PROGRAMME AND ABSTRACTS CAPER: 4 – 6 APRIL 2016, BANGOR.

MANAGEMENT CENTRE, BANGOR UNIVERSITY, ROOM D0:08

Monday 4th April.

12.30: Registration and lunch

13.30: Excursion to ozone solardomes and field release system, followed by Conwy catchment

17.30: Return to Management Centre

19.00: Dinner

Tuesday 5th April.

09.00: Welcome by local hosts Gina Mills and Harry Harmens, and by CAPER Chair Nancy Dise

09.15: Keynote presentation by Jon Storkey (Rothamstad Research) - Recovery of the Park Grass experiment from long-term nitrogen addition

10.00: Ulli Dragotis - Historic trends in N and S deposition in the UK - 1800 to present

10.20: Discussion

10.30 – 11.00: Coffee/tea

Theme: Air pollution impacts on vegetation and biodiversity

11.00: Katrina Sharps (CEH) – Field-based evidence of ozone impacts on vegetation: an update

11.20: Harry Harmens (CEH) - Impacts of ozone on biodiversity: mapping habitats at risk

11.40: Yunhai Zhang (Lancaster University) - Quantifying the magnitude of species richness and turnover on ecosystem productivity by the rate of N inputs

12.00: Ed Rowe (CEH) - What use are predictions of biodiversity responses to air pollution?

12.20: Discussion

12.30 – 13.30: Lunch

Theme: Policy (1)

13.30: Jane Hall (CEH) – Long-term trends in exceedance of critical loads for UK designated sites

13.50: Chris Field (Manchester Metropolitan University) - An application of dynamic modelling to produce site-specific critical loads

14.10: Nancy Dise (CEH) – Policy recommendations from the PEATBOG project

14.30: Rob Kinnersley (Environment Agency) - Impact of recent findings on development of regulations

14.50: Discussion.

15.00 – 15.30: Coffee/tea

Theme: Policy (2)

15.30: Susan Zappala (Natural England) - Translating policy into action for Air Quality: A Natural England Perspective

15.50 Simon Bareham (Natural Resources Wales) – Developing a Natural Resources Management approach to air quality in Wales to protect sensitive habitats

16.10 General policy discussion

16.40: **Short presentations (3 min + 3 min discussion)**:

Jessica Bays (Ecological Continuity Trust) - The Ecological Continuity Trust

Simon Peacock (Newcastle University) – N Emissions from Cockle Park Farm at Palace Leas Experimental Grassland Plots

Catharine Pschenyckyj (University of Reading, CEH) – Attributing biological controls on recent changes in carbon cycling in organic soils

Sam Tomlinson (CEH) – Historic sulphur deposition: long-term trends

Ed Carnell (CEH) – Cumulative N deposition in the UK - a historic perspective

Gina Mills (CEH) - Preparations for the ozone critical level workshop, autumn 2016, Spain

17.30: Adjourn

19.00: Dinner

Wednesday 6th April.

Theme: Ozone impacts on wheat at different scales

09.00: Felicity Hayes (CEH) - Impacts of rising background and peak concentrations of ozone on wheat

09.20: Stephanie Osborne (SEI – York University, CEH) - Response of a European wheat cultivar to ozone exposure and drought, and applications for crop yield modelling

09.40: Gina Mills (CEH) - Quantifying the threat to global wheat production and quality from ozone pollution

10.00: Discussion.

10.10 – 10.40: Coffee/tea

Theme: Pollutant impacts on ecosystem services

10.40: Isabel Rogers (Lancaster University) - The indirect effects of atmospheric nitrogen deposition on carbon storage in grasslands: a mesocosm experiment

11.00: Divya Pandey (SEI - University of York, CEH) - Understanding the impacts of ground-level ozone on soil carbon sequestration in croplands

11.20: Netty van Dijk (CEH) – What does adding nitrogen to a bog do to the soil water?

