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NATURAL ENVIRONMENT RESEARCH COUNCIL

Air Pollution and Vegetation

ICP Vegetation

Annual Report 2007/2008

wge

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

Air Pollution and Vegetation

ICP Vegetation[1] Annual Report 2007/2008

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

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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 later 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 Bangor (CEH 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 34 countries. An overview of contributions to the WGE work-plan and other research activities in the year 2007/8 is provided in this report.

Annual Task Force Meeting

The Programme Coordination Centre organised the 21st ICP Vegetation Task Force Meeting, 26-29 February 2008 in Oulu, Finland, in collaboration with the local host at the Muhos Research Unit of the Finnish Forests Research Institute. The meeting was attended by 52 delegates from 19 Parties to the Convention; also present were the chairman of the WGE, the UNECE secretariat for the LRTAP Convention and a representative from ICP Modelling and Mapping. The Task Force discussed the progress with the work-plan items for 2008 and the medium-term work-plan for 2009-2011 for the air pollutants ozone, heavy metals and nutrient nitrogen, which are described in greater detail in this report.

Reporting to the Convention and other publications

In addition to this report, the ICP Vegetation Programme Coordination Centre has provided a technical report (ECE/EB.AIR/WG.1/2008/9) on evidence of widespread ozone damage to vegetation in Europe (1990 – 2006) and has contributed to three other ECE/EB.AIR reports of the WGE, to the WGE consolidated report on air pollution effects and the revision of chapter 3 of the LRTAP Convention Modelling and Mapping Manual. Four additional reports, four papers in scientific journals and a book chapter have also been produced by the Programme Coordination Centre. Two important reports have been published in glossy format: 'Evidence of widespread ozone damage to vegetation in Europe (1990 – 2006)' and 'Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990-2005)'.

Summary of progress with ICP Vegetation research activities in 2007/8

<u>Experimental responses of vegetation to ozone</u>

As part of ongoing activities to monitor the effects of ambient ozone on crops and (semi-) natural vegetation, 12 groups participated in the clover biomonitoring exercise in 2007. New groups from Hungary and the Ukraine reported the presence of ozone injury on the sensitive biotype of white clover. Overall, in the countries reporting results, there was less ozone injury in July and August than in recent years, but ozone injury was prevalent in September. In Oulu the Task Force decided that a detailed biominitoring survey will be conducted in 2010. This would include surveys for ozone injury at NATURA 2000 sites, an extensive clover biomonitoring network and possibly a new experiment with ozone-sensitive and ozone-resistant strains of *Phaseolus vulgaris* that are being developed in the USA, which is being trialled in 2008. Additional experimental contributions to other ozone activities include exposure experiments with grassland species and crops and stomatal conductance measurements for use in flux models.

Evidence for effects of current ambient ozone on vegetation in 1990 - 2006

Over the last two years, the Programme Coordination Centre for the ICP Vegetation has collated as far as possible, all of the published and unpublished evidence of ozone damage to crops and (semi-) natural vegetation growing in ambient air in European countries over the time period 1990 to 2006. The data has been analysed in relation to EMEP[2] maps which predicted those areas that were of greatest risk of ozone damage over the time period. Two methods of risk assessment were compared: the AOT40-approach based on the ozone concentration in air above the canopy, and the generic flux-approach, a more biologically relevant method based on predicting the uptake of ozone through the stomatal pores on the leaf surface. The report showed that visible ozone injury symptoms had been detected on over 30 crops and 80 species of (semi-)natural vegetation growing in commercial fields, experimental sites or (semi-)natural ecosystems, with effects reported in 14 countries. The highest impacts were reported in Greece, Italy and Switzerland although effects in northern countries such as Sweden were also frequently reported. AOT40-based maps under-estimated detected effects at approximately one-third of the sites whilst ozone-flux based risk maps accurately identified those areas with effects.

Flux-based maps of ozone damage risks to crop and tree species using local parameterisations

In the last year, the flux parameterisation specialists of the ICP Vegetation have concentrated on the development of localised parameterisations for forest trees. Chaired by Ms Lisa Emberson (UK), the forest sub-group (established at the LRTAP Convention Ozone Critical Level meeting held in Obergurgl, 2006), including participants from the ICP Forests and EMEP/MSC-W, have established flux model parameterisations for coniferous, deciduous and/or Mediterranean evergreen species representative of the five main geographical regions of Europe.

Flux-based methods for (semi-)natural vegetation

The further development of modelling methods for the assessment of risk of damage by ozone to (semi-)natural vegetation is a priority research area for the ozone sub-programme of the ICP Vegetation. Participants contribute by: conducting ozone exposure experiments with grassland species; measuring ozone flux, stomatal conductance and canopy characteristics such as leaf area index in naturally-occurring grasslands; developing models of ozone flux to (semi-)natural vegetation; linking the flux models to effects data and developing methods to identify and map vegetation at potential risk of damage from ozone in Europe. For example, a whole canopy flux-effect relationship is being developed at the Stockhom Environment Institute-York for productive managed pasture that is capable of differentiating ozone flux (both stomatal and non-stomatal) to the legume and grass fractions. This model will be applied to experimental dose-response data where available, and will be applied at the regional scale with the aim of initiating flux-based risk assessment for grasslands.

