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PRESENTATION & POSTER ABSTRACTS

DOES IT MATTER THAT AIR POLLUTION IS CHANGING THE SPECIES COMPOSITION OF SEMI-NATURAL HABITATS?

Stan Harpole

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Human activities are changing multiple global factors that limit the growth and fitness of organisms and therefore affect coexistence and drive biodiversity loss. Species' responses to changes in limiting factors are often non-linear and multiple factors can interact, yet much of our understanding of global change impacts on biodiversity is based on linear and single factor concepts. I will focus on nutrient pollution effects on primary producer communities, highlighting results from a recently established global experimental network (the Nutrient Network) as well as the meta-analysis work that inspired the network. In contrast to paradigms of single nutrient limitation, we found widespread synergistic co-limitation of aquatic and terrestrial primary producer communities by nitrogen (N) and phosphorus (P). From our global nutrient experiment, we are finding that even communities that appear not to respond strongly to nutrient addition in terms of productivity still show strong negative effects on biodiversity suggesting that the constraints on production differ from the constraints on coexistence. Because atmospheric nutrient pollution can be stoichiometrically skewed to high ratios of nitrogen relative to other limiting nutrients, we also are testing for non-linear responses to N deposition in particular. Preliminary work is showing disproportionate species loss at the lowest levels of N input, and that the response to N is contingent on P, other nutrients and herbivory. Even where species loss response is weaker, community composition and tissue nutrient concentrations respond non-linearly to increasing N input. Nutrient pollution is just one of many global change factors that impacts species diversity, and biodiversity loss itself has negative consequences for multiple ecosystem functions.

HOW WILL SEMI-NATURAL VEGETATION IN THE UK HAVE CHANGED BY 2030 GIVEN LIKELY CHANGES IN NITROGEN DEPOSITION?

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Atmospheric nitrogen deposition has a range of impacts on vegetation in semi-natural communities including changing species composition to favour more acid-tolerant and nutrient-loving species, changing the balance of functional groups, frequently to favour grasses, and reducing species richness. Many of these effects are mediated by changes in soil chemistry, in particular acidification and eutrophication but nitrogen deposition can also lead to increased susceptibility to pests, disease and extreme weather.

In order to assess likely changes in vegetation by 2030 we used modelled values for cumulative nitrogen deposition. We extracted vegetation quadrat data and unweighted mean Ellenberg N scores for three habitats (broadleaved woodlands, grasslands and heath and bog) within 1km sample squares of the Countryside Survey for the years 1978, 1990 and 1998. A best-fitting model of change in these mean Ellenberg N scores was then produced using time and cumulative N deposition in each year as explanatory variables and a random effect of 1km square. Predictions of new Ellenberg values for 2020 and 2030 were calculated from this model. The MultiMOVE model was run to identify habitat suitability for species present in each of the habitats in Countryside Survey data from 1998 and then used to examine how changes in cumulative deposition would result in changes in habitat suitability for the years 2020 and 2030.

The results show that some species will experience quite large changes in habitat suitability if all other environmental variables remain constant and assuming no recovery from reduced deposition. In deciduous woodlands we may expect to see reductions in acid loving sub-shrubs such as *Calluna vulgaris* and *Vaccinium myrtillus*. In grasslands we see a reduction in habitat suitability for species such as *Carex panicea*, *Plantago lanceolata*, and *Lotus corniculatus* but an increase in the habitat suitability of nutrient loving species such as *Urtica dioica* and *Poa trivialis*. In heath and bog habitat suitability declines for species such as *Trichophorum cespitosum*, *Calluna vulgaris* and *Erica tetralix* but increases in *Holcus lanatus* and *Rumex acetosa*.

Combined with published findings on past and present changes in species richness and composition we predict that semi-natural habitats will become less species rich and nutrient loving species wil increase in abundance.

PHOSPHORUS CONSTRAINS BIODIVERSITY IN EUROPEAN GRASSLANDS INDEPENDENT OF ATMOSPHERIC NITROGEN DEPOSITION.

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Nutrient enrichment has been identified as a serious threat to biodiversity worldwide. In terrestrial ecosystems, the deleterious effects of nitrogen pollution, particularly in the form of atmospheric nitrogen deposition, are increasingly understood and mitigating environmental policies have been developed. Compared to N however, the effects of increased phosphorus on biodiversity have received far less attention. Here, the major objective is to explore the relative importance of nitrogen and phosphorus for plant species richness using a dataset covering 501 grasslands throughout Europe. The results show that plant species richness was consistently negatively related to soil phosphorus, independent from the level of atmospheric nitrogen deposition. Effects of increased nitrogen deposition interacted with soil acidity, showing a gradually stronger negative relationship with plant species richness in more acidic grasslands. These results suggest that environmental policies biased towards reducing nitrogen pollution will fail to preserve maximum biodiversity in grasslands. As soil phosphorus is known to be extremely persistent, agro-environmental schemes should include areas permanently free from phosphorus fertilization. Furthermore, as current knowledge regarding phosphorus aerosols is extremely limited, more attention should be paid to identifying and quantifying atmospheric transport of phosphorus as a possible source of pollution.

Ceulemans, T. *et al.* (2014) Soil phosphorus constrains biodiversity across European grasslands. *Submitted to Global Change Biology*.

NITROGEN VERSUS PHOSPHORUS ENRICHMENT EFFECTS ON PLANT SPECIES RICHNESS IN HERBACEOUS ECOSYSTEMS

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Both nitrogen (N) and phosphorus (P) from anthropogenic sources continue to enrich the biosphere, but their relative contributions in causing changes in vegetation composition and plant species losses have scarcely been quantified. Here, we compare the effects of N *versus* P enrichment on species richness of natural and semi-natural herbaceous ecosystems, using a meta-analysis of 70 longer-term nutrient addition experiments in the field (mostly Europe and USA). Our experiment-based approach shows that N additions significantly reduce plant species richness in terrestrial and wetland ecosystems on the longer term, whereas accumulating P additions hardly affect species numbers in the published experimental studies. In addition, negative effects on species richness are greatest in the most species-rich vegetation types, and hardly present in species-poor vegetation. Our finding that the effect of P input is consistently smaller than that of N in the studied ecosystems sheds new light on the ongoing debate of the relative importance of N and P enrichment. It unequivocally demonstrates the urgency for strategies to control or prevent he increase of atmospheric N loading of (semi-)natural areas in pristine, low N situations.

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RELATING SPECIES CHANGE TO BIODIVERSITY TARGETS

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Nitrogen tends to accumulate in ecosystems and cause delayed and cumulative effects. Effects on plant and lichen species can be predicted, to an extent, by coupling dynamic biogeochemical models to models of species' niches. However, defining targets and damage thresholds involves what are inevitably subjective decisions as to which aspects of habitats are most important. As a signatory party to the Convention on Long Range Transboundary Air Pollution (CLRTAP), the UK has been asked to provide biodiversity metrics for use in assessing impacts of atmospheric nitrogen (N) pollution. We consulted the specialists for bogs, grasslands and heathlands at the Statutory Nature Conservation Bodies to ascertain the best basis for such metrics. In a series of semi-structured interviews, the habitat specialists were asked to discuss the reasoning behind their evaluation of sites as good, poor or degraded examples of these habitats. The specialists were also asked to rank a set of examples of their habitat, each presented as a species list with cover values. These parallel sources of evidence were used to assess potential metrics, such as those based on the number of species, cover of species-groups, or presence of indicator-species.