11.40: Laurence Jones (CEH) - A framework for assessing heavy metal impacts on ecosystem services

12.00: Closure of the meeting

12.15: Lunch and departure

RECOVERY OF THE PARK GRASS EXPERIMENT FROM LONG TERM NITROGEN ADDITION

Storkey J, Macdonald AJ, Poulton PR, Scott T, Goulding KWT

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The Park Grass Experiment, started in 1856, is one of a suite of long term experiments at Rothamsted Research (Hertfordshire, UK) that represent a unique opportunity to observe plant community dynamics across decadal time scales in the context of constant management. Species diversity (measured as Simpson's index) on plots that have been receiving Nitrogen (N) fertiliser since the beginning of the experiment is lower than on the control plots that have never had any fertiliser additions. However, since the 1940s, species diversity has also declined on the control plots in response to soil acidification and eutrophication from atmospheric deposition of Nitrogen and Sulphur. Here we present evidence for a reversal of these biodiversity losses and rapid recovery of plant communities from eutrophication as Nitrogen deposition (measured on the Park Grass site) has reduced. This recovery was largely driven by in an increase in the proportion of legumes in the canopy, particularly *Trifolium pratense.* Since 1989, some plots on the experiment also stopped receiving N fertiliser after 133 years of annual N applications. Species diversity on these plots recovered to equivalent levels as the plot that had never received N fertiliser within the first three years of the treatment change and then followed a similar trajectory as the rest of the experiment. The species that recovered on these plots were similar to those that increased across the experiment more widely as atmospheric N deposition decreased: *Plantago lanceolata, Lathyrus pratensis, Ranunculus acris* and *Trifolium pratense.* It is likely that the recovery of plant communities from long term N inputs observed on Park Grass has been facilitated by the twice yearly cutting and removal of biomass which may partly explain why a recovery of a similar magnitude has not been observed in the wider landscape or at similar experimental sites.

Historic trends in N and S deposition in the UK - 1800 to present

Dragosits, U[1], Tomlinson, S.J.[1], Carnell, E.J.[1], Dore, A.J.[1], Misselbrook, T.H.[3] & Tipping, E.[2]

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The legacy of nitrogen (N) accumulation and its spatial distribution is an important part of assessing current threats to ecosystems and the ecological response to accumulated N-pools over time. As part of the NERC Macronutrients Long-Term Large-Scale (LTLS) project, historic N deposition and its spatial distribution in the UK from 1800 to present was calculated. The main sources of N deposition are NO_x emissions from combustion (industry, transport etc.), and ammonia (NH_3, largely from agriculture). SO_2 and NO_x emissions increased rapidly from the Industrial Revolution (~1760–1830) until mitigation measures were implemented through effective legislation from the 1980s, whereas NH_3 emissions are only decreasing very slowly.
This work reconstructed deposition timelines back to 1800 over six time slices (2010, 1990, 1970, 1950, 1900, 1800) which involved research into historical trends of emissions, their sources and respective spatial distributions, and utilised auxiliary data including historic population, agricultural statistics and practice as well as land cover data. The Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME) model was used to calculate UK concentration and deposition estimates of N and S compounds at a 5km grid resolution.

Results show that spatial patterns of N and S deposition have changed considerably over the 200+ year period, and how the local/regional deposition history (as well as the current and predicted future patterns of atmospheric deposition) vary widely across the UK. These data will enable a wealth of more detailed assessments of cumulative atmospheric N and S inputs (through deposition as well as atmospheric pollutant concentrations) and their impacts, on habitats and species as well as on human health.

FIELD-BASED EVIDENCE OF OZONE IMPACTS ON VEGETATION: AN UPDATE

Sharps, K., Hayes, F., Harmens, H. and Mills, G.

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In 2007, the ICP Vegetation Programme Coordination Centre released an 'Evidence Report' (Hayes et al. 2007), showing evidence of widespread ozone damage to vegetation in Europe in ambient air during the period 1990-2006. Visible injury was recorded in sixteen European countries (>500 records), on crops, shrubs and (semi-) natural vegetation. Here we present an overview of new data since this report was published, demonstrating the impacts of ambient ozone pollution in Europe and worldwide from 2007 onwards. Records of ozone injury from Europe, Asia and the USA have been received using the smart-phone ozone injury App, released in 2014. We also piloted an ozone garden scheme in 2015, with gardens containing ozone-sensitive species (e.g. white clover, French bean, wheat) in the UK, France and Poland. In addition, published information from treatments in ambient air, and charcoal-filtered vs. non-filtered air has been collated and analysed. Experiments using crops suggested large reductions in yield due to ozone, and other non-yield impacts, for example, negative effects on photosynthesis.