The ICP Vegetation database on the sensitivity of individual species of (semi-)natural vegetation grown in a non-competitive environment to ozone has been updated in the last year to include effects in simulated ecosystems and information on species characteristics such as plant height and canopy type. Modelling methods for identifying ozone–sensitive plant communities are currently under development.

Heavy metal concentrations in mosses: 2005/6 European survey and trends

The heavy metals in mosses survey provides data on concentrations of ten heavy metals (arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, vanadium and zinc) in naturally-growing mosses throughout Europe. In 2005/6, the concentration of aluminium and antimony was also determined in many countries.

[2] Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe

In 2005/6, the lowest concentrations of heavy metals in mosses were generally 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. The highest metal concentrations in mosses were generally found in Belgium and eastern Europe. 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%, based on 16 countries), arsenic (71.8%, five countries), vanadium (60.4%, 11 countries), cadmium (52.2%, 16 countries) and iron (45.2%, 13 countries). An intermediate decrease was found for zinc (29.3%, 16 countries), copper (20.4%, 16 countries) and nickel (20.0%, 16 countries) and no significant reduction for chromium (2%, 14 countries). Few countries reported data for arsenic and mercury in 1990, but since 1995 the arsenic concentration in mosses has declined by 21.3% (14 countries), whereas mercury showed no significant decline (11.6%, eight countries). Temporal trends in heavy metal concentrations in mosses are generally in agreement with trends in EMEP emission data or modelled deposition data for seven metals including cadmium, lead and mercury, but not for chromium (note: emission data and are not reported by EMEP for iron and vanadium). 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 for some metals. The next European moss survey is planned for 2010.

Nitrogen concentrations in mosses: 2005/6 European survey

The mosses sampled for heavy metal analysis were also analysed for total nitrogen concentration in the 2005/6 moss survey at almost 3,000 sites across 16 countries. 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 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 nitrogen deposition tended to be relatively lower in eastern Europe. The spatial variation in both the nitrogen and heavy metal concentration in mosses will be investigated in more detail in 2009. The future challenge will be to relate concentrations in mosses to impacts of nitrogen and heavy metals on ecosystems.

Developing areas of research within the ICP Vegetation

State of knowledge reviews

Following the success of the "Ozone Evidence Report", the Task Force of the ICP Vegetation agreed that further reports that synthesise information in scientific journals, the "grey" literature and national reports would be extremely useful outputs from the ICP Vegetation. No other group has such extensive access to information on air pollution impacts on vegetation within the ECE region and beyond. The following subjects (subject to continuing financial support for the ICP Vegetation) were tentatively proposed at the 21st ICP Vegetation Task Force Meeting in Oulu and included in the medium-term (2009-2011) work-plan: Comparison of SOMO35 (defined below; health indicator), AOT40 and flux-based (vegetation indicators) risk maps for Europe; Ozone impacts on vegetation in Nordic and Baltic areas; Ozone impacts on vegetation in the Mediterranean region; Review of ozone flux models and their application to different climatic regions; Ozone impacts on crop yield and quality (European regions, outreach to EECCA regions and Malé Declaration countries); Review of the 2010 biomonitoring study for ozone; Ozone, carbon sequestration and the linkages between climate change and air pollution policy. Some of these studies are already underway, with initial progress reviewed in this report and summarised below.

Comparison of location of ozone injury on vegetation with SOMO35, AOT40 and flux-based risk maps

The Task Force on Health has recently adopted the metric SOMO35 for risk assessment for effects on health. This ozone metric is defined as the yearly sum of the daily maximum 8h means that exceed 35 ppb. Since health impacts are an integral part of the negotiations related to ozone for the revision of the Gothenburg Protocol, it is timely to compare predictions using each type of effect-metric. Whilst a more in depth analysis is proposed for 2009, we present here initial findings from the study using vegetation effects data for the year 2006 and risk maps generated using the EMEP Eularian model and kindly supplied by EMEP/MSC-W. If it is assumed that all squares with a SOMO35 > 0 indicate a potential for health effects, then it can be concluded that vegetation effects (visible injury) have occurred in grid squares where ambient ozone in 2006 was likely to have been damaging to health.

Ozone impacts on vegetation in Nordic and Baltic areas

In an initiative led by Sweden, ozone impacts on vegetation in the Nordic Countries and the Baltic States are being reviewed. A workshop was held in Gothenburg on 17-18 June, 2008 to assess current knowledge of ozone concentrations and impacts. Attended by 15 participants from Sweden, Finland, Estonia, Lithuania and the Russia Federation, the workshop included presentations on factors contributing to surface ozone including synoptic circulation, climate change, emissions changes and nocturnal temperature inversions together with those on impacts of near ambient ozone concentrations on crops, trees and (semi-)natural vegetation. A workshop report will be produced at the end of this year and the scientific articles will be published in a special issue of AMBIO next year.

Development of a meta-database describing national and sub-national surveys with evidence of impacts of nitrogen deposition on vegetation

During the review of the Gothenburg Protocol the WGE identified the need for field-based evidence on the impacts of eutrophication on vegetation. In a response, the ICP Vegetation distributed a questionnaire to 71 members of the nitrogen deposition effects on vegetation research community and subsequently developed a first-stage meta-database describing national and sub-national surveys with evidence of impacts of nitrogen deposition on vegetation. Responses were received for the following habitats: Forests (EUNIS class G, 16 responses); Heathland, scrub and tundra (EUNIS class F, 2 responses); Grasslands and tall forbs (EUNIS class E, 2 responses); Mire, bog and fen habitats (EUNIS class D, 3 responses); Across habitats (5 responses). Although some surveys indicate increases in species with higher Ellenberg N values or a reduction in species richness with an increase in nitrogen deposition, impacts of nitrogen are often difficult to separate from other factors.

