass ratios of three grasses (*Holcus lanatus, Agrostis capillaries, Trifolium repens)* and four forb species *(Lotus corniculatus, Plantago lanceolata, Crepis biennis* and *Hypochaeris radicata)* in replicate 42 L pots filled with local soil. Ozone fumigation was carried out in 16 open top chambers at Silwood Park (Ascot, UK), from May to September 2009, and May-August 2010. Daytime target ozone concentrations were 0 ppb, 30 ppb, 60 ppb, and 90 ppb in each of four replicate chambers, with nighttime concentrations falling to 30ppb in all except filtered air treatments. The DO_3SE model was parameterized with site-, and species- specific environmental and physiological data to derive ozone flux estimates for all pots.

Watering regimes represented 1) average summer rainfall at Silwood Park (UK) over the last 20 years or 2) levels experienced during the summer of 2003, a particularly dry year in southern England; droughted pots received 40% less water than their paired, non-droughted counterparts over the course of the fumigation.

Results indicate species-level differences in responses to ozone and watering regime. Physiological data confirm lower stomatal conductances in water stressed plants, with an associated reduction in ozone flux under droughted conditions. This is supported by the slower and less pronounced development of visible ozone injury symptoms of plants growing under water stress. Generally increasing levels of ozone exposure resulted in a progressive reduction in aboveground biomass in both well watered and droughted mesocosms. However, there was consistent evidence of interactions between ozone and drought, with a greater negative effect of ozone in well watered (compared to droughted) pots. Overall, results provide empirical evidence that predicted changes in climate are likely to modify the effects of ozone in some species, with implications for the composition, diversity and functioning of semi-natural grasslands.

Policy relevance: Stomatal ozone flux is strongly reduced during periods of drought stress. This has implications both in terms of the magnitude of ozone impacts in a changing climate and for atmospheric ozone concentrations associated with reduced deposition to vegetation. Interactions and feedbacks between climate and ozone must therefore be taken in to account in policy decisions relating to pollution and climate change.

LONG-TERM EFFECTS OF ELEVATED OZONE ON A SEMI-NATURAL GRASSLAND COMMUNITY: THE ROLE OF A HEMI-PARASITIC SPECIES AS A DRIVER OF COMMUNITY RESPONSES

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UK ozone levels are of concern, as they usually exceed critical levels set by the LRTAP Convention, and northern hemispheric background ozone levels are expected to increase through the 21st century. Since sensitivity to ozone varies between species, elevated ozone could result in a shift in species composition within a community. Thus, elevated ozone could have a strong impact on grassland areas which are managed under environmental improvement schemes for the maintenance, restoration and creation of species-rich semi-natural grassland.

This paper reports the effects of ozone at a field site at High Keenley Fell, a mesotrophic grassland site located near Allendale (NY 7922 5586), which is managed under a Higher Level Stewardship Scheme.. In each of three replicate transects, three plots have received, since 2007, ambient air, ambient plus a target of 10ppb and ambient plus a target of 25ppb ozone. Ozone is released when wind direction is from the SW (180°-270°) and when wind speeds are above 3 m s^{-1}, with each transect using an independent ozone generator. In 2007-2010, a harvest of above-ground biomass was carried out in early August, in which 36 1m^2 subplots (4 for each plot) were cut to a height of 5cm, to comply with management practice at the site. The dry weight of each species was recorded. n In addition, a more detailed assessment of plant numbers and cover of *Rhinanthus minor* was carried out throughout much of the 2010 growing season; this species is a hemi-parasite which is often used as a management tool to promote greater species diversity.

No significant effect of ozone treatment was found for total or total grass biomass over the four years. Total forb biomass increased from 2007-2009 in the ambient treatment, but this increase was less marked in the elevated ozone treatments. In 2010, in contrast to 2009, there was no significant effect of ozone on total forb biomass, but more individual grass and forb species showed a significant effect, suggesting that impacts of elevated ozone on individual species are increasing over time. The biomass of *Rhinanthus minor* was significantly reduced in elevated ozone in 2009, suggesting that this could be an indirect mechanism whereby ozone prevented or delayed the achievement of higher species diversity under the management scheme. However, analysis through the 2010 growing season showed a reduction in the effect of ozone as the season progressed, and a lack of effect on *Rhinanthus minor* biomass at harvest. There was evidence that ozone modified the interaction between *Rhinanthus minor* and other species only in the case of *Agrostistenuis/capillaris.*

DEFRA policy relevance:

- If projected increases in background ozone concentrations are realised, major shifts in species composition could occur, even at relatively small increases of concentration, that could affect management schemes with the aim of achieving forb-rich grassland communities.
- *Rhinanthus minor* can have major impacts on grassland species composition, and thus gaining a better understanding of the effects of elevated ozone on this species is fundamental to predicting the long-term effects of elevated ozone on species composition in semi-natural grassland ecosystems.

