CAPER 2008

PAPER ABSTRACTS

IMPACTS OF INCREASING BACKGROUND OZONE CONCENTRATION ON INTERSPECIES COMPETITION IN GRASSLANDS

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Species from UK grasslands were exposed to ozone in the solardomes at CEH Bangor for 20 weeks to investigate the effects of increased background ozone concentration in the absence of 'peaks' of ozone. This represents changes in ozone profile predicted for the UK due to projected increased background concentrations in the northern hemisphere following increased industrial development and car use in Asia. Two-species mixtures of *Leontodon hispidus* grown with *Dactylis glomerata, Anthoxanthum odoratum* or *Poa pratensis* were used. Ozone exposure was based on an upland profile from Snowdonia and the treatments used were ambient air (AA), AA-20 ppb ozone, AA+12, AA+24, AA+36, AA+48, AA+60 and AA+72. Communities were cut back to 6cm mid-way through the exposure, but not at the end – plants were left to die back naturally.

Earlier and increased senescence occurred with increasing background ozone treatment for all species, with increases evident as the mean ozone concentration exceeded the current Snowdonia ambient concentration of 40 ppb. The magnitude of response of *Leontodon hispidus* was influenced by the competing species, with largest effects occurring when grown in competition with less vigorous *P. pratensis,* intermediate effects with the intermediate competitior *A. odoratum* and least effects when grown with the vigorous competitor *Dactylis glomerata*.

No differences in canopy height were found following ozone exposure, however, large reductions in root biomass of *Leontodon hispidus* plants grown individually occurred after exposure to the ozone regime for 16 weeks. The cover of each species has also been non-destructively assessed at the end of the exposure period and will be re-assessed in 2008. It is likely that re-growth of the *Leontodon* plants will be affected in 2008 and this may influence the competition with the grasses in the community.

Sampling of ozone within the plant canopy showed a diurnal profile of ozone concentration at the beginning of the exposure period, however this decreased and was eventually lost as the growing season progressed. This corresponded with increased senescence within the plant canopy, rather than changes in canopy density. This will be investigated further during exposure in 2008. Impacts of ozone on stomatal functioning and post-exposure carbon cycling are described by Mills *et al.* in the following paper.

This study has relevance to Defra policy as:

- Significant effects on widespread species were found with only small increases in current background ozone concentrations.
- Community composition may be affected which may ultimately have an effect on biodiversity.
- We are grateful to Defra and NERC for supporting this study

OZONE IMPACTS ON STOMATAL CONTROL AND CARBON TURNOVER, INCLUDING CARRY-OVER EFFECTS DURING THE WINTER

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This paper summarises recent progress with ongoing collaborative research into understanding the mechanisms behind the responses of grasslands to rising background ozone concentration presented in the previous paper (Hayes *et al*.).

During the last few weeks of the 20 week exposure, the emphasis of the mechanistic study was on quantifying the effects of ozone on stomatal functioning of leaves that had developed in the eight ozone profiles (representing pre-industrial to predicted post-2100 conditions). Clear evidence emerged that increasing background ozone increasingly impairs stomatal functioning. Under comparable climatic conditions, stomatal conductance increased with increasing ozone concentration for non-senesced inner canopy leaves of *Dactylis glomerata* and *Leontodon hispidus*, with the current ambient treatment being an approximate threshold for this effect. Leaves exposed to rising background ozone were also less able to close their stomata when severe water stress was imposed. This may possibly be due to a lack of response to the plant hormone, abscisic acid (ABA). Unlike in the ambient – 20 ppb treatment and the ambient + 24ppb treatment, *Leontodon hispidus* leaves from the ambient + 60 ppb treatment failed to close their stomata in response to feeding with ABA.

The premature senescence of older foliage due to ozone damage and decreased carbon storage in below ground tissue observed during the summer (see Hayes *et al.*) may have ongoing influence in the root-soil interface over winter, and during the next growing season, even after removal of the pollutant from the system. Therefore, ozone may have long-term and cumulative detrimental effects on microorganism communities, soil structure and the potential for carbon sequestration. Some of these effects are currently being studied for over-wintering plants; the results will be presented at CAPER. In addition, research at an open field release site at Keenley, Northumberland aims to address the long-term combined effects of ozone and nitrogen on carbon allocation below ground in the field situation, where plants are growing in natural soils in competition. This will be complimented by controlled environment and solardome studies at Bangor and Newcastle to further elucidate the mechanisms involved in ozone effects on C storage and turnover.
The policy implications of this work are:

- Rising background ozone may impair the ability of plants to respond to drought by closing their stomata
- Implications for ozone and CO_2 fluxes require further study

* We are grateful to Defra and NERC for supporting this study

IMPACTS OF OZONE ON UPLAND GRASSLAND AND HEDGEROW PLANT COMMUNITIES

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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 i) long-established upland mesotrophic (NVC MG3b) grassland mesocosms, representative of contrasting management regimes, and ii) a legume-rich, fixed-dune (NVC SD9) grassland community.

We will also report on interim results of an OTC experiment investigating a range of simulated present-day versus future UK spring ozone climates on several UK spring bulb species (*Liliaceae*) found in woodland, wood margins and hedgerows.

Finally, we will introduce a study to examine the impact of a range of ozone climates on the hemi-parasitic annual, *Rhinanthus minor*, and potential interactions with two host plants (*Lolium perenne* and *Phleum pratense*) of contrasting ozone sensitivity.

IMPACTS OF OZONE ON NATURAL VEGETATION: ARE WE BARKING UP THE WRONG TREE?

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Easily measurable surrogates are often used to determine the impacts of ozone on vegetation, but are the parameters we elect to measure (e.g. size, visible injury, senescence etc.) of any value whatsoever in the prediction of plant responses? In the present study we sought to screen a population of *Arabidopsis* (Nok-3 x Ga-0) for ‘ozone sensitivity’ in a bid to map regions of the genome determining ozone-related traits. As a first step, it was necessary to screen candidate parents in order to elect for a cross likely to exhibit the greatest span of genetic variation in ‘ozone responsiveness’. As part of this exercise we explored the value of a variety of commonly-adopted measurements as a surrogate for effects on seed yield (the parameter of greatest relevance as a measurement of ‘ozone sensitivity’ in this short-lived species). It proved unreliable to use any surrogates to determine the effects of ozone on seed yield. Subsequent QTL studies identified several strong candidate genes determining ozone effects on growth and seed yield, the nature and function of these genes will be discussed.

USING COMMERCIAL TREE NURSERIES TO MONITOR VISIBLE OZONE INJURY-AN EVALUATION

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This study investigated the extent of visible ozone injury in commercial tree nurseries across four countries in Europe, representing the north-west, central and Mediterranean areas. Visible assessments of injury were made from mid summer to the end of the growing season for all ozone sensitive species present. Commercial nurseries were chosen because nursery stocks are irrigated when necessary and therefore are not subject to the same levels of water stress as field species; these plants therefore represent the optimum conditions for assessment of potential risk; a wide range of ozone sensitive species can be assessed at each site; trees are generally smaller reducing the access problems associated with measuring ozone damage on mature forest trees.