Identification of locations of specific EUNIS classes with likelihood of exceedance of empirical critical loads of nitrogen for the EMEP domain

The methodology developed was applied to ‘Heathland, scrub and tundra habitats’ (EUNIS class F; to level 2) and ‘Grasslands and tall Forbs habitats’ (EUNIS class E, to level 3). The spatial distribution of the EUNIS categories from the LRTAP Convention Harmonised Land Cover Map was first combined with EMEP total nitrogen deposition data using a GIS overlay procedure. Minimum, mean and maximum values for the deposition in each area were compared with minimum, mean and maximum values from the relevant empirical critical load ranges. The Alpine and sub-alpine grasslands (E4) and Arctic, alpine and sub-alpine scrub habitats (F2) had the greatest exceedance although their land cover is relatively low in Europe. Across the EMEP domain, grassland and tundra dominate the area of semi-natural habitat. Mesic grasslands, the grassland ecosystem type studied that had the highest critical load range (20-30 kg ha^{-1} y^{-1}), showed no exceedance at all for 2005 and 2010. In contrast, when a similar exercise was conducted for the UK using national deposition data (2003-2005) based on a 5 x 5 km grid scale and using the UK Land Cover Map, considerable exceedances (up to 63% area) were calculated using mean deposition and mean empirical critical loads.

Contents

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 Bangor (CEH 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). In recent years, the ICP Vegetation has focussed on two air pollution problems of particular importance: quantifying the risks to vegetation posed by ozone pollution and the atmospheric deposition of heavy metals to vegetation. More recently the combined risk to vegetation of ozone and nitrogen pollution and the atmospheric deposition of nitrogen to vegetation are being considered by the programme.

Today, the ICP Vegetation comprises an enthusiastic group of over 200 scientists from 34 countries (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	Spain
Croatia	Latvia	Sweden
Czech Republic	Lithuania	Switzerland
Denmark	Norway	Turkey
Estonia	Poland	Ukraine
Finland	Portugal	United Kingdom
France	Romania	USA
FYR of Macedonia	Russian Federation	Uzbekistan
Germany		

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 (NEGTAP, 2001). 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 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 senescence 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[3] 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, 2007). 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 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, 2007). 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 2009. 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, V, Zn from tyres);

[3] 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. Indeed, over 6,000 moss samples have been collected in 28 countries in the most recent 2005/2006 European survey (Harmens *et al*., 2008a). Spatial and temporal trends in the concentrations of heavy metals in mosses across Europe have been described recently by Harmens *et al.* (2007, 2008a,b).

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). Therefore, 16 countries participating in the European heavy metals in moss survey 2005/2006 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[4] 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, including a summary of main findings.

1.3 Work-plan items for the ICP Vegetation in 2008

The following activities were agreed at the 26th Session of the WGE to be priority areas of work for the ICP Vegetation in 2008:

- Annual report on experimental responses of vegetation to ozone;
- Report on the evidence for effects of current ambient ozone on vegetation in 1990–2006;
- Flux-based maps of ozone damage risks to crop and tree species using localised parameterisations (with EMEP/MSC-W and ICP Forests);
- Progress report on flux-based methods for (semi-)natural vegetation;
- Report on European heavy metals in the 2005-2006 mosses survey;

[4] European Nature Information System

- Report on the nitrogen concentration in mosses in the 2005-2006 mosses survey.

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

- Updated review of robustness of monitored and modelled air pollution impacts;
- Updated compilation of observed parameters, monitoring methodologies and intensities of effects-oriented activities;
- Updated summary of effects-oriented activities in countries of Eastern Europe, Caucasus and Central Asia (EECCA countries).

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 2007/8 together with the medium-term work-plan (updated at the 21st ICP Vegetation Task Force Meeting, 25-29 February 2008, Oulu, Finland).

2. Coordination activities

2.1 Annual Task Force Meeting

The Programme Coordination Centre organised the 21st ICP Vegetation Task Force Meeting, 26-29 February 2008 in Oulu, Finland, in collaboration with the local host at the Muhos Research Unit of the Finnish Forests Research Institute. The meeting was attended by 52 delegates from 19 Parties to the Convention; also present were the chairman of the WGE, the UNECE secretariat for the LRTAP Convention and a representative from ICP Modelling and Mapping. The Task Force discussed the progress with the work-plan items for 2008 (see Section 1.3) and the medium-term work-plan for 2009-2011 for the air pollutants ozone, heavy metals and nutrient nitrogen. A book of abstracts, details of selected presentations and the minutes of the 21st 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 (with an in depth study to be conducted in 2010), and contributions to flux-effect modelling. Parties pledged their contributions to these activities. A workshop on ‘Quantification of ozone impacts on crops and (semi-)natural vegetation’ is tentatively planned in the autumn of 2009.

Heavy metals and nitrogen – to conduct the next European heavy metals and nitrogen in mosses survey in 2010, report on the causes of variation in heavy metal/nitrogen concentration in mosses and robustness of data, review the relationship between heavy metal/nitrogen concentration in mosses and impacts on ecosystems, and explore further development and application of the nitrogen meta-database.

