Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Air Pollution and Vegetation

ICP Vegetation

Annual Report 2008/2009

wge
Working Group on Effects of the Convention on Long-range Transboundary Air Pollution

Air Pollution and Vegetation

ICP Vegetation[1] Annual Report 2008/2009

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August 2009

[1] The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops.

Acknowledgements

We wish to thank the UK Department for Environment, Food and Rural Affairs (Defra) for the continued financial support of the ICP Vegetation (Contract AQ0810). Contributions from Lisa Emberson, Patrick Büker, Steve Cinderby, Howard Cambridge (SEI-York, UK), Andrew Terry (University of York, UK), Sally Power and Emma Green (Imperial College, London, UK) as sub-contractors of Contract AQ0810 are gratefully acknowledged. In addition, we wish to thank the UNECE and the UK Natural Environment Research Council (NERC) for the partial funding of the ICP Vegetation Programme Coordination Centre.

Contributions in kind from Winfried Schröder, Roland Pesch, Marcel Holy (University of Vechta, Germany), David Simpson, Hilde Fagerli (EMEP-MSC/West) and Ilia Ilyin (EMEP-MSC-East) are also gratefully acknowledged.

We wish to thank Ludwig De Temmerman, Eliv Steinnes, Ben Gimeno, Jürg Fuhrer, Håkan Pleijel and Per Erik Karlsson for their advice, all of the ICP Vegetation participants for their continued contributions to the programme and other bodies within the LRTAP Convention.

Photos and maps of the covers were the courtesy of:
Front cover – Laurence Jones
Back cover (from top to bottom) – Kathy Chandler, David Norris, Dimitris Velissariou, Mathias Volk, David Simpson and Alessandra Francini-Ferrante.

Executive Summary

Background

The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) was established in the late 1980s, initially with the aim of assessing the impacts of air pollutants on crops, but in recent years impacts on (semi-) natural vegetation have also been considered. The ICP Vegetation is led by the UK and has its Programme Coordination Centre at the Centre for Ecology and Hydrology (CEH) in Bangor. It is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. Today, the ICP Vegetation comprises an enthusiastic group of over 200 scientists from 35 countries in the UNECE region. An overview of contributions to the WGE work-plan and other research activities in the year 2008/9 is provided in this report.

Annual Task Force Meeting

The Programme Coordination Centre organised the 22nd ICP Vegetation Task Force Meeting, 2 - 4 February 2009 in Braunschweig, Germany, in collaboration with the local host at the Institute of Biodiversity, Johann Heinrich von Thünen-Institute (vTI). The meeting was attended by 57 experts from 20 Parties to the Convention and South Africa. Also present were the Convention secretariat, the chairman of the ICP Modelling and Mapping, the chairman of the ICP Forests Working Group on Ambient Air Quality and a representative from EMEP/MSC-East. The Task Force discussed the progress with the work-plan items for 2009 and the medium-term work-plan for 2010-2011 for the air pollutants ozone, heavy metals and nutrient nitrogen.

Reporting to the Convention and other publications

In addition to this report, the ICP Vegetation Programme Coordination Centre has provided a technical report on ‘Impacts of ozone and nitrogen on vegetation and trends in nitrogen and heavy metal concentrations in mosses’. It has also contributed to the joint report of the WGE, the report on ‘Effects of airborne nitrogen’ and the report on ‘Indicators and targets for air pollution effects’. Data on the relationships between heavy metal and nitrogen concentrations in mosses and EMEP[1] modelled atmospheric depositions were also reported in the status reports of EMEP for 2009. Two papers were submitted to scientific journals (of which one is in press), a book chapter was published and a paper was submitted for the report of the COST 729 workshop on ‘Nitrogen deposition and Natura 2000: science and practice in determining environmental impacts’. The ICP Vegetation web site was re-structured and a leaflet was produced on ‘Evidence of widespread ozone pollution damage to vegetation in Europe (1990-2006)’.

In December 2008, the Executive Body (EB) of the Convention took note of the evidence provided by the ICP Vegetation on the widespread ozone damage to vegetation. At its 26th session the EB decided that ozone effects on vegetation should be incorporated in integrated assessment modelling, especially in work for the revision of the Gothenburg Protocol, and recommended that flux-based methods be used (ECE/EB.AIR/96). It also noted that the implementation of existing legislation would not attain the ambition levels set out in article 2 of the Gothenburg Protocol, in particular, it would not provide a significant reduction in effects of ozone on health and vegetation, and policies aiming only at health effects would not protect vegetation in large areas of Europe. Based on this decision, risk assessments of ozone impacts on vegetation should be flux-based.

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[1] Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe.

Contributions to WGE common work-plan

Although the ICP Vegetation has contributed to all common work-plan items of the WGE in 2009, here we summarise progress with two in particular.

<u>Status report on airborne nitrogen impacts on the environment</u>

The ICP Vegetation reviewed the current state of knowledge on the impacts of airborne nitrogen on vegetation. Some moss and lichen species are very sensitive to enhanced atmospheric nitrogen deposition, in particular of ammonia. Therefore, a few years ago critical levels of ammonia were set at a lower concentration (1 µg m^{-3}) for lichens and mosses (and ecosystems where lichens and mosses are a key part of ecosystem integrity) than for higher plants (3 µg m^{-3}). Sensitive habitats with low empirical critical loads for nitrogen include raised and blanket bogs, nutrient poor mires, tundras, *Racomitrium* containing wet heathlands, and arctic, alpine and subalpine scrub habitats. For boreal forests, it was recently recommended to reduce the current empirical critical load of 10-20 kg N ha^{-1} y^{-1} to 5-10 kg N ha^{-1} y^{-1}. Elevated nitrogen deposition favours faster growing, more nitrogen-loving species, leading to competitive exclusion of plants adopted to low nitrogen availability, ultimately resulting in a decrease in plant diversity. Past conditioning (above 10 kg N ha^{-1} y^{-1}) may have already led to loss of rare or sensitive species.

<u>Explore merits of the different options for target setting in 2020 and non-binding aspirational targets for the year 2050</u>

The ICP Vegetation contributed to discussions related to ozone impacts on vegetation. The programme recommended that political aspirations for 2050 should be based on avoiding all detectable adverse effects of ozone on the i) yield quantity and quality of agricultural and horticultural crops (including forage); ii) growth of individual species and biodiversity of (semi-)natural vegetation; iii) leaf appearance and growth of forest trees and iv) ecosystem services (including carbon sequestration) of vegetation. For crops and trees, risk assessments of ozone impact on vegetation should be flux-based (a generic flux-based approach for (semi-) natural vegetation is currently being developed), in particular as it can take into account predicted climate change factors for 2050. For current climatic conditions, a reduction of 75% of the generic ozone flux to crop species would result in more than 90% of EMEP grid squares, currently showing evidence of ozone damage to vegetation, being within the ‘damage unlikely’ category.

Progress with ICP Vegetation research activities in 2008/9

<u>Risk of ozone damage to (semi-)natural vegetation communities in Europe</u>

Previously, a parsimonious model based on Ellenberg Light and Salinity scores was shown to be best at predicting ozone sensitivity of individual plant species. Recently, the Ellenberg modelling method was expanded to include as far as possible the complex interactions, which may alter the response of the whole community to ozone, including competition, canopy/species height, position in canopy, growth form, relative growth rate and nitrogen sensitivity. However, on the basis of testing against experimental community data none of these modifiers can be recommended as consistently improving the Ellenberg model.

Application of the Ellenberg modelling approach to European grasslands predicted that coastal grassland communities and Mediterranean tall humid grasslands were the most sensitive to ozone of the communities that could be included in this modelling approach. Previously, in a wider–ranging study using the proportion of species that are ozone–sensitive, other vegetation types such as upland grasslands, shrub heathland, forest fringes, dry and wet grasslands were also predicted to be ozone sensitive. For the tested grassland types, sensitivity to ozone and to atmospheric nitrogen deposition were found to be either unrelated or to have a weak negative relationship.

Flux-based assessment of risk of ozone damage to managed pastures in Europe

A multi-layer canopy flux model was developed for a productive grassland containing white clover (a legume) and rye grass to develop improved risk assessments. This model allowed for the variation in leaf area index (LAI) fractions of legumes and grasses, light penetration and ozone concentration to be incorporated in the assessment of ozone flux to component species of the canopy. Leaf area index proved to be a key driver of the ozone flux into the canopy and within canopy distribution of ozone flux to the component species. Incorporating the modifying influence of nitrogen on both LAI and maximum stomatal conductance of component species provides the opportunity to model and hence quantify the impacts of increased nitrogen input on community growth characteristics and ozone sensitivity. Due to lack of suitable experimental data it has not yet been possible to develop a quantitative flux-effect relationship for biomass, species composition or forage quality that is sufficiently robust for Europe-wide application. A literature review revealed that current ambient ozone concentrations can cause considerable loss in nutritive quality due to negative effects of ozone on the digestibility of forage, in particular of legumes. Recently, with new data becoming available from other research groups, the multi-layer modelling framework was extended to include three functional types (grasses, legumes and forbs) for the development of a flux-effect model for (semi-)natural grasslands.

Ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States

In an initiative led by Sweden, ozone impacts on vegetation in the Nordic Countries and the Baltic States have been reviewed. A workshop was held in Gothenburg on 17 - 18 June 2008 to assess current scientific knowledge on adverse impacts of ozone on vegetation. There is substantial evidence, especially from Sweden and Finland based on large-scale experimental work, that ozone has significant adverse effects on vegetation at (near) current ambient ozone levels in the Nordic Countries and Baltic States. Favourable climatic conditions and the long days in the summer result in considerable ozone uptake by vegetation, despite atmospheric ozone concentrations generally being lower than in central and southern Europe. Therefore, risk assessments and integrated assessment modelling of impacts of ozone on vegetation need to be flux-based.

Spatial variation in heavy metal and nitrogen concentrations in mosses

In 2005/6, naturally growing mosses were sampled from about 6,000 and 3,000 sites to determine their heavy metal and nitrogen concentration respectively. The lowest concentrations of heavy metals in mosses were generally found in northern Europe and the highest concentrations in Belgium and eastern Europe. The spatial pattern of cadmium and lead concentrations in mosses and modelled EMEP depositions agree reasonably well, i.e. regions with higher deposition had generally higher concentrations in mosses and vice versa. For mercury, the spatial patterns showed less similarity. Bivariate analysis of the data showed the highest correlations between the cadmium and lead concentration in mosses and modelled EMEP depositions, followed by EMEP total emissions and the proportion of urban land use in a 50-100 km radius. Correlations between the mercury concentration in mosses and modelled EMEP depositions or anthropogenic emissions and any other predictors were low.

In 2005/6, the lowest total nitrogen concentrations in mosses were observed in northern Finland and northern parts of the UK and the highest concentrations were found in central and eastern Europe. The spatial distribution of the nitrogen concentration in mosses was similar to that of the total nitrogen deposition modelled by EMEP for 2004, except that the modelled nitrogen deposition tended to be relatively lower in eastern Europe. The nitrogen concentration in mosses showed the highest, albeit moderate correlations with EMEP modelled depositions or air concentrations of different nitrogen forms, followed by the proportion of urban and agricultural land use and population and livestock density. In general, the total nitrogen concentration in mosses appears to mirror land use-related atmospheric nitrogen depositions. The results indicated that mosses can potentially be used as biomonitors of nitrogen deposition, although limitations and potential confounding factors were identified that require further investigation in order to improve application at the European scale.

Temporal trends in heavy metal concentrations in mosses (1990 – 2005)
Since 1990, heavy metal concentrations in mosses have been determined every five years across Europe. The decline in emission and subsequent deposition of heavy metals has resulted Europe-wide in a significant reduction in the heavy metal concentration in mosses since 1990 (1995 for mercury) for many metals, but not for chromium (2.0%) and mercury (11.6%). Between 1990 and 2005 the metal concentration in mosses has declined the most for lead (72.3%), arsenic (71.8%, based on data from only five countries), vanadium (60.4%), cadmium (52.2%) and iron (45.2%). A smaller decline was found for zinc (29.3%), copper (20.4%) and nickel (20.0%). Initial data analysis showed that Europe-wide temporal trends in heavy metal concentration in mosses agreed reasonably well with temporal trends in EMEP modelled heavy metal deposition, in particular for lead and cadmium. Further data analysis will be conducted in the future, in particular regarding country-specific temporal trends and factors that might contribute to discrepancies in temporal trends in heavy metal concentration in mosses in comparison with EMEP modelled atmospheric deposition.

Developing areas of research within the ICP Vegetation

Bean ozone biomonitoring experiment
In the summer of 2008, ICP Vegetation participants conducted a pilot study to investigate the potential for *Phaseolus vulgaris* (bean) to be used as a biomonitor of ozone in Europe. Bean seeds of an ozone-sensitive and ozone-resistant strain, developed in the USA, were distributed to ICP Vegetation participants. At all 13 participating sites in eight countries, a clear distinction in the extent of visible leaf injury symptoms between the ozone-sensitive and ozone-resistant biotypes was apparent. The best ozone metric for use with effects data has not yet been identified, and no flux model exists for these plants to date. Participants are keen to repeat the study in future years with efforts focussed on establishing a flux-effect relationship for bean.

State of knowledge reviews on ozone
Following the success of the ozone ‘Evidence Report’, the Task Force of the ICP Vegetation agreed at its 21st meeting in 2008 that further ozone reports that synthesise information from scientific journals, the ‘grey’ literature and national reports would be extremely useful outputs from the ICP Vegetation. Colleagues in Italy are currently reviewing the impacts of ozone on vegetation in the Mediterranean region. A review of ozone flux models and their application to different climatic regions will be conducted in preparation for the next ozone workshop on ‘Flux-based assessment of ozone effects for air pollution policy’, to be held from 10 – 12 November 2009, in Ispra, Italy. Regarding the review on impacts of ozone on food security, available data for crop sensitivity and developing localised parameterisations for key crop species for use in three climatic regions will be reviewed in 2009/10. In 2010/11, maps will be produced showing those crops and areas at greatest risk of damage from ozone in Europe. These will be incorporated into a review of knowledge of current and predicted future impacts of ozone on crop security in Europe (main focus) with consideration of impacts in South Eastern Europe (SEE), Eastern Europe, Caucasus and Central Asia (EECCA) and Malé Declaration countries. There are tentative plans to review the following subject in 2011: Ozone, carbon sequestration, and linkages between ozone and climate change.