Ozone climate at each of the 13 sites was characterised using a combination of passive and active samplers to enable the estimate of accumulated ozone exposure over a threshold of 40 ppb. (AOT40). Meteorological and ozone monitoring data were used to calculate cumulative ozone flux using the DO_3SE model.

Ozone injury was observed in all countries demonstrating that the impacts of ozone are not restricted to Central and southern Europe where higher ozone concentrations are experienced. In northern Europe, longer day-length and higher moisture availability compensate for lower concentrations with enhanced stomatal uptake. The most extensive damage was found in Switzerland. The UK showed the least injury with damage confined to the south east of England in late summer. Within the limitations of the project design, the extent of injury reflected ozone exposure expressed as both AOT40 and cumulative ozone stomatal flux. Injury was not observed on sites with an AOT40 less than 12.7 ppm h, with 13.7 mmol m^{-2} the minimum cumulative ozone flux at which injury was observed.

This work was part funded by the European Union under Forest Focus regulation (EC)2152/2003 with co-funding by CEAM (Spain), Forestry Commission (UK), Ministry for Forestry (Italy).

GREENHOUSE GAS BUDGET OF FULLY VEGETATED PEATLAND MESOCOSMS; EFFECTOF WATER TABLE DEPTH AND VEGETATION/MICROTOPOGRAPHY

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Water table depth and temperature are widely cited as important drivers of greenhouse gas fluxes from peatlands. Much previous work has focussed on either CO_2, CH_4 or N_2O though they are rarely considered together. In this study fully vegetated mesocosms were collected from an ombrotrophic Scottish peatland. The mesocosms were kept outside to mimic natural temperature and light conditions as far as possible. By covering with a clear plastic roof rain water was excluded and water table depth could be controlled. The study was set-up as a repeated measures factorial design. Replicate mesocosms were collected from different vegetation types and microtopographies, including *Juncus* dominated hummocks, grass dominated hummocks and moss dominated hollows, to compare the greenhouse gas budgets of each. The mesocosms were separated into 2 groups subjected to different water table levels (0-5 cm or 30-35 cm below to soil surface). The water table was held static for 3 months then switched for approximately 1 month. During the initial 3 month period CH_4 and N_2O exchange was measured weekly using static chambers, soil atmosphere was measured weekly at 2 different depths to see if production within the soil mimicked surface fluxes, and soil water was sampled fortnightly. Soil water samples were then analysed for DOC, DIC, NO_3 and NH_4. After switching water table levels, the frequency of measurements increased until surface emissions appeared to stabilise. Preliminary results from the study will be presented.

ECOSYSTEM RESPONSES TO OZONE IN LOWLAND RAISED BOG MESOCOSMS - FINAL RESULTS FROM A 3 YEAR EXPERIMENT

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Few studies to date have considered the long-term effects of ozone on semi-natural plant communities, and especially on the ecosystem processes of communities such as grasslands and wetlands. It has been suggested that long-term ozone exposure may have an impact on carbon and nitrogen cycling, for instance through effects on carbon storage, litter quantity and microbial activity and through increased dark ecosystem respiration and methane emissions. However, there is little data available on such effects in wetland communities, and studies reported to date have been short-term.

In this study we aimed to assess the effects of elevated ozone on mesocosms taken from a lowland raised bog (Roudsea Wood and Mosses, Cumbria), with vegetation dominated by the peat moss *Sphagnum papillosum* and *Eriophorum vaginatum* (cotton sedge). The mesocosms were exposed for 3 years to control and elevated levels of ozone in open-top chambers. The control treatment received non-filtered air, whereas the elevated ozone treatment consisted of non-filtered air plus 60 ppb during the growing season, and an increased level of 10 ppb in winter (enhanced levels only for 8 hours during the daytime). Methane emissions, ecosystem respiration, plant and soil responses and litter decomposition were examined. This presentation will focus on effects observed in a harvest carried out at the end of third and final summer of exposure, including results of a laboratory study to examine effects of ozone through litter quality and soil water on decomposition.

HOW DOES TROPOSPHERIC OZONE AFFECT CARBON GAS EMISSIONS FROM WETLANDS?

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Tropospheric ozone has been known to be an important environmental pollutant since the 1950's but it is only recently that its impacts on semi-natural systems have been investigated. Wetlands have the potential to be particularly sensitive to the effects of ozone pollution as plants found in that environment are unlikely to be water limited and can keep their stomata open even during hot, sunny afternoons when ozone concentrations are highest. Adverse effects of tropospheric ozone on wetland plants could change the quantity of carbon stored in peat-forming wetlands with wider implications for climate change.

Peat cores were taken from two contrasting North Wales wetlands and exposed to ozone in the solardomes at CEH Bangor for 20 weeks during the summer of 2007. Ozone concentrations were based on measurements taken in Snowdonia during summer 2006 and each dome followed the same ozone profile but with incremental starting points (see Hayes *et al.,* for details). Exchange of carbon dioxide and methane from the peat cores was measured monthly throughout the ozone exposure. At the end of the ozone exposure peat from the cores was used to assess the potential of the cores to produce and consume methane.

Ozone exposure did not appear to have a direct effect on methane emissions or carbon dioxide uptake from wetlands but both carbon gas fluxes were correlated with ozone-effects on plant physiological status and plant growth. For example, ozone induced reductions in canopy height and root cover occurred with increasing ozone exposure. At the same time, the net flux of methane from bog cores increased and the uptake of carbon dioxide decreased.

Policy implication:

> This study suggests that future ozone impacts on wetland plants could have a negative affect on the ability of northern peat-forming wetlands to act as a sink for carbon.

INTERACTIONS BETWEEN ATMOSPHERIC NITROGEN DEPOSITION AND CARBON DYNAMICS IN PEATLANDS

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The impact of increased levels of nitrogen deposition on carbon cycling in peatlands is uncertain and limits our understanding of the future role of peatlands as global carbon sinks. This atmospheric pollution has the potential to alter both recalcitrant and labile carbon inputs to soils and the activity of micro-organisms that process it. Because ombrotrophic bogs are adapted to very little nitrogen availability, they may be particularly susceptible to increased loads of inorganic nitrogen. Our main study site is the Whim Moss Experiment Site, in which inputs of nitrogen (NH_4^+ and NO_3^-) have been manipulated since 2002.

1) The turnover of recalcitrant and labile sources of carbon in peat was studied using enzymatic assays and MicroResp analysis. Results showed that nitrogen had an effect on the usage of simple forms of carbon, but not on the activity of enzymes involved in the degradation of the more complex forms of carbon.

2) The fate of recently synthesised carbon was studied using *in situ* $^{13}CO_2$ pulse labelling on two functionally different species: *Calluna vulgaris* and *Eriophorum vaginatum*. Preliminary results showed that nitrogen affected the way *E. vaginatum* allocated its photosynthetically fixed carbon, but did not affect allocation in *C. vulgaris.*

3) Plant wax profiling was proposed as a tool for predicting past changes in vegetation composition in peatlands due to nitrogen amendments. The prediction accuracy of this method is currently being tested against known litter mixtures.