The 22nd Task Force Meeting will be held at FAL, Braunschweig, Germany, from 2 – 5 February, 2009

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 27th session of the WGE:

- ECE/EB.AIR/WG.1/2008/3: Joint report of the ICPs and Task Force on Health;
- ECE/EB.AIR/WG.1/2008/9: Technical report from the ICP Vegetation on ‘Evidence of widespread ozone damage to vegetation in Europe (1990–2006)’;
- ECE/EB.AIR/WG.1/2008/15: Consolidated report on air pollution effects (Executive Summary).

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

- ECE/EB.AIR/WG.1/2008/16: Draft guidelines for reporting on the monitoring and modelling of air pollution effects.

These reports can be found at:
http://www.unece.org/env/lrtap/WorkingGroups/wge/27meeting.htm.

The full ‘Consolidated report on air pollution effects’ will be published by the Bureau of the WGE later this year.

The revised chapter 3 ('Mapping critical levels for vegetation') of the LRTAP Convention's Modelling and Mapping Manual has been updated with revised critical levels for ammonia and "real tree" parameterisations for the ozone flux models for forest trees.

The Programme Coordination Centre for the ICP Vegetation has also produced the following three glossy reports in the last year:

Mills, G., Harmens, H., Hayes, F., Jones, L., Norris, D., Hall, J., Cooper, D. and the participants of the ICP Vegetation (2008). Air Pollution and Vegetation: ICP Vegetation Annual Report 2007/2008. ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-1-85531-240-1.

Harmens, H., Norris, D. and the participants of the moss survey (2008). Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990-2005) Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-1-85531-239-5.

Hayes, F., Mills, G., Harmens, H., Norris, D. (2007). Evidence of widespread ozone damage to vegetation in Europe (1990–2006). Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-0-9557672-1-0.

2.3 Scientific papers in refereed journals and book chapters

Harmens, H., Norris, D.A., Koerber, G.R., Buse, A., Steinnes, E., Rühling, Å. (2008). Temporal trends (1990 – 2000) in the concentration of cadmium, lead and mercury in mosses across Europe. Environmental Pollution 151: 368-376.

Harmens, H., Norris, D.A., Koerber, G.R., Buse, A., Steinnes, E., Rühling, Å. (2007). Temporal trends in the concentration of arsenic, chromium, copper, iron, nickel, vanadium and zinc in mosses across Europe between 1990 and 2000. Atmospheric Environment 41: 6673-6687.

Schröder, W., Pesch, R., Englert, C., Harmens, H., Suchara, I., Zechmeister, H.G., Thöni, L., Maňkovská, B., Jeran, Z., Grodzinska, K., Alber, R. (2008). Metal accumulation in mosses across national boundaries: uncovering and ranking causes of spatial variation. Environmental Pollution 151: 377-388.

Schröder, W., Englert, C., Pesch, R., Zechmeister, H.G., Thöni, L., Suchara, I., Maňkovská, B., Jeran, Z., Harmens, H., Grodzinska, K., Alber, R. (2008). Metallakkumulation in Moosen: Standörtliche und regionale Randbedingungen des Biomonitoring von Luftverunreinigungen. Umweltwissenschaften und Schadstoff-Forschung - Zeitschrift für Umweltchemie und Ökotoxikologie 20: 120 – 132.

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

2.4 Additional reports

Harmens, H., Norris, D., Cooper, D., Hall, J. and the participants of the moss survey (2008). Spatial trends in nitrogen concentrations in mosses across Europe in 2005/2006. ICP Vegetation, Defra contract AQ0810. http://icpvegetation.ceh.ac.uk

Hicks, K., Harmens, H., Ashmore, M., Hall, J., Cinderby, S., Frey, S., Cooper, D., Rowe, E., Emmett, B. (2008). Impacts of nitrogen on vegetation. ICP Vegetation, Defra contract AQ0810. http://icpvegetation.ceh.ac.uk

3. Ongoing research activities in 2007/8

In this chapter, the progress made with common items on the WGE work-plan and the ICP Vegetation work-plan for 2008 is summarised.

3.1 Contributions to WGE common work-plan items

3.1.1 Updated review of robustness of monitored and modelled air pollution impacts

An inter-laboratory calibration exercise conducted during the 2005/6 European moss survey showed that the coefficient of variation in heavy metal concentrations in moss reference material using a range of analytical techniques varied from about 8% for antimony and zinc to about 14% for aluminium. For nitrogen, the uncertainty was about 7%. Previous research showed that for the metals aluminium and chromium/iron the applied method of sample dissolution in the moss survey represents approximately 60% and 85%, respectively, of the total metal concentration in moss reference material (Smodiš and Bleise, 2007).

Uncertainties in the comparison of effects in ambient air with EMEP risk maps for ozone are described in Section 3.2.2 and in more detail in Hayes *et al*. (2007b).

3.1.2 Updated compilation of observed parameters, monitoring methodologies and intensities of effects-oriented activities

In the last three years, 39 site in 20 countries have been participating in the ozone activities of the ICP Vegetation, of which 13 sites in 11 countries delivered data for or participated in modelling of ozone stomatal flux. Twelve countries reported meteorological data (22 sites) such as air temperature, precipitation and relative humidity, concentrations of ozone in ambient air (22 sites) and vegetation parameters (19 sites) such as growth or yield reduction and foliar damage. Four sites reported data on soil water potential for modelling ozone stomatal flux. Exceedance of selected AOT values were measured and modelled and, accumulated stomatal flux and exceedance were modelled.