Interview responses revealed that vegetation composition is very important for assessing habitat condition. The specialists generally did not assess similarity to a "reference" assemblage, however, since distinct types of a habitat could all be considered to be of high quality. Scarce species are considered important for biodiversity conservation, and sites are often designated because they support populations of scarce species. However, these scarce species tend to occur on few sites, and may be hard to see or identify, so assessments of habitat condition are generally made on the basis of the occurrence or abundance of positive indicator-species. These have been defined, for example in the Common Standards Monitoring Guidance, on the basis that they are distinctive for the habitat but not extremely scarce.

The habitat examples ranked by the experts were also ranked using various metrics calculated from the species data. Species-richness was often but not always related to the experts' assessments. The total cover of *Sphagnum* in bogs was correlated with the experts' assessments, but otherwise the abundance of functionally important groups (forbs in grasslands and subshrubs in heathlands) did not seem to be a reliable indicator of quality. The metric that was most consistently and clearly related to experts' ranking was the number of positive indicator-species. Negative indicator-species are a more varied group – some indicate poor environmental conditions, but others invade habitats that are otherwise in good condition.

A metric based on predictions of habitat suitability for positive indicator-species was shown to increase with decreased N pollution on all test sites. This was not a foregone conclusion since the metric is based on the niches for many species, each of which responds individually to changes in fertility, alkalinity and canopy height. The metric has been applied in the UK response under the CLRTAP. The study illustrates that a combination of qualitative and quantitative survey methods can be very useful in achieving consensus on appropriate and pragmatic measures of biodiversity value.

AIR POLLUTION IMPACTS ON THE REST OF BIODIVERSITY

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When air pollution scientists talk about evidence for the biodiversity impacts of pollutants, we often really mean just terrestrial plant biodiversity. Plants make up a tiny proportion of the total number of species in all habitats and we know remarkably little about how air pollution affects most organisms in most ecosystems. To make the point this talk will focus on an obscure and unfashionable group of microorganisms which most of the audience have probably never heard of: the testate amoebae. It will be argued that despite their obscurity testate amoebae are actually rather important in many ecosystems through their role in ecosystem functioning and contribution to total biodiversity. Evidence for sensitivity to N, S and O_3 pollution will be explored using examples from peatlands to demonstrate how testate amoeba communities are shaped by air pollution impacts on both their food sources and physical environment, and how such changes might affect carbon cycling. The potential role of testate amoebae as bioindicators in both ecological and palaeoecological studies will be advocated and the reasons underlying the lack of research on air pollution impacts on most of biodiversity will be explored. Even if I fail to convince the audience of the intrinsic interest of testate amoebae I hope to make the case for more research on air pollution impacts below-ground and greater engagement with soil biologists.

CARBON STORAGE IN GRASSLANDS: THE IMPACT OF ATMOSPHERIC NITROGEN POLLUTION

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Human processes now account for the conversion of more N_2 into reactive N than is produced naturally in the world per year. This has caused significant changes to the global N cycle, and has disrupted the sensitive nutrient balance of ecosystems worldwide. It is known that the C and N cycles are very closely linked. Soil is a major C sink, which makes it essential for climate change mitigation. By looking at the effects of N dose and form on the above and belowground C pools of acid grasslands, this project aims to further our understanding of how grassland soil can be managed as a C sink, and what processes should be prioritised when devising mitigation strategies for the effects of N on these systems.

In 2007, replicated N-addition experiments were set up on two species-rich, acid grassland sites; one in Trefor, North Wales, the other in Revna, Norway. Since then, N has been added in three doses (0, 35 and 70 kg N ha^{-1} yr^{-1}) and in three forms (oxidised N, reduced N and a 50-50 combination). In 2013 and 2014, analyses of soil, aboveground biomass and gas fluxes were carried out in order to find out whether the treatments have had any effects on the amount of C stored in these grasslands.

Although preliminary analysis of the data collected so far does not show any significant differences between treatments, some interesting patterns have emerged. In Wales, for example, the 50-50 combination treatments seem to be having a negative impact on aboveground biomass. This is not seen in Norway, where reduced aboveground biomass is only present in the reduced nitrogen treatment, an effect probably caused by increased acidity in these plots. In addition, the combination treatments have decreased the CN ratio of the vegetation at the Welsh site, potentially making litter in these plots more readily decomposable – an effect present in the oxidised and reduced treatments, but to a much lesser extent. Interestingly, N-addition seems to have slightly increased the CN ratio of the soil (0-10 cm) at both sites. In Norway however, when C and N were measured at different depths, this effect was only seen below 5 cm, indicating that perhaps vegetation subjected to the N treatments is investing more in deeper roots. Further investigations such as organic matter fractionations and ingrowth cores will be carried out in order to ascertain what other effects these N treatments may be having on belowground C pools.

MICROBIAL COMMUNITY RESPONSES IN DEGRADED PEATLANDS UNDERGOING RESTORATION IN THE SOUTHERN PENNINES

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Over 70% of upland peatlands in the Southern Pennines are degraded, with extensive areas of bare unconsolidated peat incised with networks of gullies often down to the bedrock. Land management, air pollution and climate change are implicated as major factors leading to loss of vegetation and susceptibility to erosion. Over the last 40 years, efforts have been made to re-vegetate bare peat in order to recover biodiversity, hydrological function, and carbon sequestration capacity. These restorative efforts began relatively soon after the clean air act, but even now over 50 years later it is easy to detect the signature of historical air pollution in the surface layers of peat at Holme Moss. Ironically the most degraded bare peat is the most pristine in terms of heavy metals contamination because the polluted surface layers have been eroded away, but fails to naturally re-vegetate.

We characterized microbial communities in this varied landscape with the aim of better understanding the role of microbes in natural and managed moorland restorations, as well as collecting primary data identifying the indigenous microbes of peatlands. This is important because microbes underpin peatland resilience and functioning but their identities and ecology in this ecosystem are very poorly known. Sampling encompassed unvegetated peat and peat from 5 vegetation classes: undisturbed dwarf shrub vegetation, naturally regenerated cotton grass/grass spp. dominated gully vegetation, introduced lowland nurse grass spp. and 1- and 25-year-old restored heather. In addition to microbiological analyses, soils were analysed for standard physico-chemical properties that included heavy metal status.

On the basis of high-throughput sequencing of phylogenetic DNA markers (16S- and ITS1- rRNA), bacteria and fungi were assigned to operational taxonomic units (OTUs) at approximately species level. OTUs were taxonomically classified by searching the Greengenes and UNITE DNA sequence databases, enabling probable functions to be estimated based on existing knowledge of related microbes. Significantly more culturable bacteria and fungi were detected in all vegetation classes compared to non-vegetated peat. Bacterial phyla were identified that are known to be involved in ecologically important processes including nitrogen and carbon fixation and methane oxidation. The fungi were predominantly ericoid-, ecto- and arbuscular-mycorrhizal fungi, yeasts, saprotrophs and plant pathogens. Multivariate ordination identified vegetation-specific clustering of both fungal and bacterial communities, showing that restoration activity clearly influences the below-ground microbial community and functional potential.