CARBON AND N CYCLING IN *SPHAGNUM CAPILLIFOLIUM* IN RESPONSE TO N DEPOSITION AND N FORM

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This talk will report results from a study on the effects of wet deposition of N (nitrate and ammonium) on the productivity and decomposition of *Sphagnum capillifolium*.

The productivity is being studied with the cranked wire method. Results so far show that increased N has a detrimental effect on the length growth of *S. capillifolium*. Both ammonium and nitrate reduce the growth compared to the control treatments and when the two forms are compared, ammonium decreases the growth more than nitrate. Adding P and K with N seems to alleviate these effects, which suggests that *Sphagnum* in the plots treated with N have become P- or K-limited. Nutrient samples of *S. capillifolium* capitulums show, as expected, an increase in tissue N with increasing N deposition, although when P and K are added with N, the amount of N decreases again. This might be because of the increase in the growth rate in these plots compared to only N plots. Because the amount of C stays the same, the C:N ratio decreases with increasing N. Also, the amount of base cations, Ca and Mg, decreases with increasing N.

The decomposition is being studied with litter bags. The first results suggest that increased N decreases the rate of decomposition compared to the control plots. On the other hand, adding P and K with N seems to increase the decomposition compared to only adding N. These results are contrary to many other studies were decomposition has been found to increase. One explanation might be that in the plots treated with N not only *Sphagnum* has become N limited but also the microbial community which hampers the decomposition. Water samples are being taken from the *S. capillifolium* stands around the litter bags twice a month. In these samples the amount of dissolved organic carbon (DOC) in the samples taken from nitrate plots is lot higher than in the samples from ammonium plots treated with the same dose. This suggests faster decomposition in the nitrate plots compared to ammonium plots.

As a conclusion, the results so far suggest that the plots are turning from N-limited into P- or K-limited.

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DO WE NEED TO CONSIDER N FORM IN RELATION TO CRITICAL LOAD SETTING?

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This talk will bring together the results from 5 years of experimental additions of different N forms and doses to an ombrotrophic bog, Whim bog in the Scottish Borders. Exposure to ammonia gas, at concentrations simulating those downwind of a 25000 bird broiler unit, caused the death of the matt forming lichen, *Cladonia portentosa* in < 1 year. The damage was thought to be caused by toxic effects associated with very high episodic NH_3 concentrations, and was exacerbated if exposures coincided with dry hot sunlight. Other lower plant species and *Calluna* have also been negatively affected by NH_3 and the effects have occurred at lower and lower concentrations over time, *ie.* the zone of damage has moved out from the source. Sensitive species include *Sphagnum capillifolium* and P*olytrichum commune* growing on hummocks, although red pigmented *S capillifolium* are far less sensitive than green pigmented forms .Mechanisms of damage differ depending on the species but the potential for significant negative interaction between NH_3 exposure and drought has been observed especially for *Calluna* and the understorey moss flora. Other ericoids e.g. *Erica tetralix, Empetrum nigrum* and *Vaccinium myrtillus* and the moss *Racomitrium laguninosum* appear to be tolerant to NH_3. Calculation of NH_3-N deposition, based on controlled flux chamber studies using the same vegetation in an OTC, confirms that per unit N deposited NH_3-N causes a much greater impact on the ecosystem than wet deposited NH_4-N or NO_3-N.

Detectable changes in response to wet N deposition have taken longer to develop on this N limited ecosystem. However, after 5 years, significant shifts at the species cover level are now apparent, together with significant changes in soil chemistry. The most obvious differences with respect to N form below-ground are underpinned by the ph response. The addition of ~ 56 kg N ha^{-1} y^{-1} as ammonia increased soil pH by ~ 0.5 units, as nitrate by 0.2 to 0.3 units whereas ammonium has not changed pH. PH underpins many biological responses and the increase in pH has been accompanied by increases in DOC and NO_3^-, through increased nitrification potential.

- These observations provide evidence for the effects of N to be considered in terms of N form and not just N deposition as the different N forms bring about different effects.
- Effects per unit N are greatest for NH_3-N.

MODEL BASED RISK ASSESSMENT OF THE VULNERABILITY OF RARE COASTAL SPECIES TO N DEPOSITION.

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Policy Relevance:

Sand dunes are a Priority BAP habitat and contain over 70 red data book or nationally rare or scarce species, as well as other species of conservation importance. Many of the rarer species occur in early successional habitats and biodiversity in these habitats is highly susceptible to N-deposition driven soil and vegetation change. Until now, very little has been known about the likely effects of N deposition on rare species in any UK habitat. While many factors contribute to rarity, this study has provided the first data predicting how sensitive some rare species are to changes in the soil bio-chemistry caused by increased N deposition, using dune slacks as a model habitat.

Method and results:

The objective was to test a modelling framework to determine the potential chemical and biological impacts of nitrogen deposition on rare species. Species rarity presents great problems for modelling due to data availability. The approach taken here was to relate rare species occurrence to associated soil data. Probability of occurrence was then estimated under a future N deposition regime, *via* impacts on soil chemistry.

Four rare sand dune species (*Equisetum variegatum, Petalophyllum ralfsii, Centaurium littorale* and *Parnassia palustris*) were selected for modelling. Twelve UK sites were surveyed for community composition and soil data associated with the target species; control locations at each site were surveyed where the target species did not occur. Species-environment models were built up for each species using binary logistic regression. These were then used to predict changes in the probability of occurrence under a scenario of a + 10 kg N ha^{-1} yr^{-1} increase in N deposition over 50 years. Changes in the soil N parameters were estimated using a simplified N accumulation model under this scenario and in combination with the species-environment models, a ranking of the sensitivity of the four species to changes in nitrogen deposition was produced. In order with most sensitive first the species were: *Equisetum variegatum* (strong decrease in probability of occurrence), *Centaurium littorale* (no change), *Parnassia palustris* (slight increase), and *Petalophyllum ralfsii* (increase).

TRANSLATING FORECASTS OF ECOSYSTEM RESPONSES TO N AND S POLLUTION INTO POLICY-RELEVANT BIODIVERSITY INDICATORS

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The UNECE-Coordination Centre for Effects (CCE) defines Critical Loads (the maximum deposition possible for a habitat to remain undamaged) and Target Loads (the maximum deposition possible for a habitat to recover by a target date) for major air pollutants. These both imply the definition of a habitat quality indicator, and a threshold for this indicator below which the habitat is damaged and above which it is undamaged or recovered. Habitat quality indicators have hitherto been defined in terms of soil chemical properties. There is a need to develop indicators more closely related to the habitat quality definitions used in the EU Birds and Habitats Directives.