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1. Introduction

1.1 Background

The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) was established in the late 1980s, initially with the aim to assess the impacts of air pollutants on crops, but in later years also on (semi-)natural vegetation. The ICP Vegetation is led by the UK and has its Programme Coordination Centre at the Centre for Ecology and Hydrology (CEH) in Bangor. The ICP Vegetation is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. The Convention provides the essential framework for controlling and reducing damage to human health and the environment caused by transboundary air pollution. So far, eight international Protocols have been drafted by the Convention to deal with major long-range air pollution problems (Working Group on Effects, 2004). The ICP Vegetation focuses on the following air pollution problems: quantifying the risks to vegetation posed by ozone pollution and the atmospheric deposition of heavy metals and nitrogen to vegetation. Currently, the ICP Vegetation work contributes to the revision of the Gothenburg Protocol, aiming to abate acidification, eutrophication and ground-level ozone.

Today, the ICP Vegetation comprises an enthusiastic group of over 200 scientists from 35 countries in the UNECE region; in addition, scientists from South Africa participate (Table 1.1). The contact details for lead scientists for each group are included in Annex 1. In many countries, several other scientists (too numerous to mention individually) also contribute to the biomonitoring programmes, analysis and modelling procedures that comprise the work of the ICP Vegetation.

Table 1.1. Countries participating in the ICP Vegetation.

Austria	Greece	Serbia
Belarus	Hungary	Slovakia
Belgium	Iceland	Slovenia
Bulgaria	Italy	South Africa
Croatia	Latvia	Spain
Czech Republic	Lithuania	Sweden
Denmark	Netherlands	Switzerland
Estonia	Norway	Turkey
Finland	Poland	Ukraine
France	Portugal	United Kingdom
FYR of Macedonia	Romania	USA
Germany	Russian Federation	Uzbekistan

1.2 Air pollution problems addressed by the ICP Vegetation

1.2.1 Ozone

Ozone is a naturally occurring chemical present in both the stratosphere (in the ‘ozone layer’, 10 – 40 km above the earth) and the troposphere (0 – 10 km above the earth). Additional photochemical reactions involving NO_x, carbon monoxide and non-methane volatile organic compounds (NMVOCs) released due to anthropogenic emissions (especially from vehicle sources) increase the concentration of ozone in the troposphere. These emissions have caused a steady rise in the background ozone concentrations in Europe and the USA since the 1950s (The Royal Society, 2008). Superimposed on the background tropospheric ozone are ozone episodes where elevated ozone concentrations in excess of 50-60 ppb can last for several days. Ozone episodes can cause short-term responses in plants such as the development of visible leaf injury (fine bronze or pale yellow specks on the upper surface of leaves) or reductions in photosynthesis. If episodes are frequent, longer-term responses such as reductions in growth and yield and early die-back can occur.

The negotiations concerning ozone for the Gothenburg Protocol (1999) were based on exceedance of a concentration-based long-term critical level of ozone for crops and (semi-) natural vegetation. This value, an AOT40[1] of 3 ppm h accumulated over three months was set at the Kuopio Workshop in 1996 (Kärenlampi and Skärby, 1996) and is still considered to be the lowest AOT40 at which significant yield loss due to ozone can be detected for agricultural crops and (semi-)natural vegetation dominated by annuals, according to current knowledge (LRTAP Convention, 2004). However, several important limitations and uncertainties have been recognised for using the concentration-based approach. The real impacts of ozone depend on the amount of ozone reaching the sites of damage within the leaf, whereas AOTX-based critical levels only consider the ozone concentration at the top of the canopy. The Gerzensee Workshop in 1999 (Fuhrer and Achermann, 1999) recognised the importance of developing an alternative critical level approach based on the flux of ozone from the exterior of the leaf through the stomatal pores to the sites of damage (stomatal flux). This flux-based method provides an indication of the degree of risk for adverse effects of ozone on vegetation with a stronger biological basis than the concentration-based method. The flux-based approach required the development of mathematical models to estimate stomatal flux, primarily from knowledge of stomatal responses to environmental factors. To date, flux-based critical levels have been derived for wheat, potato and provisionally for beech and birch, and flux-based risk assessment methods have been developed for a generic crop and generic tree species (LTRAP Convention, 2004). Two AOT40-based critical levels have been derived for (semi-)natural vegetation depending on whether annuals or perennials are dominant in the communities.

The Executive Body of the LRTAP Convention decided at its 25th meeting in December 2007 (LRTAP Convention, 2008) to start the revision of the Gothenburg Protocol by mandating the Working Group on Strategies and Review to commence, in 2008, negotiations on further obligations to reduce emissions of air pollutants contributing to acidification, eutrophication and ground-level ozone. The outcome of the revision will be presented to the Executive Body in December 2010. The ozone sub-group of the ICP Vegetation contributes models, state of knowledge reports and information to the LRTAP Convention on the impacts of ambient ozone on vegetation; dose-response relationships for species and vegetation types; ozone fluxes, vegetation characteristics and stomatal conductance; flux modelling methods and the derivation of critical levels and risk assessment.

1.2.2 Heavy metals

Concern over the accumulation of heavy metals in ecosystems, and their impacts on the environment and human health, increased during the 1980s and 1990s. Currently some of the most significant sources include:

- Metals industry (Al, As, Cr, Cu, Fe, Zn);
- Other manufacturing industries and construction (As, Cd, Cr, Hg, Ni, Pb);
- Electricity and heat production (Cd, Hg, Ni);
- Road transportation (Cu and Sb from brake wear, Pb and V from petrol, Zn from tires);

[1] The sum of the differences between the hourly mean ozone concentration (in ppb) and 40 ppb for each hour when the concentration exceeds 40 ppb, accumulated during daylight hours.

- Petroleum refining (Ni, V);
- Phosphate fertilisers in agricultural areas (Cd).

The heavy metals cadmium, lead and mercury were targeted in the 1998 Aarhus Protocol as the environment and human health were expected to be most at risk from adverse effects of these metals. Recently, the Task Force on Health reviewed the health risks of cadmium, lead and mercury from long-range transboundary air pollution in greater detail (Task Force on Health, 2007). Atmospheric deposition of metals has a direct effect on the contamination of crops used for animal and human consumption.

The ICP Vegetation is addressing a short-fall of data on heavy metal deposition to vegetation by coordinating a well-established programme that monitors the deposition of heavy metals to mosses. The programme, originally established in 1980 as a Swedish initiative, involves the collection of naturally-occurring mosses and determination of their heavy metal concentration at five-year intervals. Surveys have taken place every five years since 1980, with the four most recent surveys being pan-European in scale. Ca. 6,000 moss samples have been collected in 28 countries in the most recent 2005/2006 European survey. Spatial and temporal trends (1990 – 2005) in the concentrations of heavy metals in mosses across Europe have been described by Harmens *et al.* (2008a). The next European moss survey is scheduled for 2010.

1.2.3 Nitrogen

The ICP Vegetation agreed at its 14th Task Force Meeting (January 2001) to include consideration of the impacts of atmospheric nitrogen deposition on (semi-)natural vegetation within its programme of work. This stemmed from concern over the impact of nitrogen on low nutrient ecosystems such as heathlands, moorlands, blanket bogs and (semi-)natural grassland (Achermann and Bobbink, 2003). Plant communities most likely at risk from both enhanced nitrogen and ozone pollution across Europe were identified (Harmens *et al*., 2006). A pilot study has shown that mosses can be used as biomonitors of atmospheric nitrogen deposition in Scandinavian countries (Harmens *et al*., 2005). As a follow-on study, 16 countries participating in the European heavy metals in moss survey 2005/6 have also determined the total nitrogen concentration in mosses (almost 3,000 samples) to assess the application of mosses as biomonitors of nitrogen deposition at the European scale. In a recent pilot study, the ICP Vegetation assessed the evidence for the impacts of nitrogen on vegetation by: a) identifying locations of sensitive 'Heathland' and 'Grassland' EUNIS[2] classes with likelihood of exceedance of empirical critical loads of nitrogen for the EMEP domain, and b) developing a meta-database describing national surveys on nitrogen impacts on vegetation (Hicks *et al*., 2008). There are many groups within Europe studying the atmospheric nitrogen fluxes and its impact on vegetation (e.g. Nitrogen in Europe (NinE), NitroEurope, COST 729). In the last year, the ICP Vegetation has started to synthesise the main results on impacts of nitrogen on vegetation for the benefit of the LRTAP Convention and is also contributing to the work of the Task Force on Reactive Nitrogen.

1.3 Work-plan items for the ICP Vegetation in 2009

The following activities were agreed at the 27th session of the WGE to be priority areas of work for the ICP Vegetation in 2009:

- Report on the risk of ozone damage to (semi-)natural vegetation communities in Europe;
- Report on flux-based assessment of risk of ozone damage to managed pastures in Europe;

[2] European Nature Information System

- Report on ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States;
- Report on the spatial variation in heavy metal and nitrogen concentrations in mosses;
- Report on the temporal trends in heavy metal concentrations in mosses between 1990 and 2005.

In addition, the ICP Vegetation was requested by the WGE to contribute to the following common items on the WGE work-plan:

- Status report on airborne nitrogen impacts on the environment (in collaboration with the Task Force on Reactive Nitrogen and the Task Force on Integrated Assessment Modelling);
- Compilation report on selected key monitored and modelled parameters, tentatively based on the guidelines on reporting of monitoring and modelling of air pollution effects;
- Report on the update of the strategy of the effects-oriented activities;
- Explore merits of the different options for target setting in 2020 and non-binding aspirational targets for the year 2050 (in collaboration with the Task Force on Integrated Assessment Modelling and the Centre for Integrated Assessment Modelling);
- Further quantification of policy-relevant effects indicators such as biodiversity change, and to link them to the integrated modelling work.

Progress with each of these WGE work-plan activities is described in Chapter 3, whilst developing areas of research for the ICP Vegetation are described in Chapter 4. Chapter 5 of this report summarises the key achievements in 2008/9 together with the medium-term work-plan for 2010/11 (updated at the 22nd ICP Vegetation Task Force Meeting, 2 – 4 February 2009, Braunschweig, Germany).

2. Coordination activities

2.1 Annual Task Force Meeting

The Programme Coordination Centre organised the 22nd ICP Vegetation Task Force Meeting, 2 - 4 February 2009 in Braunschweig, Germany, in collaboration with the local host at the Institute of Biodiversity, Johann Heinrich von Thünen-Institute (vTI). The meeting was attended by 57 delegates from 20 Parties to the Convention. Also present were the secretariat for the LRTAP Convention at the United Nations Economic Commission for Europe (UNECE), the chairman of the ICP Modelling and Mapping, the chairman of the ICP Forests Working Group on Ambient Air Quality, a representative from EMEP/MSC-East and two experts from South Africa. The Task Force discussed the progress with the work-plan items for 2009 (see Section 1.3) and the medium-term work-plan for 2010 - 2011 (see Section 5.2) for the air pollutants ozone, heavy metals and nutrient nitrogen. A book of abstracts, details of selected presentations and the minutes of the 22nd Task Force Meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk). The main decisions made at the Task Force meeting for the future work programme of the ICP Vegetation were as follows:

Ozone – activities fall into three main subject areas: state of knowledge reviews, biomonitoring (i.e. extending the new bean biomonitoring experiment), and contributions to flux-effect modelling. In collaboration with the Convention secretariat and the European Commission Joint Research Centre, the Programme Coordination Centre is organising the an ozone workshop on 'Flux-based assessment of ozone effects for air pollution policy', 10 – 12 November 2009, Ispra, Italy. The aim of the workshop is to improve application of flux-based methods described in the Modelling and Mapping Manual (LRTAP Convention, 2004).

Heavy metals and nitrogen – to conduct the next European heavy metals and nitrogen in mosses survey in 2010, report on factors influencing heavy metal and nitrogen concentration in mosses, study in detail the relationship between heavy metal/nitrogen concentrations in mosses and modelled atmospheric depositions and/or air concentrations (in collaboration with EMEP), and review the relationship between heavy metal/nitrogen concentration in mosses and impacts on ecosystems.

The 23rd Task Force Meeting will be held at Veterinary and Agrochemical Research Centre (CODA – CERVA) in Tervuren, Belgium, from 1 – 3 February 2010.

2.2 Reports to the Working Group on Effects

The ICP Vegetation Programme Coordination Centre has reported progress with the above work-plan items in the following documents for the 28th session of the WGE (http://www.unece.org/ env/lrtap/WorkingGroups/wge/28meeting.htm):

- ECE/EB.AIR/WG.1/2009/3: Joint report of the ICPs and Task Force on Health;
- ECE/EB.AIR/WG.1/2009/9: Technical report from the ICP Vegetation on 'Impacts of ozone and nitrogen on vegetation and trends in nitrogen and heavy metal concentrations in mosses';
- ECE/EB.AIR/WG.1/2009/15: Effects of airborne nitrogen;
- ECE/EB.AIR/WG.1/2009/16: Indicators and targets for air pollution effects.

The ICP Vegetation Programme Coordination Centre has also contributed to the following WGE document:

- ECE/EB.AIR/WG.1/2009/14: Draft long-term strategy.

The Programme Coordination Centre for the ICP Vegetation has produced the current annual glossy report and a two-page colour brochure on ‘Evidence of widespread ozone pollution damage to vegetation in Europe (1990 – 2006)’. In addition, it contributed to a chapter on the relationships between nitrogen concentrations in mosses and modelled atmospheric depositions in the EMEP Status Report 1/2009. Analyses on the relationship between heavy metal concentrations in mosses and modelled atmospheric depositions were reported in the EMEP Status Report 2/2009 and the EMEP/MSC-East Technical report 1/2009.