Many metals laid down by air pollution or mobilised from source minerals were significantly related to bacterial community structure, but not fungal community structure. These variables also varied in relation to vegetation cover which confounds attempts to relate historical air pollution to present microbial community structure at Holme Moss. However, initial analyses indicate that none of the restoration trajectories from bare peat are leading to the same microbial community structure found in the oldest intact vegetation stand in the area. One possible explanation for this is that persistence of pollutants in these non-eroding intact areas has selected for specific communities including metal resistant organisms, but this selection is not present in the relatively pristine restoration areas.

IS AMMONIA THE MAIN DRIVER OF SPECIES COMPOSITION CHANGE IN SEMI-NATURAL PLANT COMMUNITIES IN AREAS OF ENHANCED N DEPOSITION?

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There is compelling evidence: experimental, transect based (from point sources) and mechanistic of the potent effects of elevated atmospheric ammonia concentrations on semi-natural ecosystems. However, there remain important gaps in our understanding of the role of ammonia as a component of N deposition e.g. the significance of peak versus chronic elevated concentrations, timing of high concentration events in relation to physiological activity, to what extent effects are driven by direct (toxic) effects on plants or indirect via biogeochemical changes in the soil. Also, we don't fully understand if, and to what extent dry deposition drives the overall response to N deposition dominated by wet deposition. In areas where dry deposition of ammonia is minimal, N effects still occur and because of the different sources of N contributing to N deposition determining relative effects of oxidised versus reduced N is still a key issue.
This talk seeks to highlight issues to address when evaluating ammonia effects and collate observations that address the significance of N form effects, and how these might influence the relevance of form based critical loads. It is difficult from surveys to discriminate between their effects because of the level of auto correlation. Results from the peatland experiment at Whim suggest that sensitive components of the ecosystem are sensitive to both forms but that their mode of action may differ. Increasingly the significance of soil pH is highlighted as a controlling influence over the effects of N form. Ecologically speaking soil pH is a key determinant of the type of vegetation growing at a site and the form of N that vegetation is adapted to. We concur that soil pH may determine species and ecosystem response to N deposition through biogeochemical processes, microbial transformations and plant physiological effects that are sensitive to climate, especially temperature and The response of non vascular plants may also be underpinned by pH but via different mechanisms, such as inhibition effects of excess ammonium on nitrate reductase activity in bryophytes, or pH-mediated effects on epiphytic lichens.

We will discuss the case for estimating N risk by form, based on species composition, pH and climate at the site level.

ASSESSING THE GLOBAL ROLE OF NITROGEN

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Environmental science to date has specialised tightly with communities distinguishing between air pollution, climate change, biodiversity, water pollution and wider challenges such as food and energy security. The global nitrogen cycle provides a challenge to this traditional specialisation because of its multiple impacts on all of these issues. This presentation will summarise some of the key outcomes from the European Nitrogen Assessment and how these have provided a platform to prepare the Global Overview on Nutrient Management for UNEP entitled “Our Nutrient World”. These efforts at global and regional synthesis emphasise the need to quantify the inter-linkages between multiple threats and benefits of nitrogen and to establish the connections between process analysis, regional upscaling and evaluation of policy options including cost-benefit analysis. The outcomes of Our Nutrient World are now feeding into the development of a new process for nitrogen science-policy support with the Global Environment Facility and the United Nations Environment Programme. This process, towards the establishment of the International Nitrogen Management System (INMS) is currently in development and building stakeholder involvement towards the establishment of a first phase of the global programme. It is planned that this first phase will run 2015-2019, working to couple the developing global scale perspective, including indicator and integrated assessment model development, with key regional scale demonstration activities.

VALUING NITROGEN IMPACTS ON ECOSYSTEM SERVICES, CURRENT STATUS AND NEXT STEPS

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The UK Department of the Environment Food and Rural Affairs (Defra) has adopted the Ecosystems Services Approach as a risk assessment methodology to answer policy questions such as "What are the costs and benefits associated with controlling air pollution?" Key outputs from this work are to produce damage costs for individual air pollutants which can be used in wider policy appraisal. We outline recent developments in using the Ecosystems Services Approach to value impacts of atmospheric nitrogen deposition on ecosystem services & highlight the key knowledge gaps.

We quantified spatially for the UK the impact of nitrogen pollution on the cultural ecosystem service "Appreciation of biodiversity". Quantification was based on a marginal cost approach, using two scenario comparisons: 1) Historical scenario: Changing nitrogen deposition between 1987 and 2007 against continuation of 1987 pollutant levels as a reference; 2) Future scenario: Projected nitrogen deposition from 2007 to 2020 against continuation of 2007 pollutant levels as a reference. Difference in value of each service in each year was calculated, discounted at 3.5%, and Net Present Value (NPV) and Equivalent Annual Value (EAV) calculated over the scenario periods. Valuation utilised market/shadow prices and value transfer of non-market/contingent valuation methods, as appropriate. Monte Carlo simulation was used to quantify the uncertainty in the estimates of damage costs, presented as 95% Confidence Intervals.

Nitrogen impacts on 'Appreciation of Biodiversity' were calculated for four habitats: acid grassland, dune grassland, bogs and heathland. Valuation used value-transfer of stated preference (Willingness To Pay) values for increasing, or avoiding decline of, populations of non-charismatic species (plants, insects, amphibians, etc.). We calculated damage costs per tonne of ammonia and NO_2 emitted, for use in policy appraisal by Defra.

We also summarise findings from a gap analysis for modelling N impacts on other services, which highlights that despite significant recent developments in the methodology, there remain considerable knowledge gaps. These include: insufficient synthesis of existing scientific evidence of impacts on natural systems; some gaps in underpinning scientific research; major gaps in valuation evidence. Missing information in one or more of these aspects currently restricts both quantification and valuation for many impacts on ecosystem services.

TWENTY FIVE YEARS OF THE RUABON NITROGEN EXPERIMENT

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The Nitrogen addition experiment on heather moorland at Ruabon started in May 1989 and is still maintained with monthly treatments of ammonium nitrate solution, making it one of the longest regularly managed experiments of its type anywhere. It started as a project run by Prof John Lee within the NERC Special topic on air pollution towards the end of peak period of concern over Acid Rain, but before research on CO_2 and climate change had really got going in the UK. By this stage John Lee, amongst others, had raised worries over the potential impact of nitrogen deposition on semi-natural ecological communities. The experimental site that we selected in North Wales was seen as a cleaner air contrast to the pollution (sulphur, nitrogen, metals) ravaged moorland areas downwind of the Manchester conurbation in the South Pennines. Research at the Ruabon site became a key part of several PhDs and post-doctoral projects and has provided underpinning knowledge for the development of Critical loads guidelines for upland heath and other heathland habitats. The research has given us improved knowledge of at least the following: dynamic of nitrogen cycling & nutrient leaching; effects of managed burn on nitrogen leaching; nitrogen saturation; base cation leaching; effects on stress sensitivity; vulnerability of bryophytes and lichens; responses to lowered nitrogen loading; interactions with phosphorus limitation; the carbon cycle and control on DOC loss; invertebrate communities and of course the benefits of long term experiments over short ones! Results from this experiment, and the related landscape scale moorland surveys that grew out of it, have played a very important part in guiding Government (UK and UNECE) policies on regulation of nitrogen emissions which remains a continuing concern.