With major reductions in sulphur pollution since the 1980s and consequent recovery of many ecosystems from acidification, attention has focussed on eutrophying effects of nitrogen (N). Simple soil chemical metrics can be defined for acidification, such as pH or Ca/Al ratio. Defining metrics and thresholds for N eutrophication is more difficult. Soil N measurements all have their limitations (e.g., total soil N includes much inert N, and soil mineral N can fluctuate rapidly), and effects on plants and plant competition may precede changes to soil N. It is thus particularly important to move beyond soil indicators when defining damage due to eutrophication.

Capacity for forecasting effects of pollution on plant species has recently been developed in the UK, by coupling models of soil and vegetation change to models of environmental suitability for individual plant species (Smart et al., in prep.). We are now combining these forecasts with Common Standards Monitoring criteria to predict changes in an aggregate, habitat-specific quality indicator. Increases in environmental suitability for positive CSM indicator species and decreases in suitability for negative CSM indicator species both increase the overall habitat quality score. The approach does not yet adequately cover those aspects of habitat quality definitions that are based on vegetation structure, or presence of rare and non-plant species. However it seems a useful step towards translating pollutant emissions scenarios into policy-relevant indicators.

- Changing environmental suitabilities for CSM species can be translated into forecasts of habitat quality change
- The proposed indicators and thresholds need to be thoroughly discussed with biodiversity specialists if they are to be used within the CCE process

MOSSES AS BIOMONITORS OF ATMOSPHERIC N POLLUTION: RELATIONSHIP BETWEEN THE N CONCENTRATION IN MOSSES AND MODELLED N DEPOSITION FOR DIFFERENT UK HABITATS

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Since 1990 the European moss survey has been repeated at five-yearly intervals to determine the concentration of ten heavy metals in naturally growing mosses. The moss technique provides a surrogate, time-integrated measure of metal deposition from the atmosphere to terrestrial systems. A pilot study showed good correlations between the N concentration in mosses and the atmospheric N deposition rates in Norway and Sweden in 2000 (Harmens et al., 2005). Other studies have also indicated a clear relationship between atmospheric N deposition and the concentration of N in mosses. Therefore, it was decided to include the determination of the N concentration in mosses in the European moss survey 2005/6 for the first time to assess whether mosses can be used to monitor atmospheric N pollution at the European scale.

Here we report on the N concentration in mosses in the UK for 2005. Between May and September mosses were collected from 170 sites across the UK. The following moss species were sampled: *Pleurozium schreberi* (65 sites), *Hylocomium splendens* (45 sites), *Rhytidiadelphus squarrosus* (34 sites), *Hypnum cupressiforme* (24 sites), and *Pseudoscleropodium purum* (2 sites). Fresh samples were dried at room temperature, sorted for the last three year's growth and analysed for total N concentration by CHN 2000 combustion analysis.

The median N concentration in mosses was 0.79% (min. = 0.44%, max. = 2.45%), with low concentrations generally found in Scotland, Northern Ireland and parts of northern and southern England and Wales. The highest concentrations were found in mid and east England. The fact that different moss species were sampled across the UK confounds the interpretation of the results as different moss species potentially accumulate N at different rates. The relationship between the accumulation of N in mosses and modelled total N deposition rates for different UK habitats as potential predictor of areas at risk from N critical load exceedance will be discussed.

- Review sufficiency and effectiveness of 1999 Gothenburg Protocol (including abatement of eutrophication).
- Provide information on areas at risk from N pollution.

Reference

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OPEN AIR LABORATORIES PROJECT (OPAL)

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OPAL is a multi-disciplinary environmental research programme supported by the BIG Lottery Fund. It targets areas of highest deprivation in England and seeks to engage minority groups in environmental research activities. Projects are generally at three levels: PhD studentships addressing topics of importance at the national level (air pollution impacts on vegetation, climate change) and regional level (such as the demise of the orchards of East Anglia, loss of heathlands in the West-Midlands), community scientists working with local groups to identify and record biodiversity and habitat data (River Tyne, brown-field sites, inner-city ecosystems) and five national participation surveys (Wild Worm survey). This five-year project involves 9 universities, NHM, FSC, Met Office, NBN and the Environment Agency. OPAL has established a biological monitoring group, Chaired by Prof Nigel Bell, that will provide support and advice in relation to the national survey programme and make appropriate links to policy makers and other relevant bodies such as CEN and UNECE. Members of CAPER are encouraged to sign up to OPAL and to join in the national surveys.

OPAL is particularly relevant to Defra's new approach to environmental quality, the Ecosystems Approach Action Plan, which signals a move away from separate natural environment policies towards a more joined-up approach taking account of the natural environment as a whole.

CONSERVATION OF HABITATS AND SPECIES IN THE UK: PROTECTED SITES AND THE WIDER COUNTRYSIDE – AN INTRODUCTION

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This presentation sets out the background to nature conservation practice in the UK, and briefly highlights links to air pollution as a threat to habitats and species.

Sites of Special Scientific Interest (SSSI) have been around in Britain for a long time, but the Wildlife and Countryside Act of 1981 and subsequent country-based legislation has strengthened the protection afforded to these designations. Northern Ireland has followed suit with Areas of Special Scientific Interest (ASSIs). Then in 1992 the Habitats Directive required the UK to designate Special Areas of Conservation (SACs) for habitats and species of European importance. SACs, along with Special Protection Areas (SPAs) designated under the earlier Birds Directive (1979), are intended to form the Natura 2000 network across Europe. In the UK most Natura sites are also underpinned by SSSI/ASSI status.

Legislation protecting these sites varies in its strength and effectiveness. For Natura sites there are stringent tests for ‘plans and projects’ which statutory bodies must apply before granting permission. Other obligations apply to SSSIs and ASSIs.

In addition the conservation agencies have ambitious targets set by government to achieve ‘favourable condition’ for designated sites in each country. Designated site features are assessed by the conservation agencies on a six year cycle to determine their condition using ‘Common Standards Monitoring’. This has shown that a substantial proportion of site features across the UK are in unfavourable condition. Causal factors are wide ranging although air pollution impacts tend to be poorly detected by the methods used.

Yet more challenging, a primary aim of the Habitats Directive is to achieve Favourable Conservation Status for the listed habitats and species across their range – not only on Natura sites. The UK has recently reported to Europe on the conservation status of these habitats and species and very few were assessed as favourable; threats from air pollution contributed to unfavourable status in many cases.

Alongside SSSIs and Natura 2000, in response to the Rio earth summit, the UK Biodiversity Plan was published in 1994 and introduced the concept of Action Plans for priority habitats and species (HAPs and SAPs) with associated targets and reporting. This ‘wider countryside’ approach has had patchy success with limited legislative backing, though the introduction of a biodiversity duty for public bodies is starting to make a difference.

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DEVELOPING THE USE OF BIOLOGICAL MEASUREMENTS IN A REGULATORY FRAMEWORK

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The current regulatory framework for controlling the impacts of atmospheric pollutants on the biosphere relies heavily on the use of proxy measurements, such as pollutant flux or concentration. This approach is simple to enforce and has served us well in reducing environmental pollution from historically high levels to the greatly reduced levels we generally experience today in the UK.