2.3 Scientific papers and book chapters

Emberson, L.D., Büker, P., Ashmore, M.R., Mills, G., Jackson, L., Agrawal, M., Atikuzzaman, M.D., Cinderby, S., Engardt, M., Jamir, C., Kobayashi, K., Oanh, N.K., Quadir, F., Wahid, A. (2009). Dose-response relationships derived in North America underestimate the effects of ozone (O_3) on crop yields in Asia. Atmospheric Environment 43: 1945-1953.

Harmens, H., Norris, D.A., Cooper, D.M., Schröder, W., Pesch, R., Holy, M., Fagerli, H., Alber, R., Coşkun, M., De Temmerman, L., Frolova, M., Jeran, Z,, Kubin, E., Leblond, S., Liiv, S., Maňkovská, B., Santamaría, J., Suchara, I., Thöni, L., Yurukova, L., Zechmeister, H.G. (submitted). Mosses as biomonitors of atmospheric nitrogen deposition: potential application at Natura 2000 sites. In: Proceedings COST 729 workshop on ‘Nitrogen Deposition and Natura 2000. Science and practice in determining environmental impacts’, 18 - 20 May, 2009, Brussels, Belgium.

Mills, G., Hayes, F., Norris, D., Harmens, H., Simpson, D. (submitted). Widespread ozone damage to crops and (semi-)natural vegetation in Europe (1990 – 2006) is better described by flux-based than AOT40-based risk maps. Global Change Biology.

Vandermeiren K., Harmens H., Mills G., De Temmerman L. (2009). Impact of ground-level ozone on crop production in a changing climate. In: Climate Change and Crops (Ed. S.N. Singh). Springer, Germany. ISBN: 978-3-540-88245-9.

3. Ongoing research activities in 2008/9

In this chapter, progress made with the WGE common work-plan items and the ICP Vegetation work-plan for 2009 is summarised.

3.1 Contributions to WGE common work-plan items

3.1.1 Status report on airborne nitrogen impacts on the environment

The consequences of nitrogen enrichment (eutrophication) for ecosystems are a concern in many areas within the ECE region due to the continued high emission and depositions of reactive nitrogen. European areas at risk from eutrophication are predicted to decline only marginally from 49% in 2000 to 47% in 2020 based on current legislation emission scenarios (Hettelingh *et al*., 2008). In 2009, the Programme Coordination Centre of the ICP Vegetation conducted a literature review with the aim of synthesising current knowledge on the impacts of airborne nitrogen on vegetation; a summary of the review is presented below.

Lichens and mosses contain species that are among the most sensitive to elevated atmospheric nitrogen deposition. Therefore, critical levels of ammonia have recently been set at a lower concentration (1 µg m^{-3}) for lichens and mosses (and ecosystems where lichens and mosses are a key part of ecosystem integrity) than for higher plants (3 µg m^{-3}; ECE/EB.AIR/WG.5/2007/3; Cape *et al*., 2009). Lichen communities in mixed conifer forests in an American Mediterranean climate were affected at nitrogen depositions above 3.1 kg N ha^{-1} y^{-1}, affecting food webs and other wildlife (Fenn *et al*., 2008).

Sensitive habitats with low empirical critical loads for nitrogen include raised and blanket bogs, nutrient poor mires, tundras, *Racomitrium* containing wet heathlands, and arctic, alpine and subalpine scrub habitats (ECE/EB.AIR/WG.1/2003/14; Bobbink *et al*. 2003, in press). Despite conservation efforts, many lowland heaths in Western Europe have become dominated by grass species over the past 20-50 years. The shift from dwarf shrub to grass dominance is triggered by opening of the canopy caused by for example heather beetle attacks, frost damage or drought, which in its turn is affected by the nitrogen concentration in the plants (Bobbink *et al*., in press). For boreal forests, it was recently recommended to reduce the current empirical critical load of 10-20 kg N ha^{-1} y^{-1} to 5-10 kg N ha^{-1} y^{-1} (ECE/EB.AIR/WG.1/2007/15).

The loss or decline in abundance of species with a high retention efficiency (so called nitrogen 'filters') such as mosses and lichens results in an increase in the amount of inorganic nitrogen available to higher plants and soil microbes (Emmett, 2007). Elevated nitrogen availability favours faster growing, more nitrogen-loving species, leading to competitive exclusion of plants adopted to low nitrogen availability, ultimately resulting in a decrease in plant diversity. In addition, secondary factors associated with enhanced nitrogen supply are stimulated, such as soil acidification and susceptibility of plants to herbivory, frost and wind damage and drought. Recently it has been hypothesised that the onset of nitrogen leaching is due to the loss of species with high nitrogen retention efficiency and the suppression of microbial immobilisation of deposited nitrate due to increased ammonium availability in the early stages of nitrogen saturation (Emmett, 2007). Nitrogen leaching can result in eutrophication of ground and surface waters. Assessment in terms of biomass and/or physiological health of mosses and lichens may provide a useful indicator of early stages of nitrogen saturation and the onset of nitrogen leaching in some habitats.

Plant species that are characteristic for low nitrogen conditions are particularly sensitive to airborne nitrogen pollution. Some of the most species-rich, infertile grasslands are often found in weakly buffered or neutral conditions, which makes them sensitive to acidification and negative impacts of ammonium. For example, acid grasslands in the UK showed a large decline in species richness with increased nitrogen deposition above 10-15 kg N ha^{-1} y^{-1} (Stevens *et al*., 2004). In grasslands, there is evidence that enhanced nitrogen deposition affects forbs negatively with reduced flowering occurring, whilst grasses increase in abundance. (Semi-)natural vegetation with minimal empirical critical loads extending below 10 kg N ha^{-1} y^{-1}, such as 'Alpine and subalpine grasslands' and 'Arctic, alpine and subalpine scrub habitats' were predicted to be most at risk of elevated nitrogen inputs (Hicks *et al*., 2008). Upland areas are also most prone to wet deposition of high nitrogen due to cloud droplets and precipitation. Many of the rarer species occur in early successional habitats such as coastal habitats. In sand dunes, rarer species are highly susceptible to nitrogen-deposition driven soil and vegetation changes (UKREATE, 2007).

Impacts of eutrophication on vegetation can manifest itself as changes in species frequency or abundance, changes in species composition or ultimately a decline in species richness, i.e. plant biodiversity. Species change or loss may be quite sensitive to nitrogen availability and occur early in the sequence of nitrogen saturation (up to 15 kg N ha^{-1} y^{-1}). Surveys conducted in recent decades might not show significant changes in ground vegetation with time as a result of baseline assessments being made at times at which vegetation changes have already happened and adaptation to higher nitrogen inputs has occurred (Emmett, 2007). Past conditioning (above 10 kg N ha^{-1} y^{-1}) may have already led to loss of rare or sensitive species. Recovery from eutrophication can be a very slow process and it might already be later then we think.

The impacts of nitrogen on European Mediterranean vegetation has hardly been studied. In Mediterranean climates dry deposition (gases and particulates) of nitrogen prevails. The first autumn rain washes and dissolves accumulated particulates, resulting in a nitrogen pulse that is not reflected in the annual deposition. Evidence from California showed that the major risk of nitrogen deposition on plant biodiversity in 'Mediterranean' climates is an increase in invasive annual grasses in low biomass nutrient poor ecosystems, resulting in species loss at rather low nitrogen loads of 10-15 kg N ha^{-1} y^{-1} (Fenn *et al*., 2008).

The ICP Vegetation participated in the second meeting of the Task Force on Reactive Nitrogen, 28 - 29 April 2009, Garmish-Partenkirchen, Germany and contributed to the COST 729 workshop on 'Nitrogen Deposition and Natura 2000. Science and practice in determining environmental impacts', 18 - 20 May 2009, Brussels, Belgium. At the 25th Task Force Meeting of the ICP Modelling and Mapping it was proposed to organise a new workshop on Emperical Critical Loads for nitrogen in the spring of 2010, which will reflect new scientific knowledge since the previous workshop in 2002 (Achermann and Bobbink, 2003).

3.1.2 Explore merits of the different options for target setting in 2020 and non-binding aspirational targets for the year 2050

In 2008, the Executive Body of the Convention took note of the evidence provided by the ICP Vegetation on the widespread ozone damage to vegetation (Hayes *et al*., 2007b) and decided at its 26th session that the latest scientific knowledge and data should be used, in particular that ozone effects on vegetation be incorporated in integrated assessment modelling, especially in work for the revision of the Gothenburg Protocol, and recommended that flux-based methods be used (LRTAP Convention, 2009a). It also noted that the implementation of existing legislation would not attain the ambition levels set out in article 2 of the Gothenburg Protocol, in particular, it would not provide a significant reduction in effects of ozone on health and vegetation, and the policies aiming only at health effects would not protect vegetation in large areas of Europe (see Mills *et al*., 2008). Based on this decision, risk assessments of ozone impacts on vegetation should be flux-based.

The Programme Coordination Centre participated in a workshop on non-binding aspirational targets for air pollution for the year 2050, organised by the Task Force on Integrated Assessment Modelling, 5 - 6 March 2009, Utrecht, The Netherlands. Regarding ozone impacts on vegetation, political aspirations for 2050 should be based on avoiding all detectable adverse effects of ozone on the:

- Yield quantity and quality of agricultural and horticultural crops (including forage);
- Growth of individual species and biodiversity of (semi-)natural vegetation;
- Leaf appearance and growth of forest trees;
- Ecosystem services (including carbon sequestration) of vegetation.

At current climatic conditions, a reduction of 75% of the generic ozone flux ($AF_{st}3_{gen}$) to crop species would result in more than 90% of EMEP grid squares, currently showing evidence of ozone damage to vegetation (Hayes *et al.*, 2007b), being within the 'damage unlikely' category (Figure 3.1).

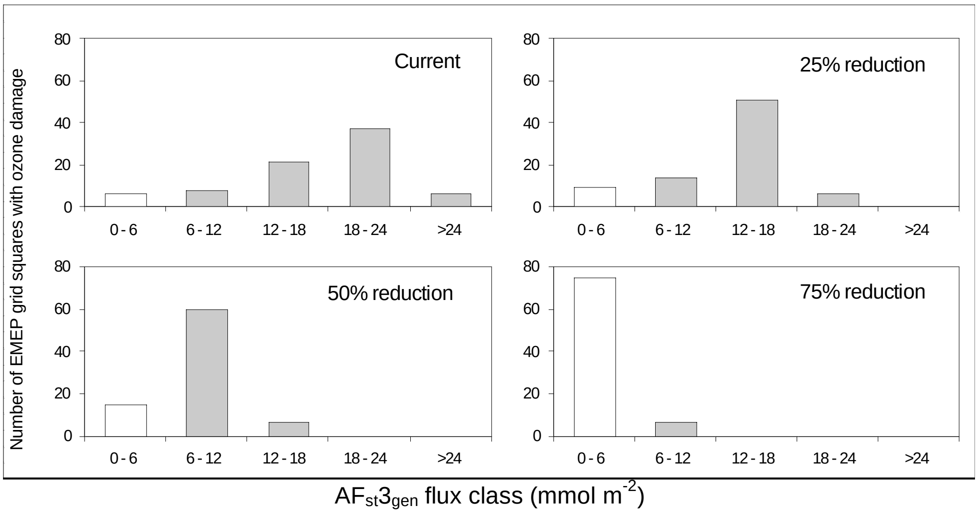

Figure 3.1. Number of EMEP grid squares with ozone damage at the current generic ozone flux (mean of 1995-2004) and at 25, 50 and 75% reduction in the current generic ozone flux to crops. Note: ozone damage is unlikely to occur up to a generic flux of 6 mmol m^{-2} (white bars).

An advantage of the flux-based compared to the concentration-based (AOT40) method is that the generic flux models can be applied to the predicted climate in 2050 (Table 3.1); climate change cannot be considered using the AOT40 approach.

Table 3.1. Factors that can be taken into account using generic ozone flux models regarding predicted climate change for 2050.

2050 climate	**Can be taken into account using generic flux models**
Changes in ozone profile	Yes
Increases in temperature	Yes
Changes in vapour pressure deficit	Yes
Increase in atmospheric CO_2 concentration	By including a factor to simulate reduced stomatal conductance with enhanced CO_2 concentration
Changes in soil water availability	Irrigation assumed for crops where water supply is limited; would need to use full flux model for trees

The ‘gap closure’ principal as used before for critical loads/levels, or other cost-effective strategies that would prioritize areas with high ozone fluxes, could be useful for defining interim targets for 2020. At the next ozone workshop on ‘Flux-based assessment of ozone effects for air pollution policy’, 10 – 12 November 2009, Ispra, Italy, current ozone flux methods and their application to different climatic regions will be reviewed with the overall aim to improve application of the flux-based methods (LRTAP Convention, 2004). In addition, interim targets for 2020 will be considered during this workshop.

3.1.3 Compilation report on selected key monitored and modelled parameters

At its 26th session in December 2008, the Executive Body of the LRTAP Convention approved the ‘Guidelines for reporting of the monitoring and modelling of air pollution effects’ (LRTAP Convention, 2009b), as adopted at the 26th session of the WGE in September 2008 (ECE/EB.AIR/WG.1/2008/16/Rev.1). The Executive Body decided that the exchange of information on effects between Parties of the Convention should take place in accordance with these Guidelines. The Executive Body recommends that Parties within the geographical scope of EMEP should use the Guidelines when preparing and reporting their annual submissions on air pollution effects and exchanging available similar information. The ICP Vegetation is currently reporting on the following suggested key parameters:

- *Eutrophication effects on terrestrial ecosystems*: Total nitrogen concentration in mosses (currently not included in Annex 2 of the Guidelines);
- *Ground-level ozone effects on vegetation*: Leaf damage, growth and yield reduction, climatic factors, exceedance of AOT40 values, accumulated flux exceedance;
- *Heavy metal effects on ecosystems*: Concentrations of heavy metals in biota (mosses in particular).

3.1.4 Further quantification of policy-relevant effects indicators

The ICP Vegetation has developed methods for ozone, which are technically ready for use in integrated assessments. These include the generic flux model for crops and trees, and concentration-based critical levels for (semi-)natural vegetation. A generic ozone flux for (semi-)natural vegetation is currently being developed. Maps of the generic ozone flux to vegetation should be used to indicate the risk of damage for a given scenario. However, it is currently not possible to quantify loss in for example agricultural production as the generic flux method does not have a dose-response function attached for each receptor.