OZONE EFFECTS ON SEMI-NATURAL VEGETATION

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We will present an update of ongoing DEFRA- funded work investigating impacts of present and future (2050) upland ozone climates on productivity and species composition of long-established upland mesotrophic (*Anthoxanthum-Geranium-Briza media* sub-community NVC MG3b) grassland mesocosms. Now in the eighth consecutive year of the study, the results show marked effects of ozone on this now scarce upland plant community of high conservation value.

A report will also be provided as to progress with an ongoing study establishing responses to ozone for a legume-rich sand dune community (*Ammophila-Arrhenatherum-Geranium sanguenium* sub-community NVC SD9b) of high conservation value. Now in the fourth year of the study, mesocosms subjected to elevated ozone levels are exhibiting dramatic reductions in productivity and marked changes in species composition; the three dominant legume species (*Ononis repens, Lathyrus pratensis, Vicia spp.*) being suppressed to the advantage of several competitive grasses.

Furthermore, we present outcomes of an OTC study to a) evaluate the effect of present-day vs. 2050 ozone climates on the frequency of *Rhinanthus minor* plants in the MG3b mesocosms, and b) construct a multiplicative stomatal conductance model for *Rhinanthus minor* using stomatal conductance data gathered from both OTCs and field locations.

DEFRA Policy relevance:
Increasing concentrations of tropospheric ozone can decrease productivity and detrimentally alter species composition and biomass of upland grassland communities and sand-dune grassland communities of high conservation value. This work will assist in mapping and modelling risks posed by ozone and aid policy derivation for the protection of sensitive plant species and communities

POSTERS

NITROGEN DEPOSITION EFFECTS ON PHOSPHATASE ACTIVITY IN *CLADONIA FOLIACEA* (HUDS.) WILLD., A COMMON TERRICOLOUS LICHEN OF SEMI-ARID MEDITERRANEAN SHRUBLANDS

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We evaluated the potential use of *Cladonia foliacea* phosphomonoesterase (PME) activity as biomarker of N (nitrogen) deposition by means of a fertilization experiment. In order to do this, we continuously added N (NO_3NH_4) to a semi-arid shrubland at 4 rates: 0, 10, 20 and 50 kg N ha^{-1} yr^{-1} starting in October 2007. After 2.5 years of the experiment, tissue PME tended to increase with 10 kg N ha^{-1} yr^{-1} over the background, which was attributed to an induced N to P imbalance. Above this threshold, PME started to decrease, most likely as consequence of toxic effects of extra N. However, these effects depended on soil properties experienced by *C. foliacea* individuals, mainly pH, Ca, Mg, Fe and Cu. The response of *Cladonia foliacea* in terms of percentage of cover change between years clearly showed a lag phase when compared to the immediate response of PME, as no significant N effects were found in this case. Our data also suggests that changes in cover could be mediated by potassium availability and organic matter. Finally, further *C. foliacea* and soil surveys conducted across wide N deposition gradients will confirm the potential use of this species as biomonitor of N pollution and also the importance of soil properties on its ability to respond to atmospheric reactive N.

WHAT AFFECTS CONCENTRATIONS OF SOLUBLE AMMONIUM IN *SPHAGNUM CAPILLIFOLIUM*?

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The search continues for robust indicators of atmospheric N deposition in vegetation. Previous studies (van Dijk *et al.*, 2009), have suggested that the relationship with atmospheric N is more precise for soluble ammonium (NH_4-N) than for total tissue N (%N) in plants. This study extends van Dijks, and aims to understand which factors influence soluble ammonium concentrations. Most samples were taken from Whim bog, 30 km south of Edinburgh, in the Scottish borders. Since 2002, wet deposition has been manipulated by spraying rainwater with nitrogen added in different doses and forms, onto 4 replicate plots per treatment. Reduced (NH_4Cl) and oxidised ($NaNO_3$) nitrogen is added at an equivalent of 8, 24 and 56 kg ha^{-1} yr^{-1}, on top of a background deposition of 8 kg ha^{-1} yr^{-1}. Also phosphate and potassium was added in some plots in the form of K_2HPO_4 and doses of 8 and 56 kg ha^{-1} yr^{-1} (ratio 1P:14N).