Epidemiology studies have been used to determine the impact of ozone on mature trees, for example, a reduction in annual growth. While there is strong evidence of the negative effects of ozone in Europe, coverage remains poor in South America, Africa and Asia. The largest (and easiest to record) source of evidence is visible leaf injury, however this can be difficult to quantify, as only presence of injury is recorded. The collation of field-based evidence is required by policy makers to demonstrate the impact of ambient ozone on vegetation, therefore we continue to encourage the use of the smart-phone App and development of a global ozone garden network.

IMPACTS OF OZONE ON BIODIVERSITY: MAPPING HABITATS AT RISK

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Although impacts of ground-level ozone on individual plant species have been studied and ozone-sensitive species have been identified, little is known about the implications for biodiversity. The existence of differences in ozone-sensitivity between plant species suggests that ozone pollution might cause shifts in species composition in plant communities. However, field evidence is scarce, and most evidence for the impact of ozone on plant diversity is from data from controlled experiments with either artificial model communities or with intact ecosystems exposed to varying ozone concentrations. Results from field exposure studies are limited and rather mixed, with ozone affecting plant species composition in some studies but not in others (Mills et al., 2013).

Following the methodology developed by Mills et al. (2007), we predicted the ozone-sensitivity of EUNIS (European Nature Information System) habitats, based on the relative ozone-sensitivity of the above-ground biomass of component species to the 24 hr mean ozone concentration. Using the UK National Vegetation Classification (NVC), communities for which at least 20% of the species were tested for ozone sensitivity, were converted into EUNIS habitat code to assess their potential ozone-responsiveness. Gridded data (0.5^{o} lon, 0.25^{o} lat) for the phototoxic ozone dose (POD) to grasslands was combined with the percentage of area per grid occupied by Natura 2000 grassland habitats, to map the potential risk of ozone impacts on those habitats across Europe. Natura 2000 grassland areas at highest risk from ozone are scattered across central and southern Europe, in those areas where grasslands are most abundant and where the phytotoxic ozone dose is medium to high. Whilst there is evidence that ozone might affect plant species composition, consequences for biodiversity require further study.

Mills et al., 2007. Identifying ozone-sensitive communities of (semi-)natural vegetation suitable for mapping exceedance of critical levels. Environmental Pollution 146(3): 736-743.

Mills et al., 2013. Ozone pollution: Impacts on ecosystem services and biodiversity. ICP Vegetation Programme Coordination Centre, CEH Bangor. http://icpvegetation.ceh.ac.uk/publications/documents

Acknowledgement. We thank the UK Department for Environment, Food and Rural Affairs (Defra) for funding the ICP Vegetation Programme Coordination Centre. Further financial support was provided by the UNECE and the UK Natural Environment Research Council (NERC).

QUANTIFYING THE MAGNITUDE OF SPECIES RICHNESS AND TURNOVER ON ECOSYSTEM PRODUCTIVITY BY THE RATE OF N INPUTS

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Reactive nitrogen (N) currently provides important benefits to society, in particular in agriculture to increase crop production to provide food to sustain a growing population. Reactive N enrichment also triggers biodiversity and species composition alterations which may change ecosystem functioning. However, how the rate and frequency of N addition affects ecosystem productivity through alterations in species richness by loss, gain and inert (persisting) is still unclear. Based on a six-year nine rates crossing with two frequencies of N addition in a temperate natural grassland, north China, results showed that the rate rather than the frequency of N enrichment had both direct and indirect effects on ecosystem aboveground productivity. The rate of N enrichment increased the production from new colonization and inert species richness. The contributions via new species colonization on ecosystem production decreased with the rate of N addition, while the contributions through inert species was relative large and constant. Our study suggests that the effect of losses of species on ecosystem production due to N enrichment may be minimized by managing the abundance of these inert species with tall clonal traits in natural and artificial ecosystems. Our study also reveals that species richness and turnover may play important roles to regulate ecosystem functioning and services in ecosystems in facing with ever increasing N fertilizers usage.