AMMONIUM AS A DRIVING FORCE OF PLANT DIVERSITY AND ECOSYSTEM FUNCTIONING: OBSREVATIONS BASED ON 5 YEARS' MANIPULATION OF N DOSE AND FORM IN A MEDITERRANEAN ECOSYSTEM

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Enhanced nitrogen (N) availability is one of the main drivers of biodiversity loss and degradation of ecosystem functions. However, in very nutrient-poor ecosystems, enhanced N input can, in the short-term, promote diversity. Mediterranean Basin ecosystems are nutrient-limited biodiversity hotspots, but no information is available on their medium- or long-term responses to enhanced N input. Since 2007, we have been manipulating the form and dose of available N in a Mediterranean Basin maquis in south-western Europe that has low ambient N deposition (<4 kg N ha^{-1} yr^{-1}) and low soil N content (0.1%). N availability was modified by the addition of 40 kg N ha^{-1} yr^{-1} as a 1:1 NH_4Cl to $(NH_4)_2SO_4$ mixture, and 40 and 80 kg N ha^{-1} yr^{-1} as NH_4NO_3. Over the following 5 years, the impacts on plant composition and diversity (richness and evenness) and some ecosystem characteristics (soil extractable N and organic matter, aboveground biomass and % of bare soil) were assessed. Plant species richness increased with enhanced N input and was more related to ammonium than to nitrate. Exposure to 40 kg NH_4^+-N ha^{-1} yr^{-1} (alone and with nitrate) enhanced plant richness, but did not increase aboveground biomass; soil extractable N even increased under 80 kg NH_4NO_3-N ha^{-1} yr^{-1} and the % of bare soil increased under 40 kg NH_4^+-N ha^{-1} yr^{-1}. The treatment containing less ammonium, 40 kg NH_4NO_3-N ha^{-1} yr^{-1}, did not enhance plant diversity but promoted aboveground biomass and reduced the % of bare soil. Data suggest that enhanced NH_y availability affects the structure of the maquis, which may promote soil erosion and N leakage, whereas enhanced NO_x availability leads to biomass accumulation which may increase the fire risk. These observations are relevant for land use management in biodiverse and fragmented ecosystems such as the maquis, especially in conservation areas.

BIOLOGICAL N_2-FIXATION IN SCOTTISH PEATS: THE P^2 PATTERN - CAN PHOSPHORUS AND POTASSIUM ALLEVIATE CHRONIC N LOADING WHEN ASSESSING SENSITIVE ECOSYSTEM FUNCTION?

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Recently, rates of biological N_2-fixation have been shown to be historically underestimated in peatland ecosystems globally due to methodological constraints (Vile *et al.* 2014), affording us the opportunity to reevaluate this process in a variety of peatlands. In Scotland, background nitrogen (N) deposition at Whim Bog is approximately 8 $kg{\cdot}N{\cdot}ha^{-1}{\cdot}yr^{-1}$, and the experimental N additions at Whim Bog provide up to 64 $kg{\cdot}N{\cdot}ha^{-1}{\cdot}yr^{-1}$ (which takes into account background N deposition). In boreal western Canada, where exceptionally low atmospheric N deposition anchors the global extreme (<1 $kg{\cdot}N{\cdot}ha^{-1}{\cdot}yr^{-1}$), we have shown some of the highest rates of biological N_2-fixation in northern Alberta to rank among the highest rates found globally (20-45 $kg{\cdot}N{\cdot}ha^{-1}{\cdot}yr^{-1}$; Vile *et al.* 2014). Biogeochemical theory predicts that biological N_2-fixation should represent the dominant N-input to pristine ecosystems, which we have documented for ombrotrophic bogs of boreal Alberta, Canada. Given high inputs of N through simulated N-deposition at Whim Bog for the past 11 years, biogeochemical theory would predict the down regulation of N_2-fixation in the high N-deposition plots, yet we observe the opposite pattern. We measured rates of N_2-fixation in diazotrophs associated with two species of moss, *Sphagnum capillifolium* and *Pleurozium schreberi* using $^{15}N_2$. Rates of N_2-fixation associated with *S. capillifolium* were either zero or exceptionally low in the 8 kg·N and 16 kg·N treatment plots (< 1 $nmol{\cdot}gdm^{-1}{\cdot}da^{-1}$), yet 3-30x higher rates of N_2-fixation (3.0-28.6 $nmol{\cdot}gdm^{-1}{\cdot}da^{-1}$) in the highest N treatment plots (*i.e.*, 64 kg·N), but only when phosphorus (P) and potassium (K) were also applied. A similar pattern was observed for *P. schreberi*. Interestingly, rates of N_2-fixation outside the plots at Whim and at two additional sites (Isle of Skye and Meall Dubh) exhibit rates on par with those observed in western Canada (282-1086 $nmol{\cdot}gdm^{-1}{\cdot}da^{-1}$), representing 4.0-21.2 $kg{\cdot}N{\cdot}ha^{-1}{\cdot}yr^{-1}$, respectively, suggesting that biological N_2-fixation represents an important source of new N to Scottish peatlands located in lower N deposition regions. Further, sustained fixation in the high N plots when both P and K are added suggest that either P or K or both can moderate chronic N loading for some of the more N-sensitive processes in peatland ecosystem, such as N_2-fixation.

Vile, M.A. *et al.* N_2-fixation by methane oxidizing bacteria sustains high rates of carbon and nitrogen sequestration in pristine boreal peatlands, *in review* (2014).

PHYSIOLOGICAL RESPONSE OF *SPHAGNUM CAPILLIFOLIUM* AND ITS N_2-FIXING COMMUNITY TO LONG- TERM ADDITION OF REDUCED AND OXIDISED NITROGEN

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Bog vascular vegetation responds slowly to increments of atmospheric nitrogen (N) inputs, as the living *Sphagnum* layer filters N by retaining and storing substantial amounts of N in its biomass and in the peat formed. Under pristine conditions, *Sphagnums* complex mutualism with dinitrogen fixing microbes, present on the surface and in the hyaline cells of the mosses, provide the most important source of N. In the Whim Bog experiment in Scotland, high loads (of 32 and 64 kg $ha^{-1}y^{-1}$) of both reduced (NH_3 and NH_4^+) and oxidised (NO_3) nitrogen in deposition were found to cause direct physiological changes in *Sphagnum capillifolium*: excess nitrogen was stored in N-rich amino acids in cells. The accumulation of these amino acids therefore acts as a strong bio-indicator of stress in *Sphagnum* mosses caused by increased N availability. Interestingly, increased N deposition did not reduce N_2 fixation rates compared to control treatments with background levels of 8 kg ha^{-1} y^{-1}, as was expected. This indicates that the microbial diazotrophic community does not compensate for the increased N inputs by lowering its activity.

PHYSIOLOGICAL RESPONSE OF LICHENS TO LONG-TERM AND SHORT-TERM NITROGEN TREATMENTS UNDER CONTROLLED CONDITIONS

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Lichens are among the most sensitive organisms to nitrogen (N) pollution at the ecosystem level. They respond differently depending on their functional traits, N form and dose, and exposure time. Several authors have considered N tolerance in lichens, however many questions on the topic are still unsolved

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The Whim Bog manipulation site with wet and dry deposition to ombrotrophic bog vegetation allows long- and short-term experiments on *in situ* and transplanted lichens in a controlled environment.