Further improvements will be progressively harder, and more expensive, to win. There is therefore a greater need than ever to be able to demonstrate the scale of positive environmental outcome that can be achieved for each unit of investment. In a world of finite resources it is necessary to prioritise that investment at the sectors with the potential to return the greatest environmental improvement.

Measurements of environmental outcome have the potential to give a more direct demonstration of the consequences of changing pollution level than proxy measurements, and so provide the evidence base required to justify further controls and to prioritise effort. In practice, however, outcomes-based monitoring is not a trivial task. The responses of biota to pollution stresses can be similar or identical to those brought about by other stressors such as climate change or changing land management. Effective outcome measurements are dependent upon having the means to take such confounders into account. Outcomes-based monitoring therefore faces a burden with respect to effective network design, statistical planning and understanding of the environmental system under scrutiny than proxy monitoring. The latter does not escape these burdens, however. Rather, they are effectively deferred to separate studies of dose-response relationship from which acceptable proxy levels are defined.

A crucial question, then, in weighing the benefits of outcome and proxy measurements in a given situation is whether residual uncertainties arising from confounders which decouple outcome from pollution pressure are more or less than those uncertainties which arise from applying dose-response responses, often gained under laboratory or idealised field conditions, to real ecosystems.

An ideal situation would be one in which the “real world” outcomes measured were ones which were free of confounders, and which could therefore be linked unequivocally to pollution pressure. It is essential, therefore, to keep a watching brief on developments in biomonitoring in the hope of finding techniques which can bring us closer to that ideal.

CRITICAL LOADS - MAPS OR MYSTIQUE: ISSUES INVOLVED IN 'DOWNSCALING' CRITICAL LOADS

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Critical loads are defined as the highest deposition load of a pollutant that will not cause adverse harmful effects on the receptor (eg, soil, vegetation, water). Methods to calculate critical loads for acidity, nitrogen and heavy metals have been developed and agreed at national and international meetings. In the UK critical loads are calculated for broad habitats sensitive to acidification and eutrophication.

Critical loads provide an effects-based policy tool and have been successfully used in the development of pollutant abatement strategies both in the UK (Defra, Environment Agency) and in Europe (UNECE Convention on Long-Range Transboundary Air Pollution).

National and European scale maps of critical loads and critical load exceedance (ie, the excess deposition above the critical load) have proved to be an effective method of communicating the results to the policymaker. These maps are based on data from different sources, and of different resolutions and scales, from site-specific measurements to national-scale databases. However, there are no error bars on maps and so they may "hide" the uncertainties in the data and methods, and the limitations for their use and application at the national, regional or site-specific scale. To help prevent the data and maps being misused or misinterpreted it is therefore important that the uncertainties and limitations are communicated to, and understood by the policymaker.

PPC AND THE HABITATS DIRECTIVE ASSESSMENTS FOR POWER STATIONS AND INTENSIVE LIVESTOCK

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Under the IPPC regime power stations and intensive farming sectors were assessed using Critical loads to determine adverse effects to Natura 2000 sites. For power stations the conclusion was that their emissions were not causing an adverse effect to site integrity and could therefore be given permits, with conditions imposed to reduce emissions within a prescribed timescale. The conclusions made for the intensive livestock sector were varied with some farms able to continue without improvement conditions and those that required improvements.

A collaborative project funded by CCW and Environment Agency is planned to monitor the impacts from large combustion plants and also smaller scale emitters, such as intensive farming. It is hope that the data collected will inform the Reviews of Consents process and also the IPPC regime by providing site specific information of deposition and impacts to habitats and sensitive species.

PROTECTING BIODIVERSITY FROM AIR POLLUTION: - PROGRESS MADE, OPPORTUNITIES MISSED AND FUTURE CHALLENGES

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The 1990 Environment Protection Act led to the formation of the UK statutory conservation agencies (Countryside Council for Wales, Natural England, Scottish Natural Heritage and the Joint Nature Conservation Committee) and placed duties on us as formal consultees on air pollution issues. Since then the conservation agencies have funded and developed air pollution research to support an evidence-based approach. This underpins the advice we provide and helps us target policy based outcomes. Over this period our understanding of air pollution effects on sensitive habitats has continued to develop. At the same time powerful global commitments and EU and UK legislation have provided a demanding framework that requires robust protection of habitats and wildlife. In some cases our improved understanding of impacts has married well with the increasing requirements for the protection of biodiversity. This has resulted in the adoption of new air pollution standards, revised assessment methodologies, new legislation and policy objectives. However, in some areas we have failed to translate our increasing understanding into appropriate outcomes to support biodiversity. This is an area where much greater effort and collective endeavour is required if we are finally going to resolve an historical and ongoing issue such as acidification. We will also need a much more integrated understanding and approach if we are to address growing areas of concern such as nitrogen and ozone pollution. The overwhelming issue of climate change poses the most demanding challenge to man and his environment. As we consider the difficult options ahead we should also look for the opportunity that climate change offers us to finally tackle some of the remaining threats of air pollution to the natural environment.

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THE EFFECTS OF NITROGEN ON THE DECOMPOSITION, MINERALISATION AND TURNOVER OF ORGANIC MATTER IN THREE CONTRASTING ERICACEOUS-DOMINATED ECOSYSTEMS.

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Understanding the processes that regulate carbon accumulation in soils in response to increased levels of reactive nitrogen (N) in deposition is incomplete, because N affects different ecosystem processes in different ways. Depending on factors such as soil chemistry, climate and vegetation type, it is possible that chronically elevated nitrogen deposition could increase, decrease or not affect the long-term carbon balance of a terrestrial ecosystem.

It has been well demonstrated in N fertilisation experiments that N can increase plant growth across different ecosystem types subject to different climatic regimes and a number of authors have related this increase in productivity to increased carbon sequestration. However, to date much of this research has focussed on forest ecosystems.

This study is designed to address these uncertainties and compares the interactions of the N and C cycles at three contrasting UK heathlands subject to different climatic regimes: lowland heath (Budworth, England), upland heath (Ruabon, Wales) and a raised bog (Whim, Scotland).

Results from the first two collections from a litter bag study of decomposition will be compared with field mineralisation data and both will be considered with regard to the turnover rates of organic matter and accumulation of carbon at the three sites.

The cold damp bog exhibited the lowest rates of mineralisation and decomposition than the warmer heathland sites though contrasting effects of nitrogen on mineralisation were found. Positive increases in mineralisation rate were measured at Ruabon though N seemed to negatively affect mineralisation at Whim. The soil moisture status is thought to be the controlling factor in this with a much faster cycling of nutrients in the freely-drained upland heath. Finally, Nitrogen appeared to slow initial decomposition rates at all sites, particularly at the N saturated lowland-heath of Budworth Common.