3.1.5 Report on the update of the strategy of the effects-oriented activities

For further details we refer to ECE/EB.AIR/WG.1/2009/14.

3.2 Progress with ICP Vegetation work-plan items

3.2.1 Risk of ozone damage to (semi-)natural vegetation communities in Europe

<u>Inclusion of community-related factors within the Ellenberg model</u>
The Programme Coordination Centre established a database named OZOVEG (OZOne impacts on VEGetation) incorporating all published data on the sensitivity to ozone of individual species of (semi-)natural vegetation grown in a non-competitive environment (Hayes *et al*., 2007a). Data were selected for inclusion from field-release, open-top chamber or solardome experiments involving seasonal ozone exposure. The modelling approach developed showed that sensitivity to ozone of individual species could be predicted using a parsimonious model based on Ellenberg Light and Salinity scores, which were the best predictors of ozone sensitivity (Jones *et al*., 2007). Recently, the Ellenberg modelling method

was expanded to include as far as possible the complex interactions, which may alter the response of the whole community to ozone, including competition, canopy/species height, position in canopy, growth form, relative growth rate and nitrogen sensitivity.

Table 3.2. Results of testing modifying factors on the predicted ozone sensitivity for five grassland ozone-exposure experiments, and comparison with observed biomass changes. Columns show: the number of species present in the experimental community; the number of species with sufficient information for use in predicting sensitivity of the vegetation community; the observed biomass change; the relative biomass change standardised as the difference between exposure at 15 ppmh and 3 ppmh for direct comparison with the Ellenberg prediction method; the predicted biomass change using the Ellenberg prediction tool ORI% (Ozone Response Index); the effect of each modifier on the predicted sensitivity, where - predicts lower sensitivity, + predicts greater sensitivity, and = predicts little change in ozone sensitivity; RGR = relative growth rate.

					Modifiers effect on prediction of community sensitivity				
Data source	No. spp in full species list	No. spp used for prediction	Standardised Relative Biomass Change (15 ppmh/3 ppmh)	Predicted biomass change (ORI%)	Plant height	Life form	Ellen-berg N	RGR	Compe-tition modifier
Le Meuret, Swiss grassland in-situ fumigation. 4 years data.	50	12 - 25	-8.5 to -1.2%	-6.75	-	=	-	+	-
Newcastle, grassland mesocosms, OTC. 2 years data.	12	5 - 7	-26.2 to -14.0%	-7.77	- -	=	-	-	- -
Finland, sown species mix. OTC. 2 years data.	7	2 - 3	-93.6 to -53.4%	-10.66	=	=	=	-	-
Bangor, sown 7 spp mix. Solardomes. 2 years data.	7	4 - 6	-6.3 to -0.4%	-6.44	+	=	+	=	=
Bangor, sown 8 spp mix. Solardomes. 1 year data.	8	4 - 8	-1.9%	-0.75	+	=	=	=	=

Community level data available for testing the modifiers were derived from five experiments: a field-release ozone exposure experiment on upland grassland at Le Meuret, Switzerland; an open-top chamber experiment run at Newcastle, UK, using sown mesocosms with species from a British MG3 (*Anthoxanthum odoratum* - *Geranium sylvaticum*) mesotrophic grassland; a sown mesocosm experiment using 6 species, exposed in open-top chambers in Jokioinen, Finland (Rämö *et al.*, 2007) and two mesocosm experiments using 7 and 8 species respectively exposed in the solardomes facility at Bangor, UK.

For each community, the observed ozone biomass change is shown for the highest ozone treatment relative to the control (Table 3.2). This was also standardised to the biomass change that would have occurred at an AOT40 of 15 ppm h relative to that at 3 ppm h for direct comparison with the predictions from the Ellenberg predicted biomass change (ORI%) method (Jones *et al.*, 2007). The effect of each modifier shows whether it increases (+) or decreases (-) the predicted sensitivity, or has no effect (=). Effects on the ability of the modified model to predict observed effects are included in Table 3.3 for each modifier. In general, there were no consistent effects of including each modifier other than the 'no change' effect for inclusion of life form. Competition effects were species-specific and when included for the 22 species for which data was available, ozone sensitivity was decreased for three of the five communities. Plant height decreased the predicted ozone sensitivity for two communities, and increased it for another two. This led to an improved prediction for the Le Meuret and the Bangor 8 species-mix data, and a worse prediction for the Newcastle and the Bangor 7 species-mix data. Although some authors e.g. Bassin *et al*. (2007) suggest that species with a high relative growth rate are more sensitive to ozone, inclusion of relative growth rate in the model led to a worse prediction for three communities and had no effect on the prediction for the other two communities. The effects of nitrogen on ozone sensitivity are complex. In fast-growing species, nitrogen may enhance sensitivity to ozone, while in slow-growing species with well-developed detoxification mechanisms, nitrogen may provide extra resources for defence and repair. Inclusion of Ellenberg N (nutrient indicator value) in the model decreased the predicted sensitivity of two communities and increased the predicted sensitivity for one community. This led to an improved prediction for the Le Meuret data, but a worse prediction for the Newcastle and the Bangor 7-species mix data.

Table 3.3. Summary of effects of modifiers on the Ellenberg model predictions of ozone sensitivity for five grassland ozone-exposure experiments. 'Much Better' and 'Better' denote an improved modelled prediction compared with the observed relative biomass change, 'Much Worse' and 'Worse' denotes a worse prediction, and '=' denotes no change in the prediction. RGR = relative growth rate.

Data source	Plant height	Life form	Ellenberg N	RGR	Competition modifier
Le Meuret, Swiss grassland in-situ fumigation. 4 years data.	Better	=	Better	Worse	Better
Newcastle, grassland mesocosms, OTC. 2 years data.	Much worse	=	Worse	Worse	Much worse
Finland, sown species mix. OTC. 2 years data.	=	=	=	Worse	Worse
Bangor, sown 7 spp mix. Solardomes. 2 years data.	Worse	=	Worse	=	=
Bangor, sown 8 spp mix. Solardomes. 1 year data.	Better	=	=	=	=

In summary, the effect of the modifiers was experiment-specific, with the tested modifiers improving predictions in some communities but not for others. None of the modifiers consistently improved the prediction of ozone sensitivity (Table 3.3). Therefore, on the basis of testing against experimental community data none of the modifiers can be recommended as consistently improving the Ellenberg model. This may reflect the lack of suitable *in situ* community-scale ozone exposure data with which to test the model, as well as the complexity of ozone responses and interactions with other environmental factors in the natural environment.

<u>Extending the Ellenberg modelling approach to the prediction of ozone sensitivity for European grasslands</u>

European grasslands were chosen as the test habitat as they are also the focus of the flux-modelling approach and the selected communities have critical loads for nutrient nitrogen defined (Bobbink *et al*., 2003), allowing parallel determination of the sensitivity to both ozone and nitrogen pollution. Two Mediterranean grasslands which lack critical load information were also included allowing extension of the Ellenberg approach to southern Europe (Table 3.4).

For each grassland, a list of typical or defining species was obtained from the habitat descriptions for Natura 2000 habitats matching the EUNIS classification according to correspondence tables developed by Moss and Davies (2002). Ellenberg numbers for each species (Ellenberg *et al*., 1991) were derived from a MS Access database, checking manually for synonyms and sub-species where gaps appeared. The ozone sensitivity index CORI (community ozone response index) was calculated for each community using the formula described by Jones *et al*. (2007), which predicts ozone sensitivity as a function of Ellenberg Light and Salinity scores for each species. The equation was modified for coastal species with high salinity scores such that salinity <=1, as salinity values greater than one were outside the range of values used to develop and test the prediction model.

Table 3.4. Ozone and nitrogen sensitivity of European grassland communities showing the number of species used in the prediction of ozone sensitivity expressed as the community ozone response index (CORI, scaled 0-10 of increasing sensitivity), coefficient of variation (CV%) of individual species predictions, reliability score of the prediction, and the critical load range and midpoint for nutrient nitrogen from Bobbink et al. (2003).

EUNIS code	Habitat description	No. spp.	CORI	CV %	Reliability	CL Range	CL Midpoint
B1.3	Shifting coastal dunes†	12	5.12	15.1	Medium	10 - 20	15
B1.4	Coastal stable dune grassland (grey dunes)†	27	2.86	15.3	High	10 - 20	15
E4.4	Calcareous alpine and subalpine grassland	52	2.48	12.5	High	10 - 15	12.5
E1.94 & E1.95	Inland dune siliceous and pioneer grasslands	6	2.13	10.2	Low	10 - 20	15
E3.51	Molinia caerulea meadows	28	2.08	13.9	High	15 - 25	20
E4.3	Acid alpine and subalpine grassland*	35	1.98	12	High	10 - 15	12.5
E1.26	Sub-atlantic semi-dry calcareous grassland	44	1.89	12	High	15 - 25	20
E1.7	Non-Mediterranean dry acid and neutral closed grassland	43	1.85	12.1	High	10 - 20	15
E2.3	Mountain hay meadows	27	1.6	10.6	High	10 - 20	15
E2.2	Low and medium altitude hay meadows	15	1.34	7.8	Medium	20 - 30	25
E1.55	Eastern sub-Mediterranean dry grassland	6	2.14	13.2	Low		
E3.1	Mediterranean tall humid grassland	20	3.48	21.2	Medium		

† Maximum Ellenberg Salinity values adjusted so that S <=1.

* Prediction excludes calcareous alpine grasslands, which also map to this community according to Moss and Davies (2002).

Table 3.4 shows the prediction of ozone sensitivity for the 12 grassland habitats selected. Each prediction also carries a reliability score based on the number of species used to calculate sensitivity, as a minimum of 9 species were required to reliably estimate CORI to within 5% (Jones *et al*., 2007): Low: < 9 species, Medium: 9 - 20 species, High: > 21 species. Two communities, Inland dune siliceous and pioneer grasslands, and Eastern sub-Mediterranean dry grasslands had a low reliability score, however, the coefficients of variation were relatively low (< 15%), and the CORI predictions based on the current species complement are unlikely to change substantially with the addition of further species. Therefore, all the predictions can be considered methodologically robust.

Of grassland communities that could be included in this modelling approach, those predicted to be most sensitive to ozone are coastal communities, CORI = 5.12 for shifting coastal dunes, with the prediction driven by both high Ellenberg Light values as well as higher

Salinity values. The other grassland communities show lower sensitivity, CORI ranging from 1.34 – 3.48, with Mediterranean tall humid grasslands (CORI = 3.48) and Calcareous alpine and subalpine grassland (CORI = 2.48) the most sensitive after the coastal communities. These predictions reflect a potential ozone impact on the stability of the character of the communities, since the species lists used in the predictions reflect the typical and defining species, including species of conservation interest, rather than a definitive species list. For this reason, predictions of percentage change in cover due to ozone (ORI%) are not given. In a wider–ranging study using the proportion of species that are ozone–sensitive from those tested for ozone sensitivity as an indicator of sensitivity, other vegetation types such as upland grasslands, shrub heathland, forest fringes, dry and wet grasslands were also predicted to be ozone sensitive (Mills *et al*., 2007). A comparison of sensitivity to ozone and to nitrogen, based on critical load ranges for nutrient nitrogen (Table 3.4), suggests that sensitivity to ozone and to atmospheric nitrogen deposition are unrelated, or that there is a weak negative relationship. This relationship could also be tested for other communities such as heathland and bogs using the same approach.

3.2.2 Flux-based assessment of risk of ozone damage to managed pastures in Europe

<u>Development of a productive grassland ozone flux model</u>
A first version of the DO_3SE (Deposition of Ozone and Stomatal Exchange) grassland flux model was developed in 2006/7 (Ashmore *et al*., 2007). This model assumed a uniform canopy ('big-leaf' model) and was parameterised for productive grasslands based on ryegrass (*Lolium perenne*) data, a dominant species of this grassland-type. When applying this to five different locations across Europe, the need for a better description of leaf area index (LAI) and phenology became clear. As grasslands are complex structures comprising a range of different species, the existing grassland flux model was further developed by introducing a multi-layer modelling approach and a parameterisation based on two plant functional types (grasses and legumes) to develop improved risk assessments. A comprehensive search for both primary and secondary datasets was performed to achieve this parameterisation as a precondition for applying the flux model on a regional (i.e. European) scale. This application also considered additional factors (e.g. nitrogen supply) that might influence ozone flux into grasslands.

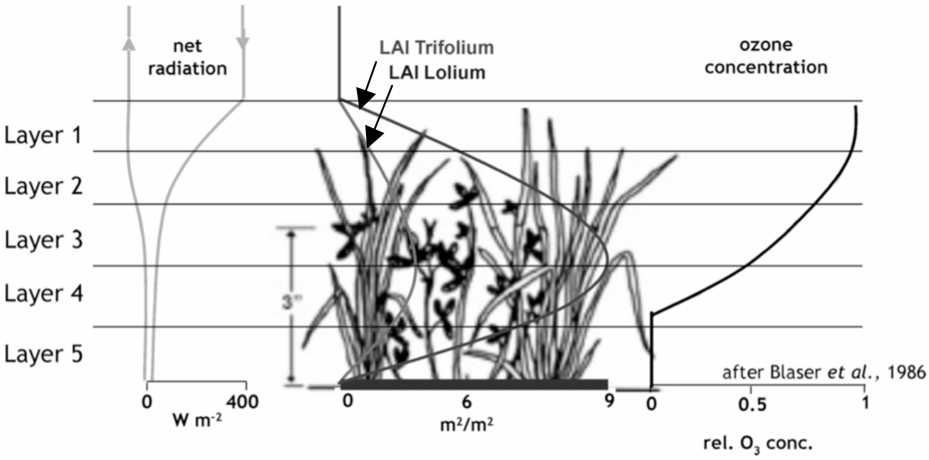

Figure 3.2. Schematic of the multi-layer model framework accounting for vertical profiles of leaf area index (LAI), net radiation and ozone concentration.

The multi-layer DO_3SE model for productive grassland canopies uses formulations consistent with the stomatal component of the DO_3SE described in Simpson *et al*. (2003).