Twenty eight countries participated in the 2005/6 European heavy metals in mosses survey (approximately 6,000 sites), of which 16 also reported on the total nitrogen concentration in mosses (2,928 sites).

3.1.3 Updated summary of effects-oriented activities in countries of Eastern Europe, Caucasus and Central Asia (EECCA countries)

In the last three years the Russian Federation has been participating in the annual Task Force Meeting, whereas Moldova, Ukraine and Uzbekistan participated in the meeting held in March 2007 in the Russian Federation. Belarus, the Russian Federation and Ukraine submitted data on the concentration of heavy metals in mosses in the 2005/6 survey and the Ukraine also participated in the ozone biomonitoring programme in 2007.

3.2 Progress with ICP Vegetation work-plan items

3.2.1 Experimental responses of vegetation to ozone

As part of ongoing activities to monitor the effects of ambient ozone on crops and (semi-) natural vegetation, 12 groups participated in the clover biomonitoring exercise. New groups from Hungary and the Ukraine reported the presence of ozone injury on the sensitive biotype of white clover. Overall, in the countries reporting results, there was less ozone injury in July and August than in recent years, but ozone injury was prevalent in September.

The Task Force Meeting in Oulu decided that due to the decline in interest in recent years in the clover biomonitoring experiment, that biomonitoring exercises should be refocused in the future. One detailed survey is planned for the year 2010. This would include surveys for ozone injury at NATURA 2000 sites[5], an extensive clover biomonitoring network and possibly a new experiment with ozone-sensitive and ozone-resistant strains of *Phaseolus vulgaris* that are being developed in the USA (Burkey et al., 2005). Activities in 2008 and 2009 would concentrate on developing methods and staff training for the 2010 survey. A new experimental protocol has been developed by the Programme Coordination Centre for the bean experiment. Seeds were kindly donated by Kent Burkey (USDA), arrived at the Programme Coordination Centre in early June following phytosanitary checks in the USA and were immediately distributed to 14 groups representing the following countries: Hungary, Spain, France, Greece, Slovenia, Italy, Ukraine, Greece, Belgium, Germany and the UK. Four groups will be validating the biomonitoring system using ozone exposure facilities.

Additional experimental contributions to other ozone activities include exposure experiments with grassland species and crops and stomatal conductance measurements for use in flux models (see below).

3.2.2 Evidence for effects of current ambient ozone on vegetation in 1990 – 2006

Over the last two years, the Programme Coordination Centre for the ICP Vegetation has collated as far as possible, all of the published and unpublished evidence of ozone damage to crops and (semi-)natural vegetation growing in ambient air in European countries over the time period 1990 to 2006 (The "Evidence Report", Hayes *et al*., 2007b). The data has been analysed in relation to EMEP maps which predicted those areas that were of greatest risk of ozone damage over the time period. Two methods of risk assessment were compared: the AOT40-approach based on the ozone concentration in air above the canopy, and the generic flux-approach, a more biologically relevant method based on predicting the uptake of ozone through the stomatal pores on the leaf surface. A summary of the main results, including the policy implications are provided below.

<u>Sources of data</u>
The Evidence Report includes ozone concentration data measured at the local scale at ICP Vegetation monitoring sites together with modelled ozone concentration and flux for 50 km x 50 km grid squares across Europe supplied by EMEP Metereological Synthesizing Centre-West (EMEP/MSC-W). Three ozone metrics were used throughout: the 12h mean (an average of the ozone concentration between 8am and 8pm); AOT40 (the accumulation of hourly mean canopy height ozone concentrations above 40 ppb during daylight hours) and $AF_{st}3_{gen}$ (a model of the cumulative flux of ozone into leaves of a generic crop which takes into account the influence of temperature, light and humidity on stomatal opening). The evidence of ozone damage was assessed at AOT40s above the critical level for yield reduction in agricultural crops (an AOT40 of 3 ppm h) and compared with risk maps based on the ozone flux metric, $AF_{st}3_{gen}$. Further information about the critical level and dose metrics used can be found in the Modelling and Mapping Manual (2007).

The evidence of effects of ambient ozone on vegetation includes visible injury records, results from exposure studies in charcoal-filtered/non-filtered air, and visible injury and

[5] Natura 2000 is a European network of protected sites which represent areas of the highest value for natural habitats and species of plants and animals which are rare, endangered or vulnerable in the European Community

biomass response data from the ICP Vegetation biomonitoring studies using ozone-sensitive and ozone-resistant biotypes of white clover. Data from peer-reviewed papers and conference proceedings as well as previously unpublished data from ozone research groups across Europe were collated to form a comprehensive database for use in this study.

The ozone climate of Europe

Current ozone concentrations vary greatly between regions and years owing to climatic variations, surface topography, landscape and local versus long-distance sources of ozone precursors and other pollutants. The highest ozone concentrations tend to occur in southern Europe, particularly in Italy, Greece, Slovenia, Spain and Switzerland. Moderate ozone concentrations are experienced in other European countries, especially those in central Europe, with all countries of Europe experiencing periodic ozone episodes with several days of peak ozone concentrations exceeding 50 ppb and sometimes exceeding 90 ppb. Maps of ozone flux show that the climatic conditions are conducive to ozone uptake by vegetation across most of Europe, with moderate/high fluxes predicted for some areas such as southern Scandinavia where ozone concentrations are relatively low.