1) Long-term treated samples of *C. portentosa* exposed to wet deposition were collected and their physiological parameters (pH, gas exchange, photosynthetic parameters, vitality index) as well as algal ultrastructural characteristics were analyzed. The role of potassium (K) and phosphorous (P) in alleviating N toxicity symptoms was considered.
Algal cells showed changes in ultrastructure in response to all treatments. Samples receiving P and K showed increased activities of the algal partner. Thallus pH was shown to be influenced by different forms and concentrations of N.

2) Thalli of an N-sensitive lichen (*Evernia prunastri*) and an N-tolerant one (*Xanthoria parietina*) were collected from clear areas and transplanted along the NH_3 transect. Their physiological response (Fv/Fm) to short-term NH_3 exposure was compared with their frequency of occurrence along an NH_3 field gradient.

Both frequency and Fv/Fm of *E. prunastri* decreased abruptly above 3 mg m^{-3} NH_3, suggesting direct adverse effects of NH_3 on its photosynthetic performance. In contrast, the frequency of *X. parietina* increased with NH_3, despite the decreased capacity of its photosystem II above 50 mg m^{-3} NH_3, suggesting that the ecological success of *X. parietina* at ammonia-rich sites might be related to indirect effects of increased N (NH_3) availability.
These results link physiological and morphological effects to the ecological consequences of excess N, allowing more integrated responses to pollution, and offering important clues for future research.

OZONE POLLUTION AND WHEAT: QUANTIFYING FUTURE IMPACTS AND SCOPE FOR INCREASING TOLERANCE

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Globally, wheat provides 20% of human calorie intake and is the most important protein source. It is especially important in emerging and developing countries, with India and China producing approximately twice as much wheat grain as the USA and Russia combined. Wheat is also one of the most ozone –sensitive crops, and the main wheat-growing areas of the world frequently coincide with areas with the highest ozone concentrations and/or fluxes. As part of the activities of the ICP Vegetation[3], we have quantified spatially the effects of ozone on wheat production for a current year (2005) and for 2020 and 2030 assuming full compliance with the recently revised Gothenburg Protocol of the LRTAP Convention[4]. Predictions of percentage wheat yield loss using the ozone flux method developed by the ICP Vegetation for integrated assessment modelling, indicate only a modest improvement from a mean 12.4% to 10.3% losses for EU27+CH+NO between 2005 and 2020. Our new analysis also shows that the potential for ozone effects on wheat yield spreads eastwards beyond the EU boundary, with substantial losses predicted for the Ukraine, Belarus and Eastern Russia[5]. Other studies summarised in Harmens and Mills, 2014[5], have shown that ozone may be currently causing as much as 15% wheat yield loss in China and 22% yield loss in India. Whilst ideally, these impacts could be substantially reduced if there are globally agreed far reaching reductions in precursor emissions, in reality it is likely that ozone effects on yield are here to stay for the foreseeable future. There is thus a growing need to develop ways of mitigating impacts of ozone on wheat yield, either by crop management or by developing ozone tolerant varieties. In the second half of this presentation, we explore how knowledge of the physiological mechanisms of ozone damage can help in achieving these long-term goals.

Our work highlights an impact of ozone on stomatal regulation of gas exchange, including an apparent loss of the stomatal drought response that is of particular concern for wheat production. We have argued that this loss of function resulting in potentially unregulated water loss from leaves may be particularly damaging when plants are growing under hot and dry conditions. Our analysis suggests that O_3 exposure can promote ethylene accumulation in shoots and that this ethylene can interfere with the stomatal response to abscisic acid (ABA), a plant growth regulator produced in increasing amounts in droughted plants. ABA is usually a potent regulator of stomatal behaviour. We show that stomatal behaviour of ozonated plants can be interpreted as a function of variation in Ethylene:ABA ratios. Further analysis shows that effects of other environmental stresses may also be mediated through a combined effect of these two hormones and we hypothesise that these effects may impact on physiological and developmental effects other than stomatal behaviour. We have identified genetic variation in stomatal responses to the ethylene:ABA ratio and are investigating whether this variation may be linked to genotypic variation in ozone tolerance. We speculate on the potential for developing ozone tolerant varieties of wheat and describe current wheat breeding efforts at CYMMIT to improve yield.

We wish to thank Defra, the UNECE and the LRTAP Convention for continued financial support of the ICP Vegetation

[3] International Cooperative programme on Effects of Air Pollutants on Crops and (Semi-)natural vegetation. See www.icpvegetation.ceh.ac.uk

[4] Convention on Long-Range Transboundary Air Pollution

[5]Harmens, H. and Mills, G. (Eds.) (2014). Air Pollution: Deposition to and impacts on vegetation in (South-)East Europe, Caucasus, Central Asia (EECCA/SEE) and South-East Asia.

OZONE AND FOOD SECURITY: A REVIEW OF OZONE-INDUCED YIELD REDUCTION IN SOYBEAN CULTIVARS

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Securing a stable and sufficient supply of food to the 9 billion people predicted to inhabit the earth by 2050 is a key research priority for the 21st century. The global ground-level concentration of the air pollutant ozone (O_3) is currently increasing, driven by rising anthropogenic precursor emissions associated with urban and industrial growth. Ozone is a known phytotoxin, and has been repeatedly shown to cause oxidative damage and photosynthetic suppression in a number of important crop species, resulting in substantial yield losses. Soybean (*Glycine max* (L.) Merr.) is one of the most ozone-sensitive crops, with global annual yield losses of up to 19% predicted for 2030. Losses of this magnitude would significantly impact food security, particularly in countries such as India where soybean represents a major source of dietary protein for much of the population.

As part of my PhD project investigating the response of soybean to ozone, I have developed a database of exposure and yield response data from the published literature. Analysis of the data has revealed a number of interesting results:

- There is high variation in ozone sensitivity between different soybean cultivars in the database, raising the possibility of intelligent cultivar selection or breeding to reduce future ozone impact on yield
- Sensitivity of soybean cultivars to ozone has increased over time, with more recently released cultivars showing greater yield reductions for a given ozone concentration than older cultivars
- Exposure-response data collected in India exhibits higher ozone sensitivity than that collected in the USA, suggesting that risk assessments based on “western” data may be underestimating potential yield losses in South Asia.

This summer, I will be conducting exposure-response experiments at the CEH Bangor solardome facility, in order to i) develop understanding of soybean cultivar differences in sensitivity, ii) investigate possible interactive effects between drought and ozone on soybean yield, and iii) generate data for development of a DO_3SE stomatal deposition-effect model for soybean.

EFFECTS OF OZONE ON PLANT PARASITE-HOST INTERACTIONS:

***Striga hermonthica* (Purple Witchweed) and *Oryza sativa* (Rice)**

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Two threats to global food security meet head-on: Tropospheric ozone pollution is already reducing crop yields worldwide, which are predicted to diminish further as a result of increasing emissions of ozone precursors in many parts of the world. This problem may be compounded by damage caused by *Striga*, a genus of parasitic plants native to the African and Asian semi-arid tropics, which can have a devastating effect on crops such as maize, rice, millet and legumes, including total crop failure.