Samples of *Sphagnum capillifolium*, a hummock forming moss common to peatlands, were taken from every plot for seven months (March – October) in 2008, cleaned and frozen and analysed for soluble ammonium using a new method developed by van Dijk *et al*. (2009). Ten ml de-ionised water was added to 1 g of frozen moss, and left for 4 hours then filtered before measuring NH_4^+ by the AMFIA (Ammonium Flow Injection Analysis). Moss dry weight was measured after three days at 80 ^oC. Mosses derive their nutrients from the atmosphere and thus their N concentration should be well coupled to N deposition. This poster will compare soluble ammonium in *Sphagnum capillifolium* and *Hypnum jutlandicum*, sampled from experimental plots and during a survey of Scottish ombrotrophic bogs, undertaken in 2009.

Sphagnum samples show a significant difference in soluble N between months; however, this is predominantly caused by different amounts of added nitrogen in between sampling periods and the potential for growth dilution: levels were highest in March. In terms of N dose, there was only a significant difference between the 8 and 56 kg N ha^{-1} yr^{-1} treatments. Adding PK with N deposition significantly reduces the amount of soluble N, suggesting that PK raises the capability of *Sphagnum* to utilize nitrogen. Samples exposed to < 15 kg N ha^{-1} yr^{-1} show similar ammonium concentrations as the samples from other natural sites. Concentrations of soluble ammonium tend to be higher in the winter months. The difference between *H. jutlandicum* and *S. capillifolium* is far greater (> twice) than the dose effect within species. N form did not significantly affect soluble ammonium.

- The value of soluble ammonium as an indicator of nitrogen dose in precipitation is limited.

Dijk, van, N., Leith, I.D., Pitcairn, C.E.R. & Sutton, A. 2009. Ammonia: Detecting emission changed and environmental impacts. *Springer Science*, Chapter 17, p281-289.

FACTORS AFFECTING THE REGENERATION OF *SPHAGNUM* SPECIES ON THE PEAK DISTRICT MOORLANDS

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The restoration of functional blanket bog is of key importance in the provision of a range of ecosystem services, including carbon sequestration, water quality and flood control. Many areas of blanket bog on the Peak District moorlands show high levels of erosion and gullying with extensive areas of bare peat.
The condition of the moorlands is likely to be due to a number of factors related to climatic changes and land-management over many years. The well-documented loss of *Sphagnum* bog forming *moss* species, and the low bryophyte cover generally on the Peak District moorlands is however thought to be largely due to the high levels of sulphur dioxide and acid deposition over the last 150 years. Levels of sulphur pollution have now fallen dramatically, although nitrogen deposition remains high, and both *Sphagnum* species and bryophytes generally are now returning to the Peak District. Recovery is slow however, and conditions may still not be suitable for many species.

A number of areas of highly eroded bare peats are currently the subject of large-scale restoration programmes (www.moorsforthefuture.org.uk) using a combination of stabilization, nurse-crops and lime and fertilizer treatments to produce a revegetated surface as a basis for the long-term regeneration of active S*phagnum*-rich peat forming blanket-bog vegetation.

Current conditions for the growth of *Sphagnum* species on the Peak District moorlands have therefore been examined using a combination of botanical survey and environmental sampling, and compared with data from the Forest of Bowland and the North Pennines. A quadrat based approach was adopted with detailed species and environmental data collected from 2 x2m quadrats together with more general information on vegetation structure, species abundance and land-use for a wider 20 x 20m area around each sampling point. Each quadrat was associated with a superficial peat sample, and analysed for pH, water content, extractable ammonium, nitrate, sulphate and metals.
The results showed a higher abundance of *Sphagnum* species at the more northerly sites, with higher levels of active bog-forming species such as *S. papillosum* and *S. capillifolium*, indicative of a healthier bog surface, when compared with the Peak District. Peat pH and moisture content was also higher at the northerly sites and showed some correlation with *Sphagnum* cover at the quadrat level.
Ammonium and sulphate levels in the peat samples collected from the quadrats were highly variable between survey locations within areas, and showed no correlation with *Sphagnum* cover at the quadrat level. Ammonium levels were significantly higher in the Bowland samples when compared with those from the Peak District, and the highest sulphate levels were seen in the samples from the North Pennines. The concentrations of sulphate and ammonium in the peat samples were in all cases

below those associated with direct effects on *Sphagnum* growth or survival. An interesting pattern of regional variation was also seen in the metal contents of the peat, but again with no clear correlation with *Sphagnum* cover or species distribution.