Separate parameterisations were performed for the two functional types using information on ryegrass (*Lolium perenne*) and the legume white clover (*Trifolium repens*). The whole canopy ryegrass/clover flux model was developed as a multi-layer model (Figure 3.2) comprising of 5 layers in total. This was necessary to allow for the variation in LAI fractions of legumes and grasses, light penetration and ozone concentration to be incorporated in the assessment of ozone flux to component species of the canopy.

<u>Canopy flux-effect relationship for productive grasslands</u>
Several researchers across Europe were contacted as possible sources of data for flux-effect modelling but at the time only two datasets were found to be suitable:

(1) Data from solardome experiments conducted at CEH Bangor, UK in 2002 in which the two species were exposed to two ozone treatments (30 ppb control and a 4d per week episodic regime peaking at 100 ppb with 30 ppb for the other days; Hayes *et al.*, 2009, submitted).

(2) An experiment carried out in open-top chambers (OTCs) in Liebefeld, Switzerland in which the two species were exposed to four different ozone treatments (cf. Nussbaum *et al.*, 1995).

A third dataset from open-top chamber experiments at Newcastle University, UK has recently been made available (Gonzalez-Fernandez *et al.*, 2008) and will be used to further develop the analysis described below.

a) b)

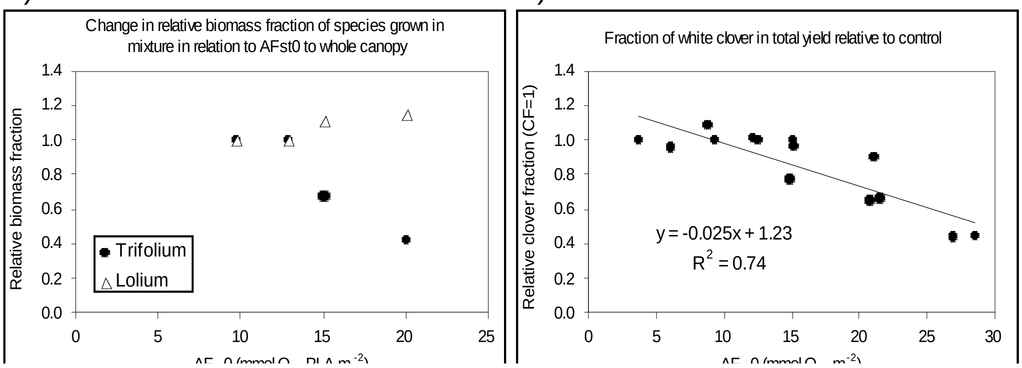

Figure 3.3. (a) Relative dry weight biomass change of *Lolium perenne* and *Trifolium repens* grown in a canopy mixture in relation to whole canopy flux ($AF_{st}0$, mmol O_3 PLA m^{-2}) at Bangor, UK and (b) relative dry weight biomass change of *Trifolium* grown in a canopy mixture in relation to whole canopy flux ($AF_{st}0$, mmol O_3 PLA m^{-2}) at Liebefeld, Switzerland.

Application of the canopy flux model to these two datasets involved further development of the flux model including estimation of direct and diffuse fractions of photosynthetically active radiation (PAR), parameterisation of LAI development and fractionation between the two species and derivation of the phenology function, f_{phen}. For both sets of data, the relative clover fraction decreased with increasing accumulated ozone stomatal flux (Figure 3.3). However, more datasets are needed before a definitive flux-effect relationship can be established. The revised flux models can also be used as tools to investigate the relative importance to ozone flux of different LAI fractions between the two species as well as within the different layers of the canopy.

<u>Application of the European flux-response model</u>
The flux models developed above were parameterised for Europe-wide application based on LAI fractions found in 'real' productive grassland. The fractions used were those described

by Woledge *et al*. (1989) and Hay and Porter (2006) who described species LAI stratification within a canopy over two years. Flux models have been generated for upper canopy leaves (the whole canopy "big leaf" model) as well as the whole canopy of productive grasslands and applied to maps of productive grassland for the year 1997. The accumulated stomatal ozone flux above a threshold of zero ($AF_{st}0$) to the entire canopy estimated using the "Big leaf" canopy model commonly reaches values between 50 and 60 mmol O_3 m^{-2}. By comparison, the $AF_{st}0$ to the individual *Lolium* and *Trifolium* canopy components are all less than 16 mmol O_3 m^{-2}, which as a maximum canopy value would equate to whole canopy accumulated fluxes of about only 30 mmol O_3 m^{-2}. The difference in the accumulated fluxes estimated according to the 'big leaf' and multi-layer flux methods indicate the importance of incorporating the within canopy variation in ozone concentration.

The accumulated stomatal ozone flux assuming no flux threshold ($AF_{st}0$) to the individual clover and grass canopy components of productive grassland shows that the $AF_{st}0$ to the grass fraction tends to be substantially higher (often exceeding 16 mmol O_3 PLA m^{-2}) than the flux to clover (which reaches values of between 14 to 16 mmol O_3 PLA m^{-2} relatively infrequently). This is predominantly driven by the assumed greater LAI fraction of grass in the total canopy (0.6 grass: 0.4 clover). As such, the high clover fluxes extend over a more limited spatial extent than do the higher fluxes to grass canopy component. For the latter, high fluxes are predicted in important regions of productive grasslands in the UK, France, Ireland and southern Scandinavia. These are areas with relatively low AOT40 that would be identified as being at no risk of damage due to ozone using an AOT40-based risk assessment. The canopy flux modelling also indicates that similar fluxes are experienced in some of the most northerly parts of Europe as experienced in the Mediterranean. This supports previous regional scale flux modelling which shows a greater homogeneity in the flux-based compared to concentration-based risk assessments (Simpson *et al*., 2007) and supports the use for flux-based in favour of concentration-based ozone risk assessment at the European scale (Hayes *et al*., 2007b).

Recently, with new data becoming available from other research groups, the multi-layer modelling framework was extended to include three functional types (grasses, legumes and forbes) for the development of a flux-effect model for (semi-)natural grasslands.

<u>Incorporation of nitrogen effects and application at the European scale</u>
Understanding the impact of enhanced nitrogen impact on ozone sensitivity is important to truly understand potential pollutant threat to (semi-)natural communities since in many upland areas these two pollutants co-exist. In relation to flux-based risk assessments, two important variables will be affected by nitrogen deposition, namely leaf area index (LAI) and maximum stomatal conductance (g_{max}).

To understand the influence of nitrogen deposition on LAI, a grassland growth model was employed; this model was developed originally for application to predict changes in productivity in response to climate change to improved grasslands in the UK (e.g. Terry and Woodward, 1994). This grassland growth model can be used to describe the growth patterns represented as LAI under different climatic conditions and management practices. The model has the capacity to simulate morphological and physiological processes of temperate grass growth and adapt automatically to changes in the environment (solar radiation, fractional day length, temperature, humidity, rainfall, soil nitrogen and CO_2 concentration).

Figure 3.4 shows grassland growth model simulations for a location in Continental Central Europe; these model runs have been performed using grid specific data provided by EMEP as input to the model. The grassland growth model has been run to simulate two forms of management. Firstly, the model was run assuming an improved sward with high soil nitrogen (initial soil N content 5 g N m^{-2}) and daily input of nitrate fertiliser of 0.15 g N m^{-2} d^{-1}, and a second simulation using low soil nitrogen (initial soil N content 2.5 kg N m^{-2}) and no fertiliser additions. The very clear difference in the seasonal profile and maximum LAI values resulting from variable soil nitrogen is apparent, with maximum LAI reaching 4 and 8 m^2 m^{-2} respectively for the low and high soil nitrogen simulation. In addition, there is substantial evidence in the literature to suggest that stomatal conductance will be increased under enhanced conditions of nitrogen availability though the extent of this will be species specific. Incorporating the modifying influence of nitrogen on both LAI and g_{max} provides the opportunity to model and hence quantify the impacts of increased nitrogen input on community growth characteristics and ozone sensitivity. The grassland growth modelling of LAI will also provide an opportunity to incorporate climatic variation in LAI which will be a key driver of the variability in ozone flux across Europe.

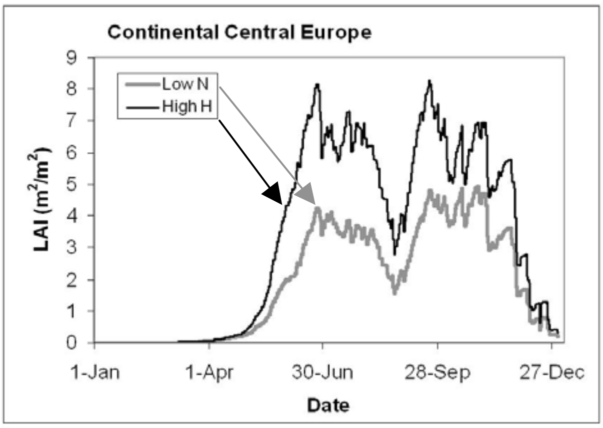

Figure 3.4. Grassland growth model simulations under variable soil nitrogen conditions for a representative site in Continental Central Europe.

<u>Ozone impacts on the nutritive quality of productive grasslands</u>
One aim of this study was to assess the availability of data on ozone effects on the nutritive quality of productive grasslands with a view to including this effect within flux-effect modelling in the future. A literature review revealed 10 studies that showed detrimental effects of ozone on the nutritive quality of the investigated forage species, though with large inter-species variation in response. High values of up to 20% loss in nutritive quality were reported for legumes (e.g. *Trifolium*, *Medicago*), whereas grasses showed a smaller response to ozone exposure with respect to their nutritive quality. The reported loss in nutritive quality has been mainly related to altered cell wall constituents, e.g. an increase in lignified cellulose, neutral detergent fibre and acid detergent fibre, all of which negatively affect the digestibility of the forage.

Plant functional types (i.e. grasses, legumes, forbs) as well as single species react differently to ozone exposure. As described above, there is evidence that legume productivity is more susceptible to ozone impacts than grass growth (Nussbaum *et al*., 1995; Wilbourn *et al*., 1995; Bass, 2006), which may lead to a shift in the grass/legume ratio at the expense of legumes. Since a high proportion of legumes in the community is desirable because of their palatability, digestibility and nutritive value for ruminant animals (Van Soest, 1994), ozone might have a negative indirect impact on the nutritive quality of productive grasslands by reducing the legume fraction. Therefore, ozone might have potentially negative economic effects on livestock production.

In summary, due to sparse experimental information on the impacts of ozone on managed pastures in Europe, it has not yet been possible to develop quantitative flux-effect relationships for biomass, species composition or forage quality that are sufficiently robust for Europe-wide application. Nevertheless, an ozone flux model framework has been established for productive grasslands (and more recently for (semi-)natural vegetation) that can be used to better understand the importance of the certain canopy characteristics that might affect stomatal ozone flux; with appropriate parameterisation, this could in the future be applied at the European scale to identify those areas most at risk of ozone effects on biomass production. Application of the model has highlighted issues for further consideration with regard to continued derivation of flux-effect relationships, mostly associated with our limited understanding of LAI profiles within the canopy and how to interpret fluxes to individual components in terms of whole canopy response to ozone. The importance of accurate simulations of seasonal LAI profiles would appear to be the main requirement for accurate modelling of ozone deposition.

3.2.3 Ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States

In an initiative led by Sweden, ozone impacts on vegetation in the Nordic Countries and the Baltic States have been reviewed. A workshop was held in Gothenburg on 17 - 18 June 2008 to assess current scientific knowledge on adverse impacts of ozone on vegetation. The workshop was attended by 16 experts from Estonia, Finland, Lithuania, the Russian Federation and Sweden. At the workshop, scientific evidence was reviewed on impacts of ozone on vegetation in Northern Europe at current, and future, ambient or near-ambient ozone concentrations. In particular, the importance of the current and future climatic conditions with increasing temperature, prolonged growing season, possibly high humidity in combination with the long summer days at high latitudes was highlighted. Near-ambient ozone concentrations in this context were defined as below twice current ambient concentrations and below a sixth-month (April – September) AOT40 of 20 ppm hours. Scientific papers will be published in a special issue of AMBIO, entitled 'Ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States', by the end of this year. A report of the workshop is available on the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk/publications.htm).

In general, ozone concentrations are higher in the southern part of the region. There is also a significant variation on a smaller geographical scale, which may be related to the local climate. Coastal areas and elevated positions in the landscape tend to experience higher ozone concentrations than inland valleys. Emissions of precursors may be of local-regional importance. Variation in ozone between the six monitoring sites in Estonia indicated a potential effect of emission of ozone precursors at a site nearby a major industrial area. The North European summer is characterised by short summer nights. Since ozone uptake takes place mainly during sunlight hours, the short nights dispose the plants for high ozone uptake and a short period of darkness recovery, in particular in the far north.

There is substantial evidence, especially from Sweden and Finland based on large-scale experimental work, that ozone at levels realistic to Northern Europe has significant effects on vegetation. Forest trees, crops and (semi-)natural vegetation are all affected. For example, in Sweden at ambient ozone levels corresponding to a sixth-month AOT40 of 10 ppm h, ozone impacts included 5 – 30% reduction in crop yield for wheat and potato, 2 – 10% reduction in tree growth and leaf chlorophyll content, variable impacts on vegetables and visible leaf injury on bioindicator plants. From Finland there is considerable experimental evidence that increasing ozone concentrations impairs the growth of several northern deciduous tree species. In Lithuania, visible ozone-induced leaf injuries were observed on various tree species. Scots pine seedlings of several different Russian provenances showed high ozone sensitivity. The considerable ozone impacts observed in the Nordic Countries and Baltic States at relatively low AOT40 values might well be explained by favourable climatic conditions and/or plant development during the summer months, allowing high stomatal ozone fluxes. Phenological aspects require further attention, as there are indications that the ozone sensitivity varies considerably during the growing season.