Here we present a pilot study demonstrating how elevated ozone concentrations can affect the growth and physiology of rice, certainly the most widely consumed staple food for a large part of the human population, in the absence or presence of Purple Witchweed, probably the most noxious of the *Striga* genus.

IMPACTS OF OZONE ON GRASSLAND SOIL BACTERIAL DIVERSITY AND FUNCTION

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Backgrounds and aims

Tropospheric ozone (O_3) reduces plant productivity and can alter species composition in semi-natural ecosystems. O_3 has the potential to alter carbon flux to soil through changes in rhizodeposition (including exudation and root and hyphal turnover), and changes in leaf litter quality or quantity; yet little is known about the potential impact on soil microbial communities and the below-ground processes they govern. This study aimed to characterize the bacterial community composition and function of three grassland soils following nine years' O_3 exposure in open top chambers.

Methods

We analysed three soils from long-established *Anthoxanthum odoratum–Geranium sylvaticum* (MG3b) grassland mesocosms which had received either Charcoal Filtered Air (CFA)+30 ppb O_3, or CFA+50 ppb O_3 for nine consecutive years in open top chambers. Soil bacterial diversity was investigated using Denaturing Gradient Gel Electrophoresis (DGGE) and 454 pyrosequencing. Soil function was assessed using MicroResp™; a method which utilizes sole carbon sources and substrate-induced respiration to obtain a metabolic fingerprint of the soil samples.

Results

The soil bacterial communities did not differ significantly in either their diversity or function between O_3 treatments. The main source of variation between samples was due to soil carbon and nitrogen content, and pH. Therefore the most influential factors which determine soil microbial diversity and function in this system include soil physiochemical properties and management practice, with O_3 pollution effects on C flux to soil likely to be subtle in comparison.

ASSESSMENT OF OZONE IMPACT ON VEGETATION AT THE UK EMEP SUPERSITES USING A CHEMICAL CLIMATOLOGY FRAMEWORK

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In 1872 Scottish chemist Robert Angus Smith sought to establish a brand new field of scientific study which he named ‘chemical climatology’. Angus Smith’s application was to assess the human health impact of ‘man-made climates’ in Victorian towns. Since then, usage of chemical climatology has been sporadic. Nowadays there are a large number of atmospheric composition datasets (from campaigns, long-term monitoring and modelling), as well as atmospheric composition metrics. An updated chemical climatology framework based on Angus Smith’s principles is a potentially powerful resource to assess these impacts. Malley et al. (2014) developed such a framework, constructed through consideration of Angus Smith’s approach and analogy with the use of the term climate in other areas. The framework first identifies an *impact* of atmospheric composition, which is then linked, through the *state* of atmospheric composition variation, to its causal *drivers.*

This paper presents the first application of the chemical climatology framework to ozone impacts on vegetation, using data from the two UK European Monitoring and Evaluation Programme (EMEP) monitoring ‘supersites’, Auchencorth Moss in south east Scotland and Harwell in south central England. The two chemical climates, one for each supersite, detail the state of O_3 variation contributing to a negative vegetation impact, assessed using the AOT40 metric for a May-July growing season. Relevant drivers such as temperature, air mass history, and the relative influence of hemispheric, regional and local processes are evaluated. AOT40 values suggest a generally lower vegetation impact at Auchencorth and less modification of hemispheric background ozone concentrations; however combinations of drivers, particularly an elevated contribution from easterly air masses, can result in anomalously high O_3 vegetation impacts in excess of those at Harwell. At Harwell, AOT40 values decrease substantially between 1990 and 2011, along with an increase in the relative contribution of May and June, and a decrease in that of July. Decreases in the diurnal variation of O_3 and NO_x indicate the driver of these changes to be regional emissions reductions.

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GROUND-LEVEL OZONE-INDUCED CHANGES IN POLLEN QUALITY

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Aim: To investigate impacts of environmentally-relevant levels of ozone on the amino acid composition of pollen

Pollen is essential for successful genetic outcrossing, providing the gamete protection from environmental stress until fertilisation. Pollen is not only crucial to plant fitness, but also to the fitness and nutrition of that of its consumers, particularly bees. Many species of bees, both eusocial and solitary, rely solely on pollen as a protein source for larval development, and essentially, colony survival. The outer coating on pollen also acts as an attractant.

To investigate how ozone pollution may influence the amino acid (protein) content and quality of pollen, we grew dwarf broad beans (*Vicia faba* L.) in four fumigation treatments; clean air (CFA), ozone (O_3) at 110 ppb, and two reciprocal transfer treatments at flowering.

Pollen was collected from mature flowers. Free amino acids were washed from the surface, then proteins were hydrolysed and amino acids from both extracts were quantified by HPLC analysis.

Ozone exposure resulted in a highly significant reduction in total free amino acids on the surface of pollen in all treatments and also changed the profile of free amino acids. Ozone had less impact on protein-bound amino acids. One of the most affected amino acid components was proline which is known to be highly influential on bee nutrition.

The potential far-reaching implications of the observed impacts of ozone on pollen quality in terms of bee behaviour and nutrition will be discussed.

NEW ICP VEGETATION SMART-PHONE APP FOR RECORDING INCIDENCES OF OZONE INJURY ON VEGETATION

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In 2007, the ICP Vegetation published a synthesis report documenting over 500 incidences of ozone injury on crops, grassland species and shrubs growing in the field under ambient air conditions in 17 countries of Europe (Hayes et al., 2007). We plan to revisit this study by compiling new spatial data on current incidences of ozone injury. Using smart-phone technology for i-phones and android phones, and web-based recording methodology, we have developed a new way of recording incidences of ozone injury in the field. The new App will allow participants to upload photographs of ozone injury direct from the field together with the coordinates for the location where the injury was detected. Participants will be taken through a series of questions designed to assist with quality assurance, including being asked if they have previous experience of identifying ozone damage or plant diseases and recent weather conditions. This smart-phone App will enable the collection of widespread information on ozone damage to vegetation across Europe and potentially, the rest of the world. The App will be launched in April 2014 for use by ozone experts (allowing us to test the process of data collection and develop a database for analysis) and will be fully accessible in 2015.

Information on how to download the App together with a web-based recording facility will be available on the ICP Vegetation website:

http://icpvegetation.ceh.ac.uk

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THE EFFECTS OF OZONE ON PASTURE MESOCOSMS

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Clovers (*Trifolium* spp.), are an important component of temperate pasture, providing a source of fixed nitrogen (N) to soil and improving forage quality and productivity. Although known to be highly sensitive to ozone pollution, surprisingly little is known about the effects of ozone on the modern cultivars of clover sewn by farmers for use in grazed pasture. In 2013, we exposed a white clover cultivar (*T. repens* cv. Crusader), in mixture with a current cultivar of high-sugar ryegrass (*L. perenne* cv. AberMagic), to current and near-future ozone scenarios for a period of 16 weeks. We investigated effects on N-fixation, and associated physiology and growth throughout the growing season, including observations of increased tolerance to ozone. The results are discussed in relation to potential mechanisms and impacts on agricultural sustainability.