Current measurements of atmospheric deposition show no clear differences in total nitrogen or acid deposition between the Forest of Bowland and the Peak District, but with lower levels in the North Pennines, and with low ambient levels of NOx, SO_2 and NH_3 throughout. The Pennines as a whole have received high levels of acid deposition of nitrogen and sulphur in rainfall over long periods. There are likely however to have been marked differences in the historical deposition patterns over these areas, with in particular, very high ambient $S0_2$ concentrations over the Peak District.

Overall the results suggest that pH and moisture levels remain key variables in the current abundance and species distribution of *Sphagnum* species across the Pennines, with no indication that current levels of ammonium or sulphate in the peat samples are likely to be limiting *Sphagnum* distribution.

- *Sphagnum* regeneration is crucial to long-term carbon sequestration on the Peak District moorlands.
- The restoration of degraded moorland has clear benefits for the provision of ecosystem services such as water quality, control of flood risk and biodiversity.

PEATLAND RESPONSES TO FIRE:
THE CONSEQUENCES TO VEGETATION AND GREENHOUSE GAS BALANCE

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Peatlands are the largest semi-natural ecosystem and terrestrial carbon store in the UK and are important commercially for agricultural and game production. Fire, or muirburn, is a traditional management tool used to maintain structurally diverse stands of vegetation and palatable grazing for livestock and grouse. The use of muirburn is principally governed by legislation in the Hill Farming Act 1946 and The Heather and Grass etc. Burning (England) Regulations 2007. However, recent consultations have highlighted the growing need for sound evidence on which to base muirburn legislation and any future changes to policies.

The aim of our research is to further the understanding of the interactions between fire regime, fire behaviour, peatland vegetation and the gaseous carbon cycle. The effects of fire on vegetation and the importance of fire frequency to post fire species composition will be studied by carrying out vegetation surveys where information on existing burning regimes is attainable through aerial photography or management records. The effects of high temperatures and the addition of nutrients through ash deposition on *Sphagnum* will also be investigated. In addition, the impact of fire on the greenhouse gas balance of blanket bogs will be intensively researched at the Langholm-Newcastleton Hills SSSI and SPA.

This research will be directly relevant to the aims of DEFRA by:

- Ensuring sustainable management of the uplands by helping to inform future legislation and best practice guidelines, such as those prescribed through agri-environment schemes, for maintaining biodiversity and carbon sinks in the UK.
- Using an ecosystem approach to gain an understanding of how to protect the important ecosystem services provided by peatlands
- Furthering our understanding of the impact of management practices on blanket bog, a priority habitat under the EC Habitats Directive

This PhD is in conjunction with the ***University of Edinburgh*** *and is funded by* ***Scottish Natural Heritage***, ***Scottish Environment Protection Agency***, *the* ***Royal Society for the Protection of Birds***

*and the **Centre of Ecology and Hydrology**.*

CARBON PRODUCTION AND TRANSPORT IN THE PEAT-STREAM CONTINUUM

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Defra policy relevance:

- This study aims to add to the understanding of hydrological processes controlling carbon transport from peatlands. This is of interest due to the impact that upland management practices and climactic changes may have on future peatland hydrology and their carbon sequestration capacity.

The transport of aqueous carbon from peatlands into the stream network is a potentially important loss of carbon from catchments. Future climate changes and new upland management practices may alter the hydrological balance of peatland catchments, impacting on the carbon storage and source/sink potential of peatlands. It is necessary to quantify and understand the processes involved in the transport of aquatic carbon to determine overall peatland carbon budgets. The riparian zone provides a key linkage between the soil and stream environments, which along with hydrological processes, influences the production and transport of aqueous carbon including POC, DOC and dissolved CO_2 and CH_4.

This study plans to use both long-term and event-based field monitoring at Auchencorth Moss to link hydrological observations with high frequency carbon concentration and flux measurements. Hydrological tracer studies (conductivity, Cl, Ca and $\delta^{18}O$) and carbon isotope analyses (^{14}C and $\delta^{13}C$) will also be conducted. The study aims to consider hydrological flow paths, the source and age of carbon, carbon transformations in the riparian soil, seasonality in carbon fluxes and disturbance through artificial drainage. The results from the Auchencorth Moss study will then be up scaled to include other UK peatlands using mesocosms and fieldwork at sites in the CEH Carbon Catchments network.