Several presentations clearly indicated the significance of the interaction between ozone effects and climate change. Firstly, climate change can promote the formation of ozone itself. In addition, climate change may promote higher stomatal conductance of plants in the Nordic climate, thus enhancing ozone uptake and thereby the risk for effects on vegetation. Since periods with high or low ozone concentrations are closely associated with the weather conditions, any changes in the climatic pattern as well as the dominating wind direction, may strongly influence future ozone patterns in the North European region. A significant problem is the rising hemispheric background ozone concentration, which has been shown to lead to rising average ozone concentration in northern Fennoscandia as well as in coastal Lithuania. This development is likely to continue in the next decades.

An important issue in relation to climate change is the possible impact of ozone on carbon sinks. The boreal forest is today mainly a carbon sink, which tends to remove carbon dioxide from the atmosphere. Aspen and birch forestry offer the greatest potential to offset global carbon emissions and help to mitigate climate change in large areas of Northern Europe. However, recent open-air experiments have indicated the high susceptibility of these species to several environmental stress factors including ozone (e.g. Kontunen-Soppela *et al*., 2007), although the variation in ozone tolerance among genotypes is high. A better understanding of ozone tolerance is needed for estimates of carbon sink strength and greenhouse gas mitigation in a future climate, and for forest tree breeding programmes, related to acclimation and adaptation to increasing oxidative stress. Long-term experiments with birch have indicated that ozone effects are cumulative, leading to increased sensitivity with exposure time and tree size. If ozone negatively affects the net carbon removal from the atmosphere through photosynthesis, this will lead to enhanced warming.

In summary, this study has indicated that:

- Near ambient ozone concentrations in the Nordic countries and the Baltic states affect various vegetation types;
- Ozone concentrations, especially the background, are likely to rise in the near future;
- Climate change may alter the rate of leaf ozone uptake, as well as the vegetation response to ozone exposure;
- The Northern European climate has short summer nights, permitting ozone uptake during many hours of the day and very limited darkness recovery;
- Continued monitoring and research into ozone effects are essential as part of the environmental studies in the Nordic countries and the Baltic states;
- The AOT40 concept that has been used in the last decade is likely to underestimate effects in Northern Europe;
- It is essential that risk assessments for negative impacts of vegetation are based on leaf ozone uptake instead of the ozone concentrations in the air.

3.2.4 Spatial variation in heavy metal and nitrogen concentrations in mosses

The European moss biomonitoring network was originally established in 1990 to estimate atmospheric heavy metal deposition at the European scale (Rühling, 1994). The moss technique is based on the fact that carpet-forming, ectohydric mosses obtain most trace elements and nutrients directly from precipitation and dry deposition with little uptake from the substrate. The technique provides a surrogate, time-integrated measure of metal and potentially nitrogen deposition from the atmosphere to terrestrial ecosystems. It is easier and cheaper than conventional precipitation analysis as it avoids the need for deploying large numbers of precipitation collectors with an associated long-term programme of routine sample collection and analysis. Therefore, a much higher sampling density can be achieved than with conventional precipitation analysis.

<u>Heavy metals</u>

In 2005/6, 28 countries submitted data on the heavy metal concentration in mosses for the metals aluminium, arsenic, antimony, cadmium, chromium, copper, iron, lead, mercury, nickel, vanadium and zinc (Harmens *et al.*, 2008a). In general, the lowest concentrations of metals in mosses were found in (north) Scandinavia, the Baltic States and northern parts of the United Kingdom, although higher concentrations were reported near local sources. Relatively low concentrations of iron, mercury, nickel and vanadium were also observed in central Europe. Depending on metal, the highest concentrations were often found in Belgium and eastern European countries, with localised lower concentrations being present. High concentrations of mercury were detected in mosses in Belgium, France, Latvia, Slovakia and Slovenia. Relatively high concentrations of aluminium, arsenic, chromium, iron, nickel and vanadium were found in eastern and southern France.

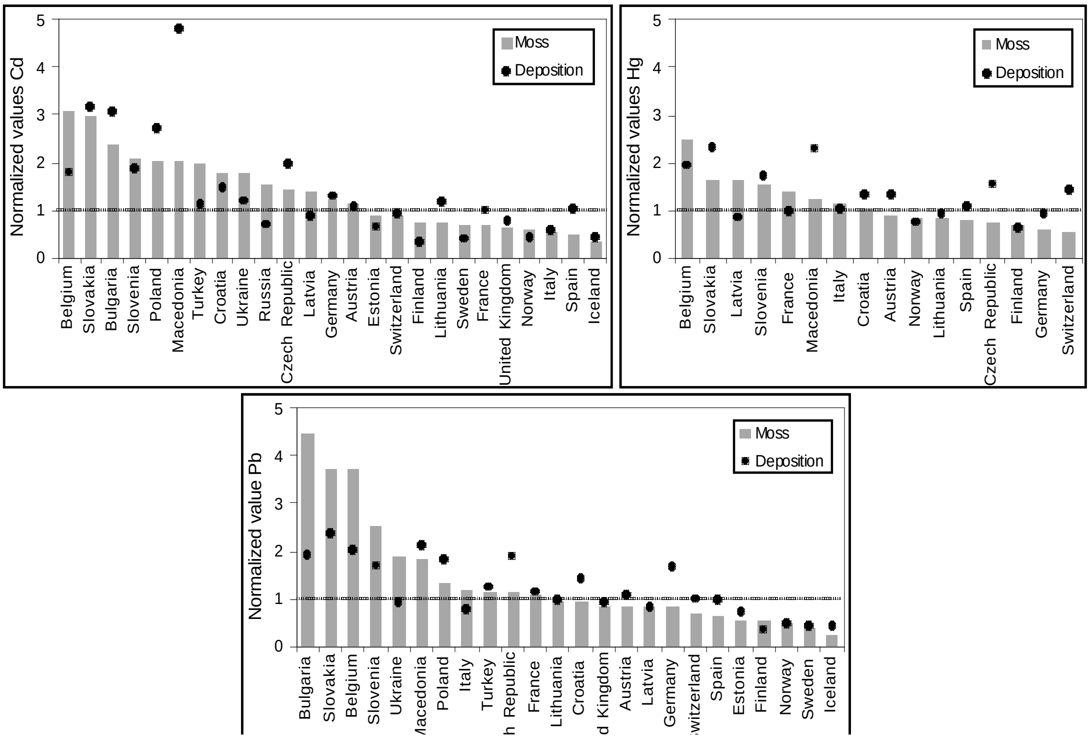

Figure 3.5. Normalized values (relative to the overall mean) of the average cadmium (top, left), mercury (top, right) and lead (bottom) concentration in mosses (2005/6) and EMEP modelled average annual deposition (2003 – 2005) per country.

In collaboration with EMEP/MSC-East, concentrations of cadmium, lead and mercury in mosses for 2005/6 were compared with average atmospheric deposition of these metals simulated by the EMEP atmospheric transport model MSCE-HM (Travnikov and Ilyin, 2005) for the years 2003 – 2005. Heavy metal concentrations in mosses were compared with the average depositions of the previous three years as the last three year's growth of mosses was selected for the determination of heavy metal concentrations. Preliminary data analysis showed that the spatial pattern of cadmium and lead concentrations in mosses and modelled deposition agree reasonably well, i.e. regions with higher deposition had generally higher concentrations in mosses and vice versa (Figure 3.5). For mercury, the spatial pattern showed less similarity. For lead, the concentration in mosses appears to be relatively higher than the modelled deposition in Bulgaria, Slovakia, Belgium, Slovenia and the Ukraine, whereas the opposite appears to be the case for the Czech Republic, Croatia and Germany. For cadmium, the lower concentration in mosses compared to modelled deposition in Macedonia is most striking. However, considering the intrinsic uncertainty of the EMEP model (30 – 40% for total deposition), i.e. excluding uncertainties in emissions (Travnikov and Ilyin, 2005), and potential limitations in the use of moss data as monitors of atmospheric deposition (see Harmens *et al*., 2008a), the spatial patterns of both data sets agree reasonably well, at least for cadmium and lead. This exercise may be regarded as a cross validation of moss data and EMEP model data, both because of potential limitations in the use of mosses as monitors of atmospheric heavy metal deposition and due to uncertainties in the modelled heavy metal deposition (including uncertainties in emissions). Further data analysis will be conducted in the future, in particular regarding country-specific relationships between heavy metal concentration in mosses and modelled atmospheric heavy metal deposition and factors that might affect these relationships.

As a contribution in kind, Prof. Winfried Schröder and colleagues at the University of Vechta, Germany conducted a more detailed statistical analysis on factors influencing the spatial variation of heavy metal concentrations in mosses. Bivariate correlation coefficients were computed to indicate the strength and direction of the statistical relationship between the heavy metal concentrations in mosses and EMEP modelled depositions and additional factors that might influence the heavy metal concentration in mosses (see Table 3.5).

These additional factors include both site-specific and regional characteristics. Raster information from surface maps were intersected with the moss monitoring sites and included in the correlation analysis. To account for the influence of the amount of precipitation on the moss heavy metal loads, long-term monthly means (1961- 1990) were provided by the Global Climate Dataset (CL 2.0) at a resolution of 12.5 x 12.5 km². Proportions of land use were derived from the Corine Land Cover Map 2000 (Keil *et al*., 2005). The area percentage of urban, forest and agricultural land use categories in a radius of 1, 5, 10, 25 km (for forests and agriculture) or 1, 5, 10, 25, 50 and 100 km (for urban areas) around each raster cell was calculated and then projected onto the 1 x 1 or 2 x 2 km² grid cells. The sea spray-effect was assessed in terms of the distances of the monitoring sites to the coastlines of the Atlantic Ocean and the Baltic, Black and Mediterranean Sea. Further data used as predictor included population density in a resolution of 100 x 100 m^2 provided by the European Environment Agency (http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=1018).

It was decided to compute the Spearman rank correlation coefficient r_s because the heavy metal concentration in mosses proved to be not normally distributed. Such non-parametric correlation methods are less powerful than parametric methods if the assumptions underlying the latter are met, but are less likely to give distorted results when the assumptions fail. An increasing rank correlation coefficient implies increasing agreement between rankings. The correlation coefficient r_s is -1 if the two rankings are completely in opposite agreement, r_s equals 0 if the rankings are completely independent and equals +1 if the agreement between the two rankings is perfectly the same. The strength of the bivariate correlations was classified according to Hagl (2008): r_s values < $|0.2|$ are very low, between $|0.2|$ and $|0.5|$ low, from $|0.5|$ to $|0.7|$ moderate, between $|0.7|$ and $|0.9|$ high and > $|0.9|$ very high.

In addition to non-parametric correlation analysis, classification and regression trees (CART) as introduced by Breimann *et al*. (1984) were applied to analyse multivariate correlations between the heavy metal concentration in mosses and characteristics of the surroundings of the sampling sites (Pesch *et al*., 2008). CART does not make any assumptions regarding the distribution of the data and can use an explanatory variable more than once, so it is able to work with multiple-interrelated data. CART can reveal hierarchical and non-linear relationships among one dependent variable (such as heavy metal concentration in mosses) and several descriptive variables (such as site-specific and regional characteristics of the sampling sites).

Bivariate analysis of the data (Table 3.5) showed the highest correlations between the cadmium and lead concentration in mosses and i) modelled EMEP depositions (r_s = 0.63 for cadmium, r_s = 0.73 for lead), ii) EMEP total emissions (r_s = 0.49 for cadmium, r_s = 0.65 for lead) and iii) the proportion of urban land use in a 100 km radius (r_s = 0.43 for cadmium, r_s = 0.44 for lead). For cadmium and lead the correlations with proportion of urban and agricultural land uses increased with increasing radius (data for intermediate radii are not shown in Table 3.5). Correlations between the mercury concentration in mosses and modelled EMEP depositions (r_s = 0.20) or anthropogenic emissions were low (r_s = 0.14). The similarity in correlations for cadmium and lead concentrations in mosses is reflected in the moderate correlation between the concentrations of both metals in mosses, whereas the correlations with mercury concentrations are low (for lead) to very low (for cadmium).

Table 3.5. Spearman rank correlation coefficients (r_s) between heavy metal concentrations in mosses and i) EMEP modelled total depositions and emissions and ii) other site-specific or regional characteristics. Values in bold indicate a moderate (0.5 – 0.7) to high (0.7 – 0.9) correlation coefficient. P < 0.001 for all correlations. * Correlation coefficients with EMEP depositions and emissions were based on median metal concentrations in mosses per EMEP 50 x 50 km^2 grid. ** anthropogenic emissions.

Independent variable	**Cd**	**Hg**	**Pb**
Cd concentration moss		0.06	0.65
Hg concentration moss			0.44
EMEP Cd depositions*	0.63		
EMEP Hg depositions		0.20	
EMEP Pb depositions			0.73
EMEP Cd emissions	0.49		
EMEP Hg emissions**		0.14	
EMEP Pb emissions			0.65
Altitude	0.19	0.02	0.37
Precipitation	-0.06	0.18	0.12
Population Density	0.31	-0.09	0.30
Sea Distance	0.33	-0.18	0.31
Proportion of Urban Land Uses (1 km radius)	0.11	-0.02	0.10
Proportion of Urban Land Uses (100 km radius)	0.43	-0.15	0.44
Proportion of Agricultural Land Uses (1 km radius)	0.10	-0.01	0.19
Proportion of Agricultural Land Uses (25 km radius)	0.23	0.02	0.34
Proportion of Forested Land Uses (1 km radius)	0.02	0.01	-0.06
Proportion of Forested Land Uses (25 km radius)	0.00	-0.03	-0.12

Multivariate analyses using CART showed that for cadmium and lead the modelled EMEP deposition was the main factor determining the variation of their concentration in mosses, whereas for mercury the variation of the concentration in mosses was primarily determined by the moss species sampled.

Nitrogen

For the first time in the European moss survey, 16 countries submitted data on the nitrogen concentration in mosses in 2005/6 encompassing almost 3,000 sites (Harmens *et al.*, 2008b). A pilot study in selected Scandinavian countries had shown that there was a good linear relationship between the total nitrogen concentration in mosses and EMEP modelled atmospheric nitrogen deposition rates (Harmens *et al*., 2005). The results of the 2005/6 moss survey indicated that mosses can potentially be used as biomonitors of atmospheric nitrogen deposition, although limitations and potential confounding factors were identified that require further investigation in order to improve application at the European scale.