LONG TERM TRENDS IN RAINFALL, THROUGHFALL AND SOIL SOLUTION CHEMISTRY IN THE LEVEL II FOREST MONITORING PLOTS IN THE UK

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Detrimental changes to soils and water ecosystems from the impact of acid deposition and acidification have lead to the development of national and international policies aimed at reducing emissions of acidifying pollutants. Increasingly, such policies have required an effects-based approach to proposing solutions for environmental problems and implementing emissions reductions in a targeted and cost-effective way. As a part of this process there is a need to provide policy makers with information showing the consequences of changing emissions on the environment and their associated ecosystems. The European forest monitoring (ICP Level II sites) have been established in 1995 monitoring the chemical inputs and outputs of the forest ecosystems, thus it can evaluate the implementation of the emission reduction policies.

- The evaluation of the long term trends in rainfall and dry deposition at the Level II intensive forest monitoring sites in the UK provides evidence for changes in important deposition chemistry which confirm the successful implementation of the emission reduction policies in the UK.

- Long term trends in throughfall and soil solution chemistry at these sites show the ecosystem response to changes in deposition and the rate of chemical recovery. Changes in soil solution DOC and DON were also detected. In addition, chemical evidence is there to support the increase of storm events at some exposed monitoring sites.

- The detailed analysis also suggest the importance of biological influence on the chemical cycling as well as improves our understanding on the chemical versus biological impacts and responses, their magnitude and nature. It is suggested that many insect pests may become more damaging as a result of climate change, in part, driven by expectations that more frequent and severe summer droughts will make trees more susceptible to biotic agents.

- The integrated nature of monitoring across the level II network enables the relationships between climate, pollutant exposure and chemical and biological response in forestry to be explored.

BIODIVERSITY OF EUROPEAN GRASSLANDS – GRADIENT STUDIES TO INVESTIGATE THE IMPACT OF ATMOSPHERIC NITROGEN DEPOSITION ON ACID GRASSLANDS

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Experiments have suggested that reactive nitrogen deposition may reduce species richness. However, until recently there was no clear evidence that widespread biodiversity reduction caused by regional air pollution was actually occurring. An extensive field survey across the UK gradient of atmospheric nitrogen deposition showed a dramatic decline in species richness of acid grasslands with increasing atmospheric nitrogen deposition (Stevens *et al.* 2004, 2006). Changes in soil chemistry were also observed (Stevens *et al.* in review). Combining the results of the gradient study with experimental manipulations allowed us to estimate the timescale of the observed change in species richness.
The BEGIN project (Biodiversity of European Grasslands – the Impact of Atmospheric Nitrogen Deposition) is a collaborative project between The Open University (UK), Manchester Metropolitan University (UK), Bordeaux University (France), Utrecht University (The Netherlands) and The University of Bremen (Germany). It builds on the results collected in the UK survey and previous experimental work to further investigate these changes. In addition to the 68 acid grasslands already surveyed in the UK, the BEGIN project surveyed 80 acid grassland sites throughout the Atlantic biogeographic region of Europe. At each site data were collected on species composition, soil chemistry and plant tissue chemistry.

Initial results of the BEGIN project will be presented, investigating whether similar declines in acid grassland species richness and changes in composition are found across Europe, expanding the range of N deposition to levels both above and below that found in the UK. We will also report initial findings for soil chemistry.

HOW DO POLLUTION-DRIVEN CHANGES IN HEATHLAND COMMUNITY COMPOSITION AFFECT ECOSYSTEM FUNCTION?

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The effects of pollution or climate-driven changes in plant community composition on the function of heathland ecosystems are being investigated using both a mesocosm experiment and field survey approaches. The mesocosm study involves three dominant heathland plants (*Calluna vulgaris, Deschampsia flexuosa and Ulex minor*), growing either in monoculture or in differing proportions within 2 or 3 species mixed communities. The principal aim of this study is to test whether the effect of a plant species on ecosystem properties is in proportion to its biomass. Mesocosms were established in spring 2007. To date, only non-destructive growth assessments have been carried out, although assessment of nutrient cycling, water demand and above- and below-ground productivity are planned.

A parallel investigation of the relationship between heathland plant species and ecosystem properties has also been initiated, at Thursley Common NNR in Surrey. Replicate areas with differing compositions of the three main heathland species were identified, and their physical and chemical properties were assessed. Preliminary results showed that soil moisture content, total nitrogen (N), total phosphorus (P), extractable N, extractable P, phosphatase activity, and phenol oxidase activity of the soils differed with differing proportions of the three heathland species and that species identity may have a disproportionate effect on some ecosystem properties. Further site replicates are planned to evaluate whether there are critical thresholds of heathland plant community composition at which point ecosystem properties switch to resemble conditions associated with monocultures of particular plant species.

RECOVERY IN EXTRACTABLE N CONCENTRATIONS AFTER CESSATION OF ARTIFICIAL N ADDITIONS

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Emissions of pollutant N in the UK have been declining since the early 1990s and the government is committed to international treaties promising further reductions by 2010. The direct and indirect effects that pollutant N has on ecosystems have been monitored through a number of long term experimental manipulations and vegetation surveys. In the light of declining emissions, research is now beginning to focus on the potential for ecosystems damaged by N deposition to recover.

Here we report changes in the concentrations of extractable N in acid and limestone grassland soils over a five year recovery period following the cessation of simulated N additions that were applied monthly for 11 years. In both grasslands the pool of exchangeable soil mineral N has fallen rapidly, but in the acid grassland effects of the previous N treatments persist into the 5th year after treatments ceased. In the limestone grassland there is also some evidence of persisting effects.

We have monitored recovery in exchangeable N concentrations in a parallel set of grassland plots in which N additions since 1995 have ceased from 2005 on one side and have continued on the other. These plots confirm that there is progressive recovery in exchangeable N concentrations over time, but treatment effects remain.

These results suggest that grassland ecosystems can recover from the eutrophic effects of N deposition, but others studies at these sites suggest acidification and base depletion may have longer-lasting and more serious implications for ecosystem health.

Importance for DEFRA's environmental policy:

- Long term studies have shed light on persistent effects of N pollution in various ecosystems but now it is essential to assess the potential for ecosystems to recover from declining N emissions
- Initial signs of recovery seen in N addition experiments in grassland soils
- Full recovery in exchangeable N concentrations have not occurred 5 years after ceasing experimental enrichment

INVESTIGATING NITROGEN DEPOSITION SIGNALS IN *CALLUNA*-DOMINATED LOWLAND HEATHLAND SYSTEMS IN ENGLAND

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Effects of nitrogen deposition on heathland vegetation may vary due to differences in vegetation structure, soil type, geology, climate and habitat management. However, given that experimental data on responses to N under controlled conditions are limited, it is useful to establish whether specific vegetation and/or soil characteristics can provide an indication of N deposition impacts more widely in the field. This study investigated the relationships between modelled N deposition and a suite of soil and plant biochemical/physiological characteristics, as well as relationships between plant and soil chemistry.