IMPACTS OF OZONE AND NITROGEN ON SILVER BIRCH

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Birch trees (*Betula pendula*) were exposed to factorial combinations of seven ozone and four nitrogen regimes for five months in solardomes at CEH Bangor in 2012 and 2013. The ozone regime was designed to investigate the benefits of changes in air quality policy that are anticipated to reduce both background and peak ozone concentrations, but with a larger reduction for the peaks. The range of ozone exposure seasonal means was 35 ppb to 70 ppb (24h mean) and the nitrogen treatments were applied weekly as ammonium nitrate to give treatments equating to 10, 30, 50 and 70 kg ha^{-1} yr^{-1}. Measurements were made at both the leaf level and at whole-tree level to investigate whether: nitrogen modifies the response to ozone; nitrogen and/or ozone treatment alter the DO_3SE parameterisations for birch; fluxes of ozone and carbon become uncoupled; whole-tree alterations in fluxes are a consequence of individual leaf physiological responses or via alterations in tree biomass.

The study found that:

- Ozone pollution decreased growth and therefore carbon sequestration of birch trees;
- Nitrogen treatment affected stomatal fluxes of birch and therefore nitrogen deposition should be accounted for when calculating ozone fluxes to inform assessments of vegetation at risk of ozone pollution;
- The cumulative effects of ozone and nitrogen pollution on trees require further study over several years as leaf-level measurements indicated that effects and interactions may occur over longer timescales.

Acknowledgement

This work was funded by the EU ECLAIRE project (FP 7, grant agreement no. 282910) and the Natural Environment Research Council, UK.

HOPPERS, SWIMMERS AND FLYERS – THE IMPORTANCE OF MULTI-MEDIA PARTITIONING ON THE LONG-RANGE TRANSPORT PERSISTENT ORGANIC POLLUTANTS (POPS)

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The fate and behaviour of persistent organic pollutants (POPs) in the environment has attracted considerable scientific and political interest, arising from concern over human exposure to these chemicals and their discovery in pristine environments far from source regions. The ability of certain POPs to undergo long range atmospheric and oceanic transport has resulted in the negotiation of international protocols (e.g. UN/ECE, UNEP) for their reduction or elimination, to reduce the risks to regional and global environments. The development of such protocols recognizes the regional and global nature of many POP compounds. Researchers, including Lancaster University, have developed a number of multi-media modelling tools that can be used to investigate the potential transport pathways and environmental impact of existing and candidate POPs. These models have been used to investigate the sources and environmental fate and behaviour of a range of substances currently being discussed under the UNEP Stockholm Convention. These modelling approaches provide a mechanistic understanding of the processes that affect environmental concentrations, and hence exposure to humans and wildlife.

MODELLING TROPOSPHERIC OZONE CHANGES, 1850 to 2100

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Changes in climate and anthropogenic and biogenic emissions have changed ozone concentrations in the past and will change them in the future, with implications for air quality, ecosystem impacts and radiative forcing. I will draw on results from global climate model experiments conducted in support of the recent IPCC report that quantify these changes, showing our estimates of the ozone increases between the pre-industrial period and the present day, and then the changes projected out to the end of the current century. The sign of the change is generally robust between the models (see Fig 1), but there are important differences in the magnitude, particularly on regional and seasonal time scales. I will also briefly discuss other results from the ACCMIP project, including the atmospheric oxidizing capacity and nitrogen deposition.

Finally, I will present a take on the current development of global Earth System Models, and the possibility of improving our understanding of atmospheric composition changes and variability with a newly started international project: the Chemistry-Climate Model Initiative (CCMI; http://www.met.reading.ac.uk/ccmi).

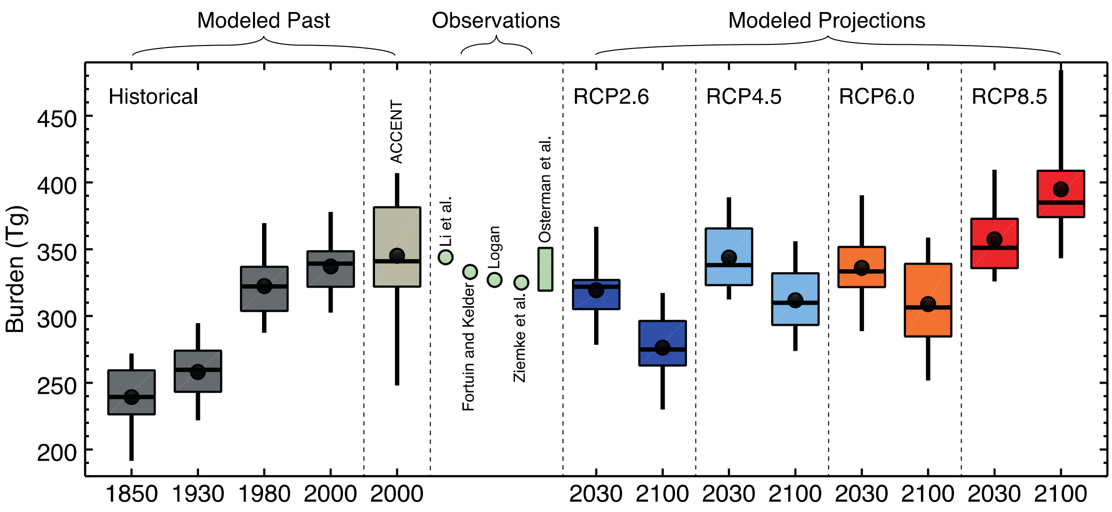

Figure 1. The annual mean global tropospheric ozone burden from 1850 to 2100 as modelled in the ACCMIP experiment (see http://www.giss.nasa.gov/projects/accmip/), with additional observational estimates and compared to an earlier model experiment (ACCENT). Future estimates cover the 4 main Representative Concentration Pathways (RCPs) developed for the recent IPCC report, which are named according to their radiative forcing at 2100 compared to 1750 (2.6 Wm^{-2}, 4.5 Wm^{-2} etc.). For ozone precursors, the RCPs generally project a decrease in their emission. The exception is RCP8.5, where methane concentrations nearly double over the 21st century. Figure is similar to Fig. 8.4 in chapter 8 of the IPCC Fifth Assessment Report, Working Group 1.

LOCAL INFLUENCES ON SPATIAL, TEMPORAL AND LONG-TERM TRENDS IN AMMONIA IN THE UK

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The UK National Ammonia Monitoring Network (NAMN > 70 sites) has been operating since 1996. Substantial spatial heterogeneity in NH_3 concentrations is observed across the network which correlates with NH_3 emission sources, with smallest concentrations at remote sites (< 0.2 µg m^{-3}) and largest in intensive agricultural areas (up to 26 µg m^{-3}). Temporally, NH_3 concentrations are also influenced by local sources. Peaks in NH_3 concentrations are observed in summer at background sites, driven by higher temperatures. In sheep dominated areas, there is a similarly strong seasonal cycle with largest concentrations in summer which may be attributed to the increased potential for grazing emissions in warm summer conditions. A more complex seasonal pattern is seen in cattle, pig and poultry dominated areas where the largest NH_3 concentrations are in spring and autumn, coinciding with usual periods of manure application in the UK.