WHAT USE ARE PREDICTIONS OF BIODIVERSITY RESPONSES TO AIR POLLUTION?

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Predictions, also known as hypotheses, have a central role in science. Ecosystem managers, including those developing policy measures that influence ecosystems at broad scale, also make use of predictions to explore the likely outcomes of different changes and interventions. Simple predictive models such as regressions or rules-of-thumb are often adequate for this task. However, to predict biodiversity responses to air pollution it may be necessary to take into account multiple pollutants; effects of other changes such as management or climate; cumulative effects and delayed responses; and definitions of biodiversity.

The MADOC-MultiMOVE model chain is being used to develop 'biodiversity-based' critical load (CL) functions that take into account the combined effects of sulphur (S) and nitrogen (N) loads. The MADOC part tracks the cycling of sulphur and nitrogen in the ecosystem and predicts changes in the environment to which plants are exposed, in terms of pH, nitrogen availability and vegetation height. The MultiMOVE part predicts plant and lichen species responses to these environmental changes, in terms of habitat suitability, which partially reflects the chance of the species occurring at a site. Habitat suitability for positive indicator species can be used as an indicator of overall habitat quality (HQI). Threshold values of HQI can be found by running the model chain forward with deposition set to the agreed empirical CLs. The combinations of N and S likely to make habitat condition unfavourable, immediately or in the long term, can then be determined. This approach is being used to calculate biodiversity-based CL functions for all UK Natura2000 sites that contain acid-sensitive habitats.

Predictions of biodiversity responses to interacting drivers of change could be applied in many contexts. We explore the uncertainties in the approach, and discuss how the limitations they present might be overcome.

AN APPLICATION OF DYNAMIC MODELLING TO PRODUCE SITE-SPECIFIC CRITICAL LOADS

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Critical loads for acidity and nutrient nitrogen represent the main policy tool to control air pollution impacts at protected sites, yet there is evidence from gradient surveys that many species are lost below the critical load. This may be because pollutants and their effects can accumulate over many years. Dynamic modelling may offer some solutions to this problem by enabling site-specific critical loads to be calculated, thereby, customising the pollutant response through the addition of a temporal element which considers pollutant accumulation.

As part of their operating permit conditions, operators of some UK Electricity Supply Industry (ESI) power stations and refineries were required to undertake a period of monitoring at key N2000 protected sites that were potentially vulnerable to acidification and eutrophication. This study uses monitoring data collected by CEH as part of this and focusses on Skipwith Common, a SSSI heathland site in North Yorkshire. At around 13 kg N ha^{-1} yr^{-1}, site monitored deposition is at the low end of the heathland critical load range for nutrient N yet there is evidence of acidification, soil CN is low and leachate N is high suggesting N saturation. Vegetation condition also appears poor with a low occurrence of Common Standards Monitoring (CSM) positive indicator forb species and some bryophytes present have been associated with high N deposition in survey work.

Here, we apply the VSD+ model and the MADOC-MultiMOVE model chain to calculate site-specific critical loads. We also test a new critical limit for biodiversity based on the habitat suitability for 31 CSM positive indicator species and investigate the impact of pollutant reduction and climate change scenarios on habitat suitability. Results suggest that the site will fail to meet future conservation objectives even, under a pollutant reduction scenario of 20%, and highlights the need to consider more invasive management practices at many of our protected sites.

DEVELOPING A NATURAL RESOURCES MANAGEMENT APPROACH TO AIR QUALITY IN WALES TO PROTECT SENSITIVE HABITATS

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2013 was the European "year of air" and a number of reports to coincide with this event demonstrated that poor air quality across Europe is having profound adverse impacts on man and the natural environment. Many parts of the UK breach air quality standards and thresholds to protect human health and sensitive habitats. The main pollutant of concern to biodiversity is nitrogen, as nutrient nitrogen deposition and in the form of gaseous ammonia. The UK conservation bodies work closely together and alongside Defra, the devolved administrations, the UK environment agencies and "the CAPER family" seek to better understand the impacts of air pollution on the environment and to promote approaches to mitigate these impacts.