Following a pilot study in 2005, thirty-two lowland heath sites across southern England, the Midlands and Yorkshire were selected to include a range of N deposition rates (13.3 – 30.8 kg ha^{-1} yr^{-1}), geographical area and different geologies for the survey. Survey work was carried out in October 2007 and field samples were collected for *Calluna* foliar material, bryophytes, litter and soil (0-2cm, 0-5cm). Measurements were made in the field of litter depth, shoot extension, canopy height and depth of soil horizons. Samples were analysed in the lab for total N & P, extractable N & P, phosphomonoesterase (PME) activity and phenol-oxidase activity. The data were compared statistically with modelled nitrogen deposition values obtained from CEH, Edinburgh.

Foliar N & P, total soil P, extractable soil P, total litter N & P, soil PME activity, soil phenol-oxidase activity and litter & humus depth were all significantly related ($P<0.05$) to modelled N deposition (total, oxidised and reduced). Total and reduced N deposition typically showed stronger relationships overall than oxidised N. No significant relationship was found between any form of N deposition and foliar N:P ratios, reflecting the positive relationships of both foliar N and foliar P concentrations with increasing deposition. Litter enzyme activities were significantly related to several plant and soil variables, including organic matter content and soil N & P concentrations.

This study suggests that the signal of N deposition is consistently detectable in a number of biological and chemical compartments at heathland sites across England. Exceedance of the critical N load results in changes in several functional properties of the ecosystem. There is also evidence that current levels of N deposition may be accelerating microbial enzyme activities and thus contributing to faster rates of nutrient cycling at many sites, with potential impacts on ecosystem functioning in these habitats of high conservation value.

PHENOL OXIDASE: AN ENZYMIC LATCH ON A GLOBAL CARBON STORE

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http://biology.bangor.ac.uk/research/wetland

Recent research suggests that the low rates of decomposition that characterise peatlands can be indirectly attributed to constraints on phenol oxidase. Without oxygen, phenol oxidase activity is impeded and phenolic materials can accumulate in the wetland soil. The wider implications of this observation can be found in the numerous studies that have shown phenolic materials to be highly inhibitory to microbes and their enzymes. Taken together, these observations suggest that oxygen constraints upon phenol oxidase can severely impair decomposition as a whole, with profound implications, not just for peatlands, but for our entire planet. This presentation will describe the events that led to an appreciation of the significance of the 'phenol oxidase latch mechanism', and how its presence has implications at a global scale.

CAN INCREASED DOC IN STREAMS AND LAKES BE EXPLAINED BY CHANGES IN ACID SULPHATE AND SEASALT DEPOSITION IN CATCHMENT SOILS?

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Concentrations of dissolved organic carbon (DOC) have increased in freshwaters draining areas of peat and organo-mineral soils across parts of Europe and North America over the last two decades. Recent analysis of regional lake and stream data has shown a link between this increase in DOC concentrations and the decline in freshwater sulphate and chloride concentrations that have been driven by the decline in acid sulphate and seasalt deposition over the same period (Monteith et al., 2007). The assumption made in the interpretation of these data is that stream water data are a proxy for chemical and biological processes operating in catchment soils that control the supply of DOC. However, DOC concentrations in freshwaters are also influenced by a number of other processes, including temperature and catchment hydrology. Variations in both of these factors have been proposed as alternate explanations for increased DOC concentrations in freshwaters. Spatial variations in catchment hydrology linked to soil type and geology may also act to obscure relationships between deposition and DOC in soils, particularly in catchments where hydrology has a major influence on DOC concentrations in stream water (e.g. in catchments draining organo-mineral soils). To remove the effect of catchment hydrology and other factors on DOC, and so verify the hypothesis that deposition changes have been a significant driver of DOC, direct experimentation on catchment soils was carried out. Soil cores were collected from the top 10 cm of peat and organo-mineral soils in six of the UK catchments studied by Monteith et al. (2007). Temperature was controlled (8 ^{o}C) and vegetation removed to reduce biological effects on DOC release so that geochemical changes in solubility could be examined. Deposition loading of acid sulphate and seasalt was varied within the range observed at these sites between 1988 and 2005. Preliminary data showed that solute loading from seasalt was more significant than acid loading from sulphuric acid in reducing DOC concentrations. However, as seasalt loading caused a greater increase in soil water acidity due to ion exchange processes it was difficult to determine whether coagulation with marine cations or increased acidity caused a reduction in DOC solubility.

Monteith DT, Stoddard JL, Evans CD, de Wit HA, Forsius M, Høgåsen T, Wilander A, Skjelkvåle BL, Jeffries DS, Vuorenmaa J, Keller B, Kopácek J, Vesely J (2007). Nature, 450: 537-541.

- Research is examining whether decline in sulphur deposition from ‘acid rain’ and natural seasalts is a more significant driver of increased dissolved organic carbon (DOC)/water colour in rivers than climate change i.e. are these upland organic soils and waters recovering from acid rain or degrading due to climate change?
- Preliminary data shows that seasalt has a greater effect on DOC concentrations in soil water than acid sulphate, however research is still in the early stages.

CHARACTERISING THE EFFECT OF N DEPOSITION HISTORY ON HEATHLAND RECOVERY FOLLOWING FIRE

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Over the past 18 years, the experiments at Thursley Common NNR have investigated the impacts and fate of elevated N deposition on the heathland plant community and on the biogeochemical cycling of N. This body of work has established the mechanisms by which nutrient loading drives above- and belowground ecosystem change, following management. However, In July 2006, a severe fire swept through a large part of Thursley Common, destroying approximately 90% of the heathland area. This, therefore, provided a unique opportunity to evaluate the impact of a major, high temperature fire on nutrient and microbial dynamics in soils of contrasting chemistry and microbiology.

The objectives of the study were to: (1) Quantify the effect of a severe summer fire on soil nutrient dynamics and nutrient economy for heathland plots which had previously received more than 7 years' N addition treatments; (2) Determine the impact of the fire on the dynamics of soil microbial community composition and activity, in relation to nutrient availability; (3) Investigate the relationship between belowground chemistry, microbial community characteristics and post-fire regeneration of aboveground vegetation.

Our results demonstrated the considerable impact of high temperature, uncontrolled summer fire on soil nutrient stores, particularly N, with implications for site nutrient budgets and associated management targets. Microbial activity was higher in unburnt samples compared to burnt plots, and in +N plots compared to controls, up to a year after the fire. Furthermore, activities were higher than those recorded before the fire, suggesting that the post-fire release of nutrients may have increased microbial activity. Molecular diversity of various microbial groups revealed persistent and reproducible differences between the communities from control, +N and unburnt plots. Differences in vegetation regeneration following fire appear to reflect differences in soil nutrient stores (and microbial communities) and may have longer-term consequences for plant community composition and key ecosystem processes.

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.