UK emissions declined by about 10% during the operation of NAMN. Long-term trends in the measurement data show no significant trend in the whole data set, but there are small trends in areas of the country in which specific sources dominate. In pig and poultry dominated areas, there is a slight (non-significant) reduction in NH_3 concentrations, consistent with, but not as large as, the estimated reduction in NH_3 emissions from these sectors. In cattle dominated areas, there is a slight (non-significant) increase in NH_3 concentrations, although estimated NH_3 emissions from this sector show a very small decrease since 1996. At background sites (defined by 5 km grid average emissions <1 kg N ha^{-1} yr^{-1}), NH_3 concentrations are approximately constant with indications of an increase which to date is non-statistically significant. These changes are consistent with a change in the aerosol from $(NH_4)_2SO_4$ to NH_4NO_3, the latter being volatile and releasing NH_3 in warm weather.

CO-BENEFITS OF TACKLING POOR AIR QUALITY AND REGIONAL CLIMATE: A FOCUS ON ECOSYSTEMS

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A substantial body of experimental evidence exists describing the impacts of ozone (O_3) and aerosols on important ecosystems (agro-, forest and grassland ecosystems). Much of this empirical data has been collected from co-ordinated studies conducted in North America and Europe; and more recently in Asia. Pooling these data allows the development of risk assessment methodologies which can be used to assess the benefits of emission reductions over regional to global scales. This talk describes these risk assessment methodologies focussing both on their strengths (in relation to providing estimates of a variety of ecosystem damage) as well as weaknesses and limitations (primarily associated with limited data availability for key global regions such as Asia, Africa and Latin America).

Within this context results are presented that describe benefits of emission reductions of O_3 and aerosol forming species for crop yields, forest productivity and grassland biodiversity along with benefits for near-term climate. Examples of indirect benefits are also given by showing the importance of ecosystems acting as sinks for atmospheric pollution; alterations to this sink under extreme climates (e.g. heat wave type conditions) are exemplified through their influence on net atmospheric pollution concentrations and subsequent human health impacts.

Finally, the importance of considering ecosystem damage and feedbacks to the climate system within a new generation of Earth System Models, currently being developed to understand the implications of climate change, is advocated based on the evidence presented.

POSTERS

EFFECTS OF NITROGEN ENRICHMENT ON LICHEN PHOSPHATASE ACTIVITY

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Most lichens occupy habitats deficient in N and P and have high uptake capacities for inorganic forms of these elements. Previous research has shown that lichens have surface-bound phosphatase activities that promote the release of covalently bonded P from organic compounds. N enrichment due to mad-made pollution alters thallus N:P ratio driving an up-regulation of phosphomonoesterase (PME) activity. It also causes changes in lichen community structure whereby species adapted to oligotrophic conditions (nitrophobes) are replaced by a small number of species that are tolerant to high nitrogen availability (nitrophytes). Currently, there is a dearth of information on the physiological basis of adaptation to high nutrient load. Here we examine differences in phosphatase activity among both nitrophobic and nitrophytic lichens. PME activity was measured using the *p*-nitrophenyl phosphate colorimetric assay and the location of activity in the lichen thallus was investigated using an enzyme-labelled fluorescent phosphatase substrate (ELF 97). Phytase, a specific phosphatase that hydrolyses phosphate bonds in inositol phosphates, was also measured in *Evernia prunastri* using high performance ion chromatography and the responsiveness of this enzyme to N deposition was examined. We show that nitrogen tolerant lichens have lower absolute rates of PME activity than nitrogen sensitive species and that this is corroborated by enzyme activity visualized using ELF 97. We suggest that reduced efficiency of nutrient scavenging mechanisms might be an advantageous trait in lichens growing in eutrophicated habitats. PME activity is located predominantly in the fungal tissue of the cortices consistent with a function in phosphorus scavenging from atmospheric deposits. Phytase activity was readily measurable in *E. prunastri* which showed a clear response to N deposition.

GUIDE TO USING A LICHEN-BASED INDEX TO ASSESS NITROGEN AIR QUALITY

http://www.apis.ac.uk/nitrogen-lichen-field-manual

Wolseley, P.A.[1]; Leith, I.D. [2]; Sheppard, L.J.; Lewis, J.E.J. [3]; Crittenden, P.D. [3]; Bealey, W.J. [2]; and M.A. Sutton[2]

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Epiphytic lichens growing throughout Europe have been shown to be good indicators of nitrogen air quality (Davies et al 2007, Wolseley et al. 2006, 2010, Seed at al. 2013). Lewis (2012) identified two functional groups: lichens that are sensitive (N-sensitive) to increasing concentrations of atmospheric N and those that are tolerant (N-tolerant). Indicator lichens were selected from leafy, bushy and crustose lichen taxa growing on trunks and branches of oak and birch trees (Figure 1) across Britain at sites where concentrations of atmospheric nitrogen were routinely measured. Commonly occurring lichen species were recorded and evaluated for their response to different forms of atmospheric nitrogen. On the basis of such characteristics the list of potential indicator lichens was reduced down to eight N tolerant and nine N sensitive indicators. Using these indicator lichens species data an 8-page fold-out 'Guide to using a lichen based index to nitrogen air quality' was produced in collaboration with the Field Studies Council.

The Guide provides a simple and robust step by step method to determine levels of risk to a habitat from gaseous N pollution by calculating a nitrogen air quality index (NAQI).

A lichen indicator score (LIS) is calculated using the presence or absence of N-sensitive and N-tolerant lichen species on either trunks or branches of oak or birch at any given location. Using the LIS score an indication of air quality at a given site can be determined from the graph provided in the lichen guide.

Mobile Phone App

The Lichen-based index guide will be developed into a mobile phone app by CEH in 2014.

HIGH RESOLUTION MEASUREMENTS OF AMMONIA AT WHIM BOG EXPERIMENTAL SITE

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High resolution, 15 minute average, ammonia concentrations were measured at Whim Bog using a wet-chemistry instrument (Airrmonia, Mechatronics, NL) deployed in 2010 and in 2012 on the ammonia dry deposition manipulation part of the Whim Bog experiment, S. Scotland. The aims of the experiments were to understand the variability in ammonia concentrations, comparison against the monthly average concentrations as measured by ALPHA samplers and model the dispersion from the line source. In 2010 one instrument was deployed at 32 m downwind of the ammonia line source on the central boardwalk and in 2012 two instruments were deployed, one upwind of the line source and the other at 32 m downwind as in 2010. Deployment in 2010 covered just approximately 1 month and showed a good agreement with the monthly average ammonia concentration. In 2012 the deployment was over close to 3 months and a more detailed study of the variability of the ammonia has been undertaken. Statistics of both deployments will be summarised and discussed in the context of the ammonia manipulation experiment.

A GLOBAL MODEL OF THE NITROGEN CYCLE

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The various forms of reactive nitrogen (NO, NO_2, N_2O, NH_3, etc.) have far-reaching effects, causing eutrophication, climate change, degradation of the ozone layer, and human health effects from aerosols. Different nitrogen compounds behave in a variety of ways in different parts of the Earth system (e.g., approximate atmospheric lifetimes of NH_3 and N_2O are a few hours and one century, respectively). Careful consideration of a wide range of physical, chemical and biological processes that control reservoir sizes and the magnitudes of fluxes between reservoirs is needed to build a comprehensive understanding of how nitrogen moves through the environment. We will present our work toward developing a global model of the nitrogen cycle.