Evidence of ozone damage at the European scale

Visible injury symptoms attributed to ozone pollution have been recorded in sixteen European countries between 1990 and 2006. The total number of records exceeds 500, and includes injury on 30 crop species (e.g. bean, potato, maize, soybean, lettuce) and 80 species of (semi-)natural vegetation encompassing both forbs and grasses. The highest numbers of records were found in Spain, Italy, Belgium, Sweden, Greece and Poland. Unfortunately, it was not possible to analyse spatial or temporal trends in this dataset as the locations where there were the most observations of injury tended to be within easy travelling distance of scientists specialising in ozone effects, rather than found in statistically designed surveys.

Some more detailed analysis was possible for the results of the ICP Vegetation biomonitoring experiments with white clover (1996 to 2006). Ozone leaf injury scores were generally highest at the sites with the highest AOT40. Across Europe, the ozone injury scores were highest in July and August, lower in June and September with a few sites recording injury in May and October. The biomass of the sensitive biotype of white clover (NC-S) was significantly reduced relative to that of the ozone-resistant biotype (NC-R) at a number of sites across Europe, especially those in central and southern Europe. NC-S biomass reduction for June-August was linearly related to AOT40 measured at the site (r^2 = 0.45 for all data and 0.81 for regional means, Figure 3.1), with the highest reductions at the sites with the highest AOT40s. Earlier experiments in 1994 to 1996, in which a chemical protectant against ozone injury was applied to *Trifolium subterraneum* (subterranean clover) produced a similar linear relationship with AOT40 when compared with untreated plants.

In a few experiments, plants were exposed to sub-ambient ozone concentrations using open-top chambers ventilated with charcoal-filtered (CF) ambient air. Biomass reductions of greater than 10% (relative to the CF treatment) were recorded for plants grown in non-filtered (NF) air-ventilated open top chambers at sites in Sweden, The Netherlands, Spain and Italy.

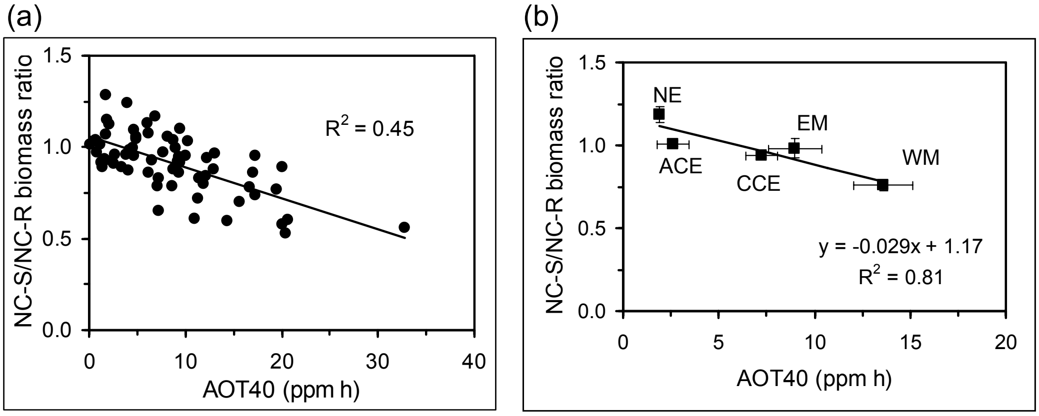

Figure 3.1. Relationship between three-month AOT40 measured at the site and the biomass of the ozone-sensitive (NC-S) white clover (relative to the ozone-resistant (NC-R) biotype) for (a) all data from ICP Vegetation sites, (b) mean data (+/- one standard error) for five geographical regions: NE: Northern Europe, ACE: Atlantic Central Europe, CCE: Continental Central Europe, EM: Eastern Mediterranean, WM: Western Mediterranean.

<u>Evidence of ozone damage at the regional scale</u>

To analyse further the evidence for damaging effects of ozone pollution, the database was divided into the following five geographical regions: Northern Europe, Atlantic Central Europe, Continental Central Europe, Eastern Mediterranean and Western Mediterranean. In Northern Europe, represented by Sweden and Finland, an average of 5 - 25% of NC-S clover leaves were damaged by ozone in 1999 and 2006, whilst between 1 and 5% of leaves were damaged in all the years in between, except in 2005. The highest injury scores detected in Atlantic Central Europe on NC-S clover were in the "high" ozone years of 2003 and 2006. Reductions in biomass in NF- compared to CF-ventilated open-top chambers were detected in Belgium and The Netherlands between 2000 and 2004. Ozone concentrations were higher in Continental Central Europe, with June – August AOT40s ranging 0.7 to 13.1 ppm h at ICP Vegetation sites in Austria, Germany, Poland and Switzerland. Interestingly, in this region the highest injury scores on NC-S clover were recorded in the more humid years of 2001 and 2002 rather than the drier "high" ozone years of 2003 and 2006, suggesting that ozone flux rather than concentration may be more important in determining the magnitude of ozone effect.