The lowest total nitrogen concentrations in mosses were observed in northern Finland and northern parts of the UK, the highest concentrations were found in parts of western, central and eastern Europe. The spatial distribution of the nitrogen concentration in mosses was similar to that of the total nitrogen deposition modelled by EMEP for 2004, except that the modelled nitrogen deposition tended to be relatively lower in eastern Europe (Harmens *et al*., 2008b). However, the relationship between total nitrogen concentration in mosses and modelled total nitrogen deposition, based on averaging all sampling site values within any one EMEP grid square, showed considerable scatter (Figure 3.6). Some of the scatter can be explained by relating site-specific nitrogen concentrations in mosses with total modelled nitrogen depositions averaged over a bigger area (50 x 50 km^2). Actual deposition values vary considerably within each EMEP grid cell due to for example topography, vegetation, local pollution sources and climate. The apparent asymptotic relationship shows saturation of the total N in mosses above a N deposition rate of approximately 10 kg ha^{-1} y^{-1}. It is not clear, however, whether this is due to an overestimation of modelled deposition at these sites, or that it indicates a non-linear relation between nitrogen deposition and total nitrogen concentration in mosses. This exercise may be regarded as a cross validation of moss data and EMEP model data for nitrogen, but is complicated by both the limitations in the use of mosses as monitors of atmospheric nitrogen deposition and the uncertainties in the modelled nitrogen deposition, including uncertainties in emissions. When the total nitrogen concentration in mosses was plotted against site-specific nitrogen deposition values in for example Switzerland, a strong positive linear relationship was observed (Thoni *et al*., 2008). There is a need to measure atmospheric nitrogen deposition at selected moss sampling sites in other countries too in the future in order to further investigate the robustness of the relationship with total nitrogen concentration in mosses.

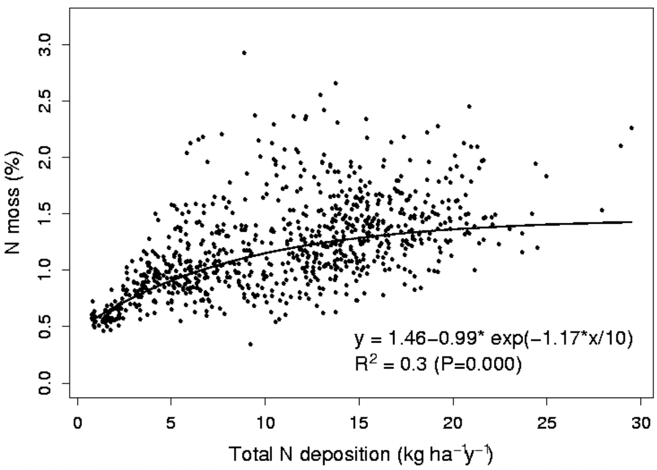

Figure 3.6. Relationship between EMEP modelled total nitrogen deposition in 2004 and averaged nitrogen concentration in mosses (2005/6) per EMEP grid square.

As a contribution in kind, Prof. Winfried Schröder and colleagues at the University of Vechta, Germany, conducted a more detailed statistical analysis on factors influencing the spatial variation of nitrogen concentrations in mosses, applying methods that were described in more detail above for heavy metals and in Pesch *et al*. (2008). Data on modelled nitrogen depositions and air concentrations were provided by EMEP/MSC-West. In addition to the predictors described above for heavy metals, livestock density was included as a predictor, using data provided by EUROSTAT (http://epp.eurostat.ec.europa.eu). Bivariate analysis of the data showed the highest, albeit moderate Spearman rank correlations between the total nitrogen concentration in mosses and modelled EMEP atmospheric deposition (r_s = 0.55 – 0.65) or air concentrations (r_s = 0.54 – 0.63) of various nitrogen forms (Table 3.6). Moderate correlations were also observed for the proportion of urban and agricultural land use (with correlations increasing with increasing radii), followed by population and livestock density. Low to very low correlations were found for the other tested predictors. In general, the total nitrogen concentration in mosses appears to mirror land use-related atmospheric nitrogen depositions.

Table 3.6. Spearman rank correlation coefficients (r_s) between total nitrogen concentrations in mosses and i) EMEP modelled depositions and air concentrations of different nitrogen forms and ii) other site-specific or regional characteristics. Correlation coefficients with EMEP depositions and air concentrations were based on median nitrogen concentrations in mosses per EMEP 50 x 50 km^2 grid. All correlations with $p < 0.001$ except for livestock density ($p < 0.01$).

EMEP modelled	**N form**	r_s	**Other predictors**	r_s
Air concentration	NO_2	0.54	Proportion urban land use (1 km radius)	0.15
	$NH_3 + NH_4^-$	0.61	Proportion urban land use (100 km radius)	0.55
	$HNO_3 + NO_3^-$	0.63	Proportion agricultural land use (1 km radius)	0.36
	Sum all N air	0.59	Proportion agricultural land use (50 km radius)	0.53
Deposition	Wet oxidised	0.65	Proportion forested land (1 km radius)	-0.11
	Total (wet + dry)	0.64	Proportion forested land (25 km radius)	-0.23
	Total wet	0.64	Population density	0.48
	Dry oxidised	0.64	Livestock density	0.42
	Wet reduced	0.62	Precipitation	0.25
	Total dry	0.59	Distance to sea	0.25
	Dry reduced	0.55	Altitude	-0.10

Multivariate relations between the nitrogen concentration in mosses and modelled EMEP nitrogen depositions/air concentrations and potential site-specific and regional land characteristics were analysed using CART (see above for heavy metals). The ammonium concentration in air proved to be the most powerful predictor of the total nitrogen concentration in mosses, followed by nitrogen dioxide concentrations in air (at sites with ammonium concentrations below 0.63 mg m^{-3}) and moss species (at sites with ammonium concentrations above 0.63 mg m^{-3}).

Further statistical analysis of the relationship between total nitrogen concentrations in mosses and EMEP modelled nitrogen depositions and air concentrations will be conducted in the future, testing EMEP data at a lower resolution (10 x 10 km^2 and 25 x 25 km^2) and averaging deposition data over longer time periods.

3.2.5 Temporal trends in heavy metal concentrations in mosses (1990 – 2005)

Since 1990, heavy metal concentrations in mosses have been determined every five year across Europe. The most recent moss survey was conducted in 2005/6 (Harmens *et al*., 2008a). Temporal trends between 1990 and 2005 were determined by calculating the average of median heavy metal concentrations in mosses for countries that had determined the metal concentration in each year for individual metals. The decline in emission and subsequent deposition of heavy metals across Europe has resulted in a decrease in the heavy metal concentration in mosses since 1990 for the majority of metals. Between 1990 and 2005 the metal concentration in mosses has declined the most for lead (72.3%), arsenic (71.8%, based on data from only five countries), vanadium (60.4%), cadmium (52.2%) and iron (45.2%). A smaller decline was found for zinc (29.3%), copper (20.4%) and nickel (20.0%) and no significant reduction for chromium (2%). Few countries reported data for arsenic and mercury in 1990, but since 1995 the arsenic concentration in mosses has declined by 21.3% (based on data from 14 countries), whereas mercury showed no significant decline (11.6%, data from eight countries). On a national or regional scale large deviations from the general European trend were found, i.e. temporal trends were country or region-specific, with no changes or even increases being observed since 1990. Therefore, even in times of generally decreasing metal deposition across Europe, temporal trends are different for different geographical scales.

In collaboration with EMEP/MSC-East, temporal trends in concentrations of cadmium, lead and mercury in mosses were compared with temporal trends in atmospheric deposition fluxes of these metals simulated by the EMEP atmospheric transport model MSCE-HM (Travnikov and Ilyin, 2005). Initial data analysis indicated that the temporal trends in metal concentration in mosses agree reasonably well with the trends in metal deposition. Taking the area of moss sampling into account, the metal concentration in mosses had declined by 73, 46 and 20% across Europe between 1990 (1995 for mercury) and 2005, whereas the modelled deposition had declined by 70, 41 and 30% for lead, cadmium and mercury respectively (Figure 3.7). Further data analysis will be conducted in the future, in particular regarding country-specific temporal trends and factors that might contribute to discrepancies in temporal trends between heavy metal concentration in mosses and modelled atmospheric deposition.

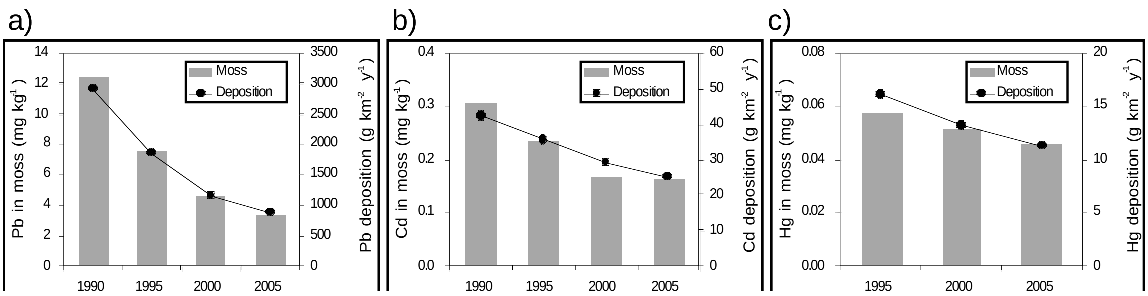

Figure 3.7. Temporal trends in the heavy metal concentration in mosses and EMEP modelled atmospheric deposition for (a) lead, (b) cadmium and (c) mercury. Source of deposition data: EMEP/MSC-East.

In conclusion, an initial analysis shows that for Europe as a whole, temporal trends in cadmium, lead and mercury concentrations in mosses agree well with the trends in depositions modelled by the EMEP atmospheric transport model. Future analyses will include a comparison of the moss and deposition data at country level.

4. Newly developing activities in the ICP Vegetation

4.1 Bean ozone biomonitoring experiment

In the summer of 2008, ICP Vegetation participants conducted a pilot study to investigate the potential for *Phaseolus vulgaris* (bean) to be used as a biomonitor of ozone in Europe. Bean seeds of the strains S156 (ozone sensitive) and R123 (ozone resistant) were received from Kent Burkey (North Carolina, USA), where they have been selected and developed as potential biomonitors of ambient ozone (Burkey *et al.*, 2005). Beans were grown by participants across Europe, assessed and harvested according to guidelines issued by the Programme Coordination Centre.

Table 4.1. Sites from which data were received for the bean ozone biomonitoring experiment in the summer of 2008. OTCs = open-top chambers.

Site	Ambient air	Exposure studies
Belgium -Tervuren		OTCs
France - Nancy	√	
German - Giessen	√	OTCs
Hungary - Budapest, Hatvan	√	
Italy - Pisa, Rome	√	
Slovenia - Ljubljana, Zavodnje	√	
Spain - Benifaió, Villar del Arzobispo	√	
UK - Ascot	√	OTCs
- Bangor		Solardomes

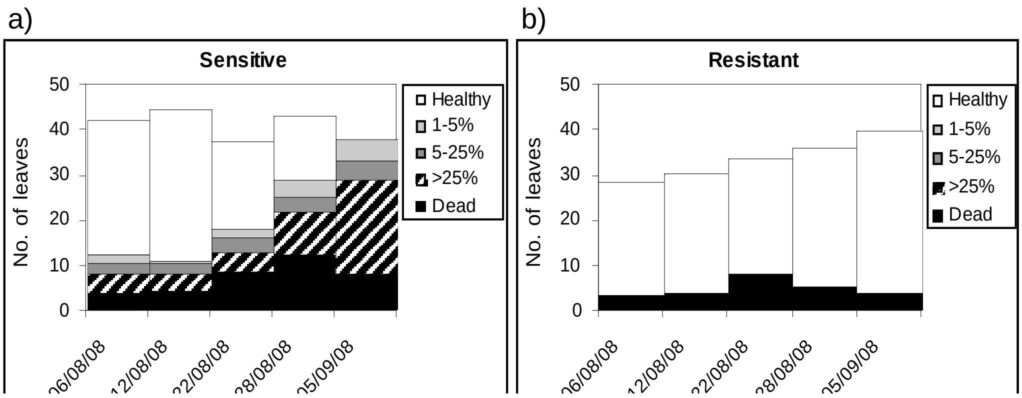

Figure 4.1. Effect of ozone on the proportion of healthy and damaged leaves of the (a) sensitive and (b) resistant biotype of bean (*Phaseolus vulgaris*) at Rome, Italy, after various days of exposure to ambient air; start date of exposure: 18/07/08. Data are the mean number of leaves per plant that are healthy, damaged by ozone (1-5%, 5-25% and >25% leaf surface area is injured) or dead.

Data were received from 13 sites in eight countries (Table 4.1; seeds could not get through customs in the Ukraine in time for the study). The beans were exposed to ambient air at 11 sites, and ozone exposure studies were carried out at four sites. At all sites, a clear distinction in the extent of visible leaf injury symptoms between the S and R biotypes was apparent (Figure 4.1), with the visible injury symptoms clear and easy to identify. Injury symptoms were observed on the S biotype at low ozone concentrations with a threshold for effect being a 12 hour mean of ca. 35 ppb (Figure 4.2a). At the highest ozone concentrations used in ozone exposure systems injury symptoms were also apparent on the R biotype, but to a lesser extent than on the S biotype. At the ambient ozone sites (where the 12 hour mean ozone concentration range was approximately 30 – 60 ppb), there was not a clear dose-response relationship for visible leaf injury. However, ozone exposure studies using the solardomes at UK-Bangor over a large concentration range (12 hour mean was approximately 15 – 90 ppb) showed a linear response of increasing injury on the S biotype with increasing ozone (Figure 4.2a). When the results for pod weight (expressed as the ratio for sensitive to resistant) were compared to those from the earlier USA study, there was a lot of scatter in the relationship (Figure 4.2b). The best ozone metric for use with the effects data has not yet been identified, and no flux model exists for these plants to date. Participants indicated that they judged the study to be a success and are keen to repeat the study in future years with efforts focussed on establishing a flux-effect relationship for bean.