Outputs from this work will be presented alongside new research findings to better understand the situation in Wales. Recently there have been major changes in legislation in Wales that present new duties and powers on bodies such as Natural Resources Wales. The objective is to promote much greater integration between public bodies to deliver "shared outcomes" to support sustainable development and "ecosystem resilience" to ensure we underpin and support the needs of "Future Generations". The term for this joined up approach is "Natural Resources Management" and this will be discussed in the context of the new legislative landscape. The presentation will outline the current issues and threats presented by a rapidly expanding poultry industry on habitats in Wales. Suggestions will be made on the tools we have available and how we can address the air pollution impacts from these developments. This will allow appropriate sustainable expansion while promoting ecosystem resilience to ensure we deliver an integrated Natural Resource Management approach in Wales.

ATTRIBUTING BIOLOGICAL CONTROLS ON RECENT CHANGES IN CARBON CYCLING IN ORGANIC SOILS

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Recent evidence show clear recovery from acidification of soils in response to decreasing levels of atmospheric pollution. This has been linked with the observed increase in dissolved organic carbon (DOC) concentration in soil solutions and surface water bodies over the past 30 years, as DOC solubility increases with increasing pH. It has been speculated that soil microorganisms play a part in this increase in DOC concentration, and yet little is known regarding the effects of pH on microbial communities in organic soils and their associated functions, particularly the processing of organic matter. This project will investigate the effects of acidity on DOC in highly organic soils, specifically how acidity affects microbial processing of different sources of carbon. In particular, this project will examine the effect of acidity on microbial community structure and the relationship with microbial DOC production and consumption distinguishing between non-humic and humic 'coloured' fractions. This research will build on an existing long-term pH manipulation field experiment (Evans, et al., 2012) in contrasting areas of historical pollution; North Wales and the Peak District, coupled with a range of sophisticated laboratory methods such as next generation sequencing of microbial diversity, Fluorescence Spectroscopy and NMR. The findings of this project will contribute to the understanding of soil microbially-mediated processes and responses to environmental change, and therefore improve our understanding of terrestrial carbon cycling. It may also help distinguish the extent to which such changes are driven by climate change or other sources of environmental change, ultimately improving the accuracy of future earth system models.

Evans, C.D., Jones, T.G., Burden, A., Ostle, N., Zielinski, P., Cooper, M.D.A., Peacock, M., Clark, J.M., Oulehle, F., Cooper, D. & Freeman, C., 2012. Acidity controls on dissolved organic carbon mobility in organic soils. *Global Change Biology*, 18 (11), p.p. 3317-3331.

HISTORIC SULPHUR DEPOSITION: LONG-TERM TRENDS

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The history of sulphur (S) deposition and its spatial distribution is important in our understanding of the environmental threats and subsequent responses to S accumulation, including recovery. As part of the NERC Macronutrients Long-Term Large-Scale (LTLS) project, historic S emissions and deposition and their spatial distribution in the UK have been quantified back to 1800 and also predicted to 2030. Throughout the time series, UK-based SO_2 emissions have been dominated by the burning of fossil fuels; coal in industry throughout the Industrial Revolution (c. 1760 – 1840) and beyond and, more recently, oil and coal usage in the power generation sector. Mitigation measures through legislation have seen SO_2 emissions drop from a peak of c. 6,500 Gg in 1970 by 92% to c. 500 Gg in 2010. To calculate deposition and concentration estimates over 5km grids across the UK, high resolution emission maps were created and used as input to the Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME) model. The results show a large increase in deposited S in the UK from 61 Gg in 1800 (58% as wet deposition) to 1101 Gg in 1970 (44% as wet deposition). The rapid decline in emissions from 1970 to 2010 is also reflected in a 90% decrease in deposited S in this period. The 2030 deposition data has been modelled using UEP43 predictions which estimate further reductions of S deposition to 63.4 Gg (78% as wet deposition), i.e. similar levels to 1800. Furthermore, the switch from dry deposition being the dominant fraction to wet deposition sometime between 1970 and 1990 has important implications on ecological impacts, but also highlights the heterogeneous spatiotemporal distribution of reductions in S deposition and the non-linearities of the emissions-deposition relationship. These new sulphur deposition datasets are being utilised as inputs for the LTLS Integrated Model (IM), which simulates pools and fluxes of N, C and P since the last ice-age.