There were numerous records of ozone injury in Slovenia and Greece, representatives of the Eastern Mediterranean region, with farmers reporting severe value loss in salad crops due to foliar ozone injury rendering the crops un-sellable. In the clover biomass experiment, ambient ozone in Greece in 2003 reduced the biomass of NC-S clover by 30% relative to that of the resistant variety. The largest number of reports of the damaging effects of ozone was from the Western Mediterranean region where the 12h mean ozone concentration at ICP Vegetation sites in Italy and Spain was in excess of 40 ppb in each year from 1999 to 2006. Mean ozone injury scores on NC-S clover showed that over 25% of leaves were injured in this region by ozone in 1998 and 2003 with significant injury recorded in all other years. Biomass reductions in NC-S clover were frequently around 20% at many Italian sites, and were as high as 47 and 42% in 1998 and 1999 in Italy (Isola Serafini) when the AOT40 was 20.4 and 32.8 ppm h respectively.

<u>Comparison of effects in ambient air with EMEP risk maps for ozone</u>

From the onset, the "Evidence Report" set out to answer a series of questions raised by policy makers on the extent of ozone effects in areas identified by the mapping process as being at risk from ozone pollution. Following a consideration of the sources of uncertainty in the data, the results of analysis of effects in ambient air in relation to EMEP AOT40 and $AF_{st}3_{gen}$ risk maps are summarized by answering policy-specific questions.

The sources of uncertainty in this study fall into two main areas: those associated with quantification of ozone effects and those related to mapping effects in relation to ozone concentration or flux.

Ozone injury assessment and biomass reduction for the ICP Vegetation clover experiment was conducted according to a common protocol using plant material supplied by the Coordination Centre, and thus was associated with the least uncertainty. Higher uncertainty was associated with field surveys of injury due to the difficulty of ascertaining the cause of the symptoms; such uncertainty was minimised in this study by only including data confirmed by ozone exposure experiments or verified by an ozone-specialist.

Uncertainties associated with the mapping process include (1) simulation of emissions, transport and deposition of ozone (see e.g. Simpson *et al*. (2007) for details); (2) the use of a threshold, with $AF_{st}3_{gen}$ being less sensitive than AOT40 as lower ozone concentrations contribute to this accumulated exposure index than to AOT40; (3) earlier in the year time periods for the EMEP risk maps than for the ICP Vegetation and other effects data used and (4) local factors including topography, altitude, local emissions etc., that influence ozone concentration within an EMEP 50 x 50 km grid square.

Answers to Policy Maker's questions

Is there any evidence of temporal trends in ozone effects? At the local scale, there was evidence of higher damage in years with higher ozone concentrations (e.g. 2003 and 2006) in regions of Europe where climatic conditions were conducive to high ozone fluxes. However, the timescale and density of data points were insufficient to allow any long-term trends related, for example, to the changing ozone profiles (lower peaks, increasing background) to be identified.

Is there evidence of ozone damage in areas of exceedance of the AOT40-based critical level? Ozone effects were found in central and southern areas of Europe where the EMEP risk maps predict that the AOT40-based critical level for yield reduction was exceeded. AOT40 worked best as a regional-scale indicator of damage: both ozone leaf injury score and biomass reduction were linearly related to the mean EMEP modelled AOT40 for the 50 x 50 km grid squares the ICP Vegetation sites represented (r^2 = 0.84 and 0.97 respectively, see Figure 3.2b for biomass). Comparison of magnitude of effects at individual sites with EMEP grid square values representing the sites were less conclusive (Figure 3.2a).

Is there evidence of ozone damage in areas with AOT40s below the critical level? Ozone damage was found in areas with AOT40s below the critical level for yield reduction (see Figure 3.2). Thus, maps of exceedance of the AOT40-based critical level for agricultural crops (an AOT40 of 3 ppm h) appear to be underestimating the potential for ozone damage in Europe. For example, at the regional scale, the EMEP risk maps indicated that mean AOT40s were just below the critical level in grid squares representative of Continental Central Europe and Eastern Mediterranean and yet mean biomass reductions of greater than 10% were recorded in clover in these regions. Furthermore, the critical level for yield reduction did not protect against ozone injury, a response which in clover at least, occurs at lower AOT40s than the biomass response. When local evidence of ozone injury on crops and (semi-)natural vegetation was compared with EMEP AOT40 maps, up to one third of data points were in regions where the maps indicated that the critical level for yield reduction was not exceeded (Hayes *et al*., 2007b).