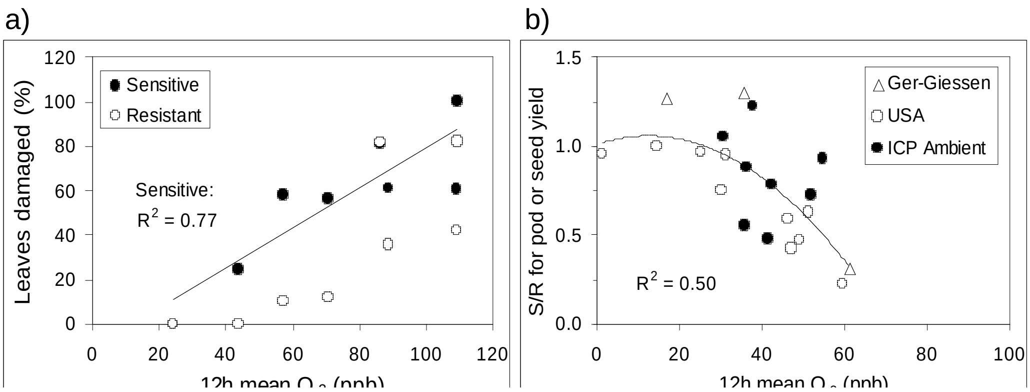

Figure 4.2. (a) Percentage of damaged leaves on the sensitive and resistant biotype of bean 28 days after flowering (plants were exposed in solardomes at CEH Bangor, UK between 29th August and 26th September 2008, and (b) effect of ambient ozone on bean seed or pod weight (expressed as the ratio of the sensitive to resistant biotype) for sites in the ICP Vegetation network (closed circles), the USA (open circles; reproduced from Burkey *et al.*, 2005 and Flowers *et al.*, 2007) and an open-top chamber experiment at Giessen, Germany (open triangles).

Following the success of the pilot study with bean in 2008, efforts in the next year will focus on a full-scale biomonitoring experiment with ozone-sensitive and ozone-resistant bean, which will include participants measuring stomatal conductance in readiness for developing a flux-effect relationship. In addition, ozone exposure experiments will be conducted in the open-top chambers at Ascot, UK and the solardomes at Bangor, UK. Data from these experiments will assist in the interpretation of the dose-response functions derived from ambient air experiments.

4.2 State of knowledge reviews on ozone

Following the success of the ozone 'Evidence Report' (Hayes *et al*., 2007b), the Task Force of the ICP Vegetation agreed at its 21st meeting in 2008 that further ozone reports that synthesise information from scientific journals, the 'grey' literature and national reports would be extremely useful outputs from the ICP Vegetation. Progress with the tentatively proposed subjects of these reviews (Mills *et al*., 2008) was evaluated at the 22nd Task Force Meeting in Braunschweig:

- *Impacts of ozone on vegetation in the Mediterranean region*. Colleagues in Italy are currently reviewing this subject;

- *Ozone flux models and their application to different climatic regions*. This will be reviewed and discussed at the next ozone workshop held from 10 – 12 November 2009 in Ispra, Italy;

- *Impacts of ozone on food security*. It was agreed that a major output from the ICP Vegetation should be an in depth review of the current state of knowledge of the potential impacts of ozone on crop security. Wherever possible, assessments will be flux-based to reflect the conclusion of the 'Evidence Report' (Hayes *et al*., 2007b) that flux-based risk assessments are much more strongly correlated with damage in the field than AOT40-based assessments. In 2009/10, the first phase of this assessment will focus on Europe by reviewing available data for crop sensitivity and developing localised parameterisations for key crop species (depending on available data) for use in three climatic regions. The second phase planned for 2010/11 would involve application of the crop sensitivity index and flux parameterisations to produce maps showing those crops and areas at greatest risk of damage from ozone in Europe. These will be incorporated into a review of knowledge of current and predicted future impacts of ozone on future crop security in Europe (main focus) with consideration of impacts in South Eastern Europe (SEE), Eastern Europe, Caucasus and Central Asia (EECCA) and Malé Declaration countries. The plan is to submit a glossy report on this subject to the Executive Body of the LRTAP Convention at its meeting in December 2011.

- *Ozone, carbon sequestration, and linkages between ozone and climate change*. There are tentative plans to review this subject in 2011;

The medium-term work-plan of the ICP Vegetation and further priorities for the future regarding ozone, nitrogen and heavy metals are described in Chapter 5.

5. Conclusions and future work-plan

5.1 Summary of major achievements in 2008/9

- Coordinated from CEH Bangor in the UK, the ICP Vegetation continues to comprise of an enthusiastic group of over 200 scientists from 35 countries in the UNECE region.

- Fifty seven delegates from 20 Parties to the Convention and South Africa, together with a member of the UNECE secretariat for the LRTAP Convention, the chairman of the ICP Modelling and Mapping, the chairman of the ICP Forests Working Group on Ambient Air Quality and a representative from EMEP/MSC-East attended the 22nd ICP Vegetation Task Force Meeting, 2 - 4 February 2009 in Braunschweig, Germany.

- The ICP Vegetation has contributed to four ECE/EB.AIR reports of the WGE of the LRTAP Convention and provided a technical report (ECE/EB.AIR/WG.1/2009/9) on 'Impacts of ozone and nitrogen on vegetation and trends in nitrogen and heavy metal concentrations in mosses'. A two-page colour brochure was published on 'Evidence of widespread ozone pollution damage to vegetation in Europe (1990 – 2006)'. In collaboration with ICP Vegetation, EMEP/MSC-West and MSC-East published data on the relationship between modelled atmospheric depositions of nitrogen and heavy metals and their concentrations in mosses respectively in their status reports for 2009. In addition, two papers in scientific journals and two book chapters have been produced by or in collaboration with the Programme Coordination Centre.

- The ICP Vegetation contributed to all the common work-plan items of the WGE and in particular to i) a status report on airborne nitrogen impacts on the environment and ii) exploring merits of the different options for target setting in 2020 and non-binding aspirational targets for the year 2050:
  i) A literature review has shown that various habitats and some moss and lichen species in particular are sensitive to current ambient levels of atmospheric nitrogen deposition, which has shown to result in a loss of plant biodiversity in some habitats.
  ii) Regarding ozone, political aspirations for 2050 should be based on avoiding all detectable adverse effects. In current climatic conditions, a reduction of 75% of the generic ozone flux to crop species would result in more than 90% of EMEP grid squares being within the 'damage unlikely' category.

- In the summer of 2008, ICP Vegetation participants conducted a pilot study to investigate the potential for *Phaseolus vulgaris* (bean) to be used as a biomonitor of ozone in Europe. At all participating sites, a clear distinction in the extent of visible leaf injury symptoms between an ozone-sensitive and ozone-resistant biotypes was apparent. The best ozone metric for use with effects data has not yet been identified, and no flux model exists for these plants to date. Participants are keen to repeat the study in future years with efforts focussed on establishing a flux-effect relationship for bean.

- A previously developed modelling approach has shown that sensitivity of individual plant species to ozone is best predicted by their Ellenberg Light and Salinity scores. Including modifiers such as competition, canopy/species height, position in canopy, growth form, relative growth rate and nitrogen sensitivity did not improve the performance of the model when testing against experimental community data.

- Application of the Ellenberg modelling approach to European grasslands predicted that coastal grassland communities and Mediterranean tall humid grasslands were the most sensitive to ozone of the communities that could be included in this modelling approach. Previously, in a wider–ranging study using the proportion of species that are ozone–sensitive, other vegetation types such as upland grasslands, shrub heathland, forest fringes, dry and wet grasslands were also predicted to be ozone sensitive. For a range of tested grassland types, sensitivity to ozone and to atmospheric nitrogen deposition were un-related.

- A multi-layer canopy flux model was developed for a productive grassland containing white clover (a legume) and rye grass. Leaf area index proved to be a key driver of the ozone flux into the canopy and within canopy distribution of ozone flux to the component species. It has not yet been possible to develop a quantitative flux-effect relationship for biomass, species composition or forage quality that is sufficiently robust for Europe-wide application. A literature review revealed that current ambient ozone concentrations can cause considerable loss in nutritive quality due to negative effects of ozone on the digestibility of forage, in particular of legumes.

- There is substantial evidence that ozone has significant adverse effects on vegetation at current ambient ozone levels in the Nordic Countries and Baltic States. Favourable climatic conditions and the long days in the summer result in considerable ozone uptake by vegetation, despite atmospheric ozone concentrations generally being lower than in central and southern Europe. Therefore, risk assessments and integrated assessment modelling regarding impacts of ozone on vegetation need to be flux-based.

- In 2005/6, the lowest concentrations of metals in mosses were generally found in northern Europe and the highest concentrations in Belgium and eastern Europe. Bivariate analysis of the data showed the highest correlations between the cadmium and lead concentration in mosses and modelled EMEP depositions, followed by EMEP total emissions and the proportion of urban land use in a 50-100 km radius. Correlations between the mercury concentration in mosses and modelled EMEP depositions or anthropogenic emissions were low.

- In 2005/6, the lowest total nitrogen concentrations in mosses were observed in northern Finland and northern parts of the UK whilst the highest concentrations were found in central and eastern Europe. The nitrogen concentration in mosses showed the highest, albeit moderate correlations with EMEP modelled depositions or air concentrations of different nitrogen forms, followed by the proportion of urban and agricultural land use and population and livestock density. In summary, the total nitrogen concentration in mosses appears to mirror land use-related atmospheric nitrogen depositions and the total nitrogen concentration in mosses might potentially be used as an indicator of atmospheric nitrogen deposition at a high spatial resolution.

- The decline in emission and subsequent deposition of heavy metals has resulted in a significant Europe-wide reduction in the heavy metal concentration in mosses since 1990 for many metals, but not for chromium and mercury. Initial data analysis showed that Europe-wide temporal trends in heavy metal concentration in mosses agreed reasonably well with temporal trends in EMEP modelled heavy metal deposition, especially for lead and cadmium.

5.2 Future work-plan (2010-2011) for the ICP Vegetation

***Ozone* -** There is a clear need to incorporate the ozone flux-based method for vegetation into integrated assessment modelling and to define effects-based targets for the future for policy purposes. To support this process, development of a generic flux-effect relationship and a generic flux-based method for (semi-)natural vegetation are urgently required. Additional priorities for the future include reviews on the impacts of ozone on i) food security and ii) carbon sequestration and iii) linkages between ozone and climate change, together with further collation of evidence on the damaging effects of ozone in the field.

***Nitrogen* -** There is a need to further develop policy relevant indicators of the impacts of nitrogen on vegetation and to enhance our knowledge on the impacts of nitrogen on Mediterranean habitats. The relationship between nitrogen concentration in mosses and atmospheric nitrogen deposition requires further investigation at various geographical scales, including the identification of factors affecting the relationship at these scales. A challenge for the future would be to relate the nitrogen concentration in mosses with impacts of nitrogen on vegetation and to investigate whether critical levels for nitrogen concentration in mosses can be defined.

Heavy metals - The relationship between heavy metal concentration in mosses and EMEP modelled atmospheric deposition requires further investigation at various geographical scales, including the identification of factors affecting the relationship at these scales. Country-specific comparisons of temporal trends could provide further validation regarding the performance of the EMEP atmospheric transport model. To enhance the application of the heavy metals in mosses data, further integration with other European datasets needs to be explored.

The following work-plan was proposed at the 22nd Task Force Meeting of the ICP Vegetation (Braunschweig, Germany, 2 – 4 February 2009):

2010:

- Report on ozone biomonitoring experiment with bean in 2009;
- Report on ozone impacts in Mediterranean areas;
- Review of ozone flux modelling methods and their application to different climatic regions;
- Report of workshop on ‘Flux-based assessment of ozone effects for air pollution policy’;
- Progress report on European heavy metals and nitrogen in mosses survey 2010;
- Report on the relationship between heavy metal concentration in mosses and EMEP modelled deposition.

2011:

- Report on the 2010 biomonitoring exercise for ozone;
- Report on ozone impacts on food security;
- Report on ozone, carbon sequestration, and linkages between ozone and climate change (tentative);
- Progress report on European heavy metals and nitrogen in mosses survey 2010;
- Review of the relationship between heavy metal and nitrogen concentrations in mosses and impacts on ecosystems.

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Annex 1. Participation in the ICP Vegetation

In many countries, several other scientists (too numerous to include here) also contribute to the work programme of the ICP Vegetation.

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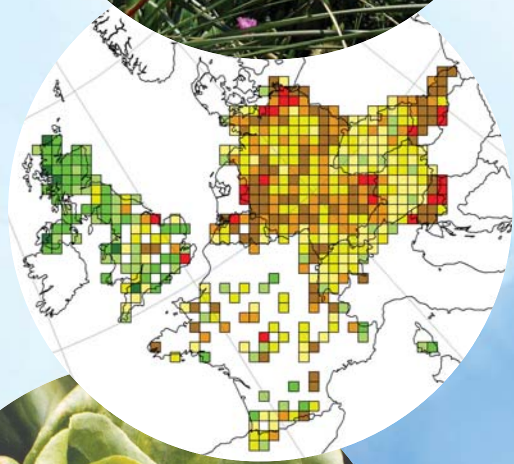
Air Pollution and Vegetation
ICP Vegetation
Annual Report 2008/2009



This report describes the recent work of the International Cooperative Programme on effects of air pollution on natural vegetation and crops (ICP Vegetation), a research programme conducted in 35 countries in the UNECE region. Reporting to the Working Group on Effects of the Convention on Long-range Transboundary Air Pollution, the ICP Vegetation is providing information for the review and revision of international protocols to reduce air pollution problems caused by, for example, ground-level ozone, heavy metals and nitrogen. Progress and recent results from the following activities are reported:

- Evidence of impacts of ambient ozone concentrations on vegetation in Northern Europe.
- New ozone biomonitoring programme with bean.
- Studies into further applying flux-based critical levels of ozone for vegetation and the development of a flux-based method for productive grasslands.
- Factors affecting the spatial and temporal variation in heavy metal and nitrogen concentrations in mosses.
- Impacts of airborne nitrogen on vegetation.

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ISBN: 978-0-9557672-9-6