TREE RESPONSES TO ELEVATED ATMOSPHERIC CARBON DIOXIDE

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In a Free Air Carbon Dioxide Enrichment experiment (BangorFACE) the response of birch (*Betula pendula*), alder (*Alnus glutinosa*) and beech (*Fagus sylvatica*) growing sinlgly and in mixture to elevated carbon dioxide is being investigated. After 3 year of enrichment, clear increases in both above and belowground growth could be seen in all species. Mixture of trees showed higher growth rates that those predicted from single species growth measurements. The degree of this over-yielding was not increased by elevated carbon dioxide. The amount of litterfall was increased in the elevated carbon dioxide treatment and birch show a longer leaf retention compared to the ambient treatment, as a consequence the vegetative period was increased. In addition, a clear response was seen ectomycorrhizal community structure. These data will be presented in context of assessing forest responses to an increase in atmospheric carbon dioxide

POSTER ABSTRACTS

HOW WELL HAVE OZONE FLUX- AND AOT40-BASED RISK MAPS FOR EUROPE PREDICTED ACTUAL DAMAGE TO CROPS AND NATURAL VEGETATION OVER THE LAST 15 YEARS?

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During the last two years, the ICP Vegetation Programme Coordination Centre has collated evidence of damage to crops and (semi-)natural vegetation in Europe caused by ambient ozone pollution over the time-scale 1990 – 2006, to quantify the link between field observations and critical level exceedance (Hayes *et al.*, 2007). The overall aim of this study was to answer the policy maker's question "is there any evidence of actual ozone damage in areas predicted to have high ozone flux or concentration (AOT40)?"

Visible ozone injury symptoms have been recorded on over 30 crop and 80 (semi-)natural vegetation species. In all, there are over 500 records of injury from 16 countries, representing all regions of Europe, i.e. from northern as well as southern Europe. Crops that have shown visible injury symptoms attributed to ozone include maize, bean, potato, lettuce, and watermelon. ICP Vegetation experiments have shown that ozone injury symptoms on well-watered clover plants occur throughout the period May to October in most regions of Europe, with symptoms being most severe in July and August. The largest impacts of ozone on the biomass of clover plants were consistently found in southern Europe, particularly in Italy and Greece where biomass reductions of over 30% have been demonstrated in some years.

By comparing the locations of effects of ozone in ambient air with EMEP generic flux maps for crops ($AF_{st}3_{gen}$), increasing stomatal flux was found to be associated with increasing incidences of ozone injury, greater severity of ozone symptoms and increasing biomass reductions. There was either no or minimal impact of ozone in EMEP grid squares with ozone fluxes close to zero. This study has also shown that the AOT40 –based critical level for agricultural crops appears to be underestimating the potential for ozone damage in Europe. AOT40 worked best as a regional-scale indicator of damage, with both ozone injury score and biomass reduction linearly related to the mean EMEP modelled AOT40 for the 50 x 50 km grid squares that the ICP Vegetation sites represent. At this scale, a mean biomass reduction of greater than 10% occurred in Continental Central Europe and Eastern Mediterranean, where EMEP risk maps indicated that mean AOT40s were at or below the critical level. Furthermore, at the local scale, approximately one third of the ozone injury data points were in grid squares where the maps indicated that the critical level for yield reduction was not exceeded.

Policy implications: Stomatal flux ($AF_{st}3_{gen}$) maps were better at predicting the widespread occurrence of ozone damage on vegetation than ozone concentration (AOT40) maps. The AOT40-based risk maps underestimated the impact of ozone across Europe and especially in northern Europe. These results are being used in the review of the Gothenburg Protocol.

Hayes, F., Mills, G., Harmens, H, Norris, D. (2007). Evidence of widespread ozone damage to vegetation in Europe (1990 – 2006). NERC publication. ISBN: 978-0-9557672-1-0. 58 pp.

- We are grateful to Defra, the LRTAP Convention and NERC for supporting this study.

RECOVERY FROM PHOSPHORUS STRESS FOLLOWING CESSATION OF SIMULATED NITROGEN DEPOSITION IN CALCAREOUS GRASSLAND

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The role of P in mediating the impacts of atmospheric N deposition on plant biodiversity may be particularly important in ecosystems where productivity is limited by P rather than N. In UK calcareous grasslands which are P limited, understanding what regulates species change is particularly important since these grasslands represent some of our most floristically rich ecosystems and have considerable conservation and amenity value.

Long-term (>15 years) experiments that simulate increased N deposition on P-limited calcareous grasslands at Wardlow Hay Cop (Peak District National Park) have allowed insight into the effects of N deposition on availability of P to plants and the mechanisms by which such effects occur. In these systems, increased atmospheric N deposition can reduce the plant available soil P pool and may therefore exacerbate P limitation to plants. Such increase in P limitation is seen further in the greater activity of root surface phosphatase enzymes in calcareous grassland plants under increased N deposition and greater soil phosphatase activities - indicating the increased P demand of plants and microbes in the system. Plant tolerance of increasing P limitation may be one mechanism that regulates species change in P limited calcareous grassland. Where such systems that have undergone reduced P availability and increased P stress resulting from N deposition, recovery of the system (including floristic diversity) may require recovery of P availability and a return of normal (unpolluted) ratios of available N:P in the soil.

This poster presents the recovery of N and P availability in calcareous grassland soils at Wardlow Hay Cop (Derbyshire Dales), and the extent to which P stress – as indicated by plant root surface phosphatase and soil phosphatase activities has recovered in the 18 “treatment free” months following 12 years of simulated N deposition. Overall the study suggests that enhanced P stress resulting from N deposition does not recovery rapidly, but that early signs of recovery are beginning to become evident after 18 months.

Understanding the rate of recovery of P availability and P stress is important for predicting recovery of P limited systems (such as high conservation value calcareous grasslands) and for providing insights into how such systems may best be managed to facilitate recovery.

20 YEARS INVESTIGATING LICHEN AND BRYOPHYTE BIODIVERSITY UNDER CHANGING ATMOSPHERIC CONDITIONS

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Burnham Beeches is a biodiversity hotspot that provides an important reservoir of lichens and bryophytes including the globally rare moss *Zygodon forsteri* and nationally rare lichen *Pyrenula nitida*. Following reductions in SO_2 concentrations, the lichen flora on free-standing trees has undergone rapid expansion from a near dominance by the SO_2-tolerant 'acidophyte' species *Lecanora conizaeoides* and *Hypogymnia physodes*. Survey results of the diverse epiphytic assemblages are summarised with reference to changes in atmospheric conditions, bark pH and conservation management.

MINERALISATION IN RUST-COLOURED *ACAROSPORA*

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The upper cortex and extracellular hyphal wall matrix are mineralised in both rust-coloured *Acarospora sinopica* and the paler *A. smaragdula* 'f. *subochracea*' in the form of microgranular or microbotryoidal phases. Analysis confirmed the distinctive colours are not simply due to hydrated iron oxides, 'rust', as previously believed, and suggests mixed sulphide and oxide phases with little crystallinity, as well as other elements arising from clay minerals are present. These aspects highlight the need for a more detailed study employing a range of micro-analytical techniques, including analytical TEM which will allow mineral characterisation and localisation down to the nanometre scale.

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