CUMULATIVE NITROGEN DEPOSITION IN THE UK –
A HISTORIC PERSPECTIVE

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The effects of atmospheric nitrogen (N) deposition are evident in terrestrial ecosystems worldwide, with acidification and eutrophicaon leading to changes in species composition. In the NERC Macronutrients Long Term Large Scale (LTLS) project, we estimated that, in the UK, N deposition has increased five-fold since the start of the 19th century. This was due to large increases in emissions of nitrogen oxides (NO_x, mainly from transport, power generation and other combustion sources) and ammonia (NH_3, mainly from agricultural sources). Although, on average, N deposition rates have been decreasing over the last two decades in many parts of the UK, it is well known that there is a lag period in ecosystem recovery due to historical accumulation of nitrogen.

New work to quantify accumulated N-pools utilises the historic N deposition maps from the LTLS project, which were produced for six time slices (2010, 1990, 1970, 1950, 1900, and 1800), using The Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME) at 5 km grid resolution. Cumulative pressure from long-term N additions through atmospheric deposition was then estimated by interpolating annually between the N deposition time slices. This analysis was carried out separately for atmospheric input through reduced and oxidised N forms (separately for dry and wet forms, as well as for total N), and for woodland and low-growing semi-natural habitats.

PREPARATIONS FOR THE OZONE CRITICAL LEVEL WORKSHOP, AUTUMN 2016, SPAIN

Mills, G.[1], Karlsson, P.-E[2]., Pleijel, H.[3], Braun, S.[4], Büker, P.[5], González Fernández, I.[6] and participants of the workshop

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Critical levels for ozone have been established at a series of workshops over recent decades. The most recent workshop was held at JRC Ispra in 2009 and progress since then has been reviewed at the annual Task Force Meetings of the ICP Vegetation. Over the last ten years, stomatal flux models have been developed for 7 crop species, 8 trees and 4 species of grassland. Critical levels have been derived for selected species based on either an ecologically significant effect or on the lowest ozone flux at which a statistically significant effect occurs. Since the last workshop, a lot of new science has been conducted and this is an ideal opportunity to revisit the critical levels to determine if there is a need for revision.

In November 2016, we are organising the next LRTAP Convention Ozone Critical Levels Workshop to be hosted by Spain. In preparation for this, we have held/are holding a series of Expert Panel meetings to prepare new dose response functions and candidate critical levels for consideration for inclusion in the Convention's Modelling and Mapping Manual.

From 23 – 25 November, 2015, we organised two back-to-back workshops in Sweden covering (i) Epidemiological evidence of effects of ozone pollution on vegetation and (ii) Agreement of common methodology to be applied in preparatory data analysis. We will host a further Expert Panel meeting in June at Deganwy, North Wales where progress with setting response functions will be reviewed and remaining work programmes established.

Acknowledgement. We thank the UK Department for Environment, Food and Rural Affairs (Defra) for funding the ICP Vegetation Programme Coordination Centre. Further financial support was provided by the UNECE and the UK Natural Environment Research Council (NERC). Funders from BECC and SCAC, research programs financed by the Swedish Environmental Protection Agency (http://www.scac.se/), are gratefully thanked for funding the workshops.

IMPACTS OF RISING BACKGROUND AND PEAK CONCENTRATIONS OF OZONE ON WHEAT

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Wheat of varieties ‘Mulika’ and ‘Skyfall’ were exposed to ozone in the solardomes at CEH Bangor. Profiles used were to compare the response to ozone supplied as peaks (representing local/regional pollution) and background (hemispheric pollution) and eight treatments were applied in matching pairs. Ozone accelerated senescence in both varieties, but whereas for Mulika the decline in chlorophyll content was similar whether ozone was applied as ‘background’ or ‘peaks’, for Skyfall the decline in chlorophyll content was faster with peaks of ozone.

Large decreases in grain yield with increasing ozone were found for both varieties, with Skyfall being the variety most sensitive to ozone. This was due to an impact on grain size, rather than the number of ears or grain number per ear.

The impact on yield was explained by stomatal ozone flux. Ozone fluxes were higher in the ‘peaks’ treatments as the highest exposure to ozone coincided with the hours and climatic conditions that were highly favourable to ozone uptake. This study therefore provides evidence that flux based dose-response relationships developed using experiments with episodic ozone exposure are also applicable for predictions of yield responses with increasing background ozone exposure.