THE FERTILITY OF LOWLAND HEATHLAND SOILS IN THE BRITISH MAINLAND AS AFFECTED BY ATMOSPHERIC N POLLUTION

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Heathland habitats once extended to some several million hectares in Western Europe, but their extent declined over the last 20-50 years, despite conservation efforts. Not only has the total area of heathland been reduced, but the remaining heathland has become increasingly fragmented due to afforestation, conversion to agriculture, and urban development. Using field and laboratory experiments, this study aimed to quantify soil fertility and to seek evidence of shifts in N/P stoichiometry at 26 heathlands at low rainfall sites on the British mainland in relation to putative N enrichment. Ammonia deposition data for ten low rainfall heathlands in the East Midlands will also be presented. Preliminary results suggest that there is a relationship between atmospheric nitrogen input and the fertility of heathland soils.

· This work will provide information about forces that modify heathland habitats, satisfying DEFRA's aim to prevent habitat loss and degradation.

· This work also has the potential to inform DEFRA policy on how atmospheric N pollution can impact habitats of high conservation value.

IMPACTS OF NITROGEN DEPOSITION ON CARBON CYCLE IN AN OLD-GROWTH BOREAL LARCH FOREST IN NORTHEAST CHINA

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The old-growth forest is an important carbon pool and traditionally thought to have minor carbon sequestration capacity. However, recent study found that the natural old-growth forests could be an important carbon sink. Large areas of young and middle-aged forest in China will reach maturity or become old growth forest in the next 50 to 100 years. Anthropogenic reactive N (Nr) emissions to the atmosphere have increased dramatically in China due to rapid agricultural, industrial and urban development, and the elevated N deposition especially in the eastern and central China has aroused great concerns of its ecological impacts on terrestrial and aquatic ecosystems. Therefore, an experiment were set up at Genhe site in daxing'anling mountain area to 1) assess the mechanism of how the simulated N deposition interacting with climate and stand age to affect the carbon cycle and 2) quantitatively evaluate the independent contribution of N deposition on carbon sequestration in the old-growth boreal larch forest. The experiment was set up in 2009, started from 2010 and was designed to run for at least 5 years.

Genhe (50°56.227′N,121°30.312′E) is located in an ecotone between the Eurasia southern boreal forest and Inner-Mongolia steppe where the ecosystem is sensitive to climate change. The plots are located in an old-growth *Betula fruticosa- L.gmelinii* R. forest (>300 yrs). The stand density was 825 trees per ha. with average DBH and height of 16.9cm and 15.5m respectively. The vertical structure includesthree layers, 1)Tree layer(>3m): *L. gmelinii* Rupr; 2)Shrub layer(0.3m-3m): *Betula fruticosa*、*Ledum palustre* L.、*Vaccinium vitis-idaea* Linn、 *Rhododendron dahuricum* DC.、*Vaccinium uliginosum* Linn ; 3)Grass/herbs and moss layer(<0.3m): *Pyrola incarnate* Fisch、*Maianthemumbif olium* (Linn.) F.W. Schmidt、*Carex*.L, *Sphagnum jensenii* lindb.The plots have a living biomass carbon storage of 68.34 ~80.58 MgC / ha, annual living biomass NPP of 1.62 ~ 2.07 MgC $ha^{-1}y^{-1}$.

Twelve 20×20 m^2 plots were set up and the experiment 4 treatments×3 replicates random block design. The plots received the following treatments: control (no N added), low N (20 kg N ha^{-1} yr^{-1}), moderate N (50 kg N ha^{-1} yr^{-1}), high N (100 kg N ha^{-1} yr^{-1}). Between adjacent plots, there is a 10 m wide buffering area. N additions were applied to the forest floor in 5 equal applications from May to

August, with 30 L concentrated solution of ammonium nitrate (NH_4NO_3) using a backpack sprayer. The control plots received 30 L water with no N added. Outwith the growing season, when the ground was snow covered, no treatments were applied. NPP and soil heterotrophic respiration were measured to assess NEP. N mineralization and bulk deposition were measured to assess the contribution and the efficiency of N addition to the changes of NPP and NEP. The effects of competition and biodiversity are also considered in this study.

- Demonstrate the effects of nitrogen deposition on the carbon cycle of old growth forest ecosystems in order to 1) reduce uncertainty in the evaluation of ecosystem carbon sequestration and 2) inform future forest management policy.