RESPONSE OF A EUROPEAN WHEAT CULTIVAR TO OZONE EXPOSURE AND DROUGHT, AND APPLICATIONS FOR CROP YIELD MODELLING

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Dr. Patrick Büker[2], Dr. Lisa Emberson[2]

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The global surface concentration of tropospheric ozone (O_3) is expected to continue to rise until at least 2050 in a number of world regions. Simultaneously, global climate change will result in increased severity and frequency of drought episodes in the coming decades. Wheat provides food calories for 4.5 billion people, and is also one of the most O_3-sensitive crops. Understanding the yield response of wheat cultivars to O_3 pollution and drought - and building models which can produce accurate simulations of these stressors on yield – will be central in assessing current and future O_3 impacts on food supply and security.

The response of yield, photosynthesis and stomatal conductance to O_3 exposure was measured over the 2015 field season in a European wheat cultivar ("Mulika") at the CEH Bangor solardomes, Abergwyngregyn, North Wales. Potential interactive effects between O_3 and early and late drought episodes were also investigated. Ozone exposure significantly reduced individual grain weight in wheat, although grain number was not affected. Light-saturated photosynthetic rate (A_{sat}), maximum carboxylation capacity of Rubisco (Vc_{max}) and the rate of photosynthetic electron transport (J_{max}) reduced over the course of the growing season, and O_3 exposure accelerated these changes by driving leaf senescence and chlorophyll content decline. Early and late drought episodes were seen to act differentially on yield parameters, and influenced the rate of life cycle development.

Physiological data for wheat collected at the 2015 CEH Bangor experiment, and from a measurement campaign at Banaras Hindu University, Varanasi, India, will be used to derive region-specific parameterisations of a new formulation of the DO_3SE (deposition of ozone for stomatal exchange) model. The model will couple the calculation of stomatal conductance and photosynthesis, to mechanistically simulate stomatal flux and assimilated carbon under seasonal O_3 stress.

QUANTIFYING THE THREAT TO GLOBAL WHEAT PRODUCTION AND QUALITY FROM OZONE POLLUTION

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At the global scale, ozone (O_3) pollution has been predicted to pose as big a threat to food security as climate change by 2030. Several of the world's most important crops such as wheat, soybean, maize and rice respond to O_3 pollution by decreasing vegetative growth, seed production and root growth leading to reductions in both quantity and quality of yield. Even though negative effects have been detected in the field under current ambient O_3 concentrations, O_3 is not currently included as a modifier of crop growth in global and regional crop modelling.

In this paper we describe a new development in quantifying losses from O_3 pollution for wheat on a global scale based on modelling the stomatal uptake of O_3. Evidence from European chamber and field studies shows that the uptake of O_3 by stomata (flux) is a superior predictor of O_3 damage, compared to more conventional exceedance of O_3 threshold concentrations. This analysis presents a major step forwards from previous predictions of risk based on O_3 concentration as it includes the modifying effects of climate and soil moisture (including irrigation) on instantaneous O_3 uptake and subsequent effect.

Our analysis showed that wheat crops in many areas of the world are being negatively impacted by the pollutant. The worst problems were identified for China, India and the USA. Globally, percentage effects were greater for the temperate climates of the northern rather than the southern hemisphere, in part reflecting the higher O_3 concentrations in the northern hemisphere. Effects were greatest in warm-temperate-dry areas of China and tropical-dry areas of India where irrigation is commonly used resulting in conditions that are highly conducive to O_3 uptake. Estimates based on stomatal uptake of O_3 were lower than those for commonly used concentration-based metrics such as the 7h mean and AOT40.

This study has highlighted the spatial variability of global impacts of ozone pollution on wheat production. It also draws attention to the need to consider ozone pollution as a modifying factor in global crop production and food security modelling.

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THE INDIRECT EFFECTS OF ATMOSPHERIC NITROGEN DEPOSITION ON CARBON STORAGE IN GRASSLANDS: A MESOCOSM EXPERIMENT

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Atmospheric nitrogen (N) deposition is causing plant community changes in grasslands across Europe. Grassland species richness has been shown to decline as N deposition increases. Over time, plants in affected grasslands shift from competing for nutrients underground to competing for sunlight, often giving an advantage to fast-growing functional groups such as grasses. Grasslands are an important carbon (C) sink, and it is not clear how plant community changes brought on by N deposition will affect C storage in these systems.

A mesocosm experiment aimed at testing the effects of N addition on the C storage potential of different grassland plant communities was run over two growing seasons (2014-15). Nine plant species (three grasses, four forbs and two legumes) were chosen based on their preference for high or low N environments. Using these species, six plant communities were designed to investigate the effects of N addition on communities with different species identity, richness and evenness. Six replicates of each community were planted in large plant pots filled with a 3:1 mixture of soil and peat. Six monocultures of each species were also planted. Over both growing seasons, 35 kg N ha^{-1} yr^{-1} was added to half of the pots in eight applications per year (once every two weeks). Aboveground biomass harvests were conducted in July of both years and the destructive sampling of soil and roots was conducted in July 2015. Data from this experiment will be presented.

UNDERSTANDING THE IMPACTS OF GROUND LEVEL OZONE ON SOIL CARBON SEQUESTRATION IN CROPLANDS

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Ozone is a secondary air pollutant that also acts as a greenhouse gas. There is strong evidence that it also creates oxidative stress in plants and causes reduction in photosynthesis. This ultimately reduces terrestrial carbon sequestration in living biomass, an effect estimated to cause more warming than the direct radiative forcing of ozone as a greenhouse gas. Because plant-soil systems are intricately linked, it is very likely that ozone also interferes with soil carbon cycling by altering litter quantity and quality, root exudation rates and quality, microbial activities and decomposition rates in soil. These effects have been observed individually in several experimental studies, but a systematic investigation is still required to be able to estimate the effect of ozone on soil carbon sequestration quantitatively.

At the CAPER meeting, we will present and discuss our ongoing research project that aims to investigate whether, and to what extent, elevated ozone might affect the carbon dioxide mitigation potential of agricultural soils in the UK over the coming decades. The approach of the study is (1) To combine an O_3 deposition and effect model for plants - DO_3SE with a soil C model - CENTURY; (2) To generate empirical data to allow the incorporation of ozone effects on litter fall, plant lignin content, root exudates, microbial activity and decomposition rates in the integrated DO_3SE-CENTURY model and; (3). To apply the DO_3SE-CENTURY model at different locations in the UK to assess the impacts of future O_3 levels on C sequestration in living biomass and soil C.

Here we identify and discuss the major processes in soil carbon dynamics and plant-soil interactions that are affected by elevated ozone levels and discuss the rationale and detailed approach of this study.

Given that soil is the largest terrestrial carbon reservoir, and ozone levels are already high enough to cause reduction in plant productivity with expected future increases; ozone induced changes in soil carbon stocks could be a significant yet unaccounted source of uncertainty in current and future estimates of carbon sequestration by terrestrial ecosystems.

WHAT DOES ADDING NITROGEN TO A BOG DO TO THE SOIL WATER?

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Whim Bog is located in the south of Scotland, about 15 km south of Edinburgh.The Whim experimental site was established with treatments running from 2002. The site offers a globally unique assessment of how semi-natural vegetation responds to different forms of nitrogen deposition, including wet and dry deposition and oxidized and reduced forms of nitrogen deposition. The experiment provides a quantified ammonia (NH_3) concentration/deposition gradient to an ombrotrophic bog, plus separate wet deposition treatments comparing different levels of oxidized ($NaNO_3$) and reduced (NH_4Cl) N deposition.

Whim is a typical *Calluna vulgaris-Eriophorum vaginatum* blanket mire with hummocks dominated by *Calluna* and the bog moss *Sphagnum capillifolium* and hollows containing *S. fallax* and *S. papillosum.* Results from this experiment have contributed to a better understanding of the effects of nitrogen on e.g. semi natural vegetation, greenhouse gasses and frost sensitivity. This talk will focus on what happens with the soil water chemistry when adding nitrogen to the bog for a long time

Results from this experiment have been used in advising government and policy makers on regulation of nitrogen emissions and critical levels/loads.