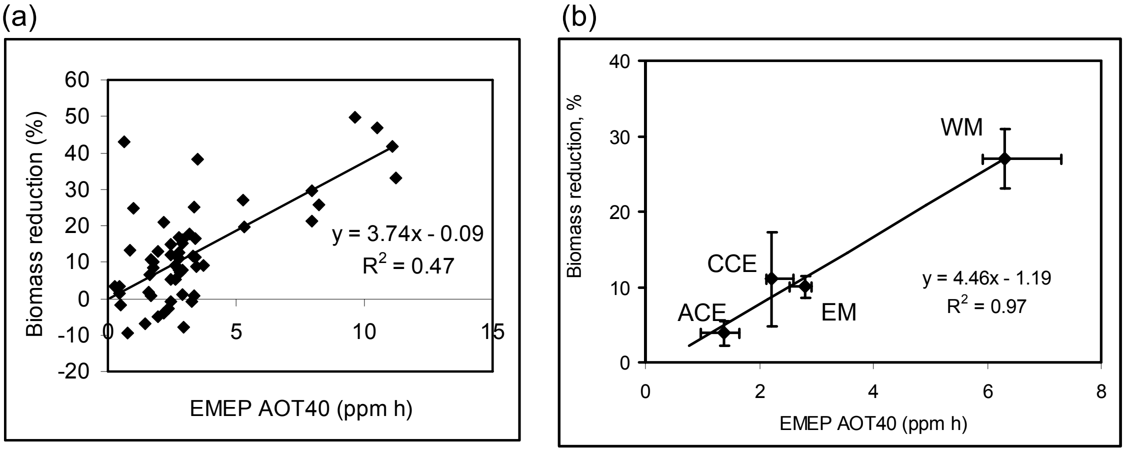

Figure 3.2. Relationship between percentage biomass reduction in the ozone-sensitive (NC-S) white clover (relative to the ozone-resistant (NC-R) biotype) and (a) EMEP grid square AOT40 values representing the sites where the experiments were conducted, (b) mean EMEP AOT40 (+/- one standard error) for the site grid squares in four geographical regions (see Figure 3.1 for key).

Does ozone damage occur in areas predicted by the flux-based method to be at risk from ozone effects? The overriding concept of the generic flux maps is that they indicate risk of ozone damage wherever there is predicted to be any ozone flux to vegetation (i.e. where $AF_{st}3_{gen}$ > 0). In this analysis, ozone damage was found in grid squares predicted to have $AF_{st}3_{gen}$ values of at least 5 mmol m^{-2}, with virtually all damage being found in grid squares with an $AF_{st}3_{gen}$ of at least 10 mmol m^{-2} (Figure 3.3). This analysis has shown quite clearly that there is either no or minimal impact of ozone in grid squares predicted to have an $AF_{st}3_{gen}$ at/close to zero.

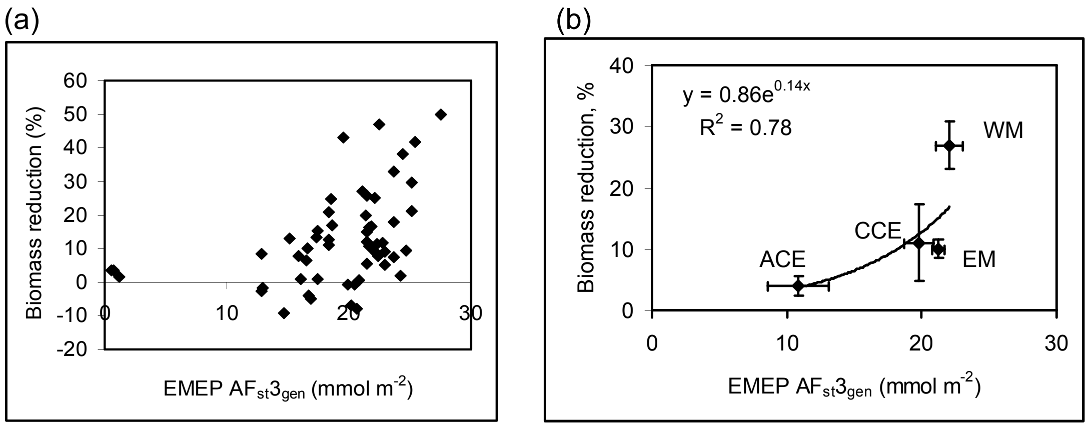

Figure 3.3. Relationship between percentage biomass reduction in the ozone-sensitive (NC-S) white clover (relative to the ozone-resistant (NC-R) biotype) and (a) EMEP grid square $AF_{st}3_{gen}$ values representing the sites where the experiments were conducted, (b) mean $AF_{st}3_{gen}$ (+/- one standard error) for the site grid squares in four geographical regions (see Figure 3.1 for key).

Is there evidence of more ozone damage in the areas with the highest fluxes? The highest biomass reductions in NC-S white clover were found in grid squares predicted to have an $AF_{st}3_{gen}$ of 18 or more mmol m^{-2} (Figure 3.3), with the highest reduction of nearly 50% being detected in the grid square having the highest predicted $AF_{st}3_{gen}$ of those considered in this study (27.5 mmol m^{-2}). As with AOT40, $AF_{st}3_{gen}$ worked best as a regional-scale indicator, with an exponential relationship between increasing $AF_{st}3_{gen}$ and increasing effect (r^2 = 0.96 for injury and 0.78 for biomass reduction, Figure 3.3b). Local-scale predictions were more susceptible to the uncertainties described above, causing some scatter in the relationship.

Is there evidence of ozone damage in areas with high flux, but low AOT40? The dose metric, $AF_{st}3_{gen}$ worked particularly well as an indicator of risk of damage in northern Europe and parts of Atlantic Central Europe. Injury was detected in these regions when $AF_{st}3_{gen}$ values were predicted to be over ca. 10 mmol m^{-2}, but not when $AF_{st}3_{gen}$ values were at/close to zero. According to the AOT40 maps, no injury or yield reduction would have been predicted at these sites because the values were too low (AOT40 was less than 1 ppm h).

Overall, which maps (AOT40 or flux) best predicted areas with ozone damage? For the reasons described above, maps of the generic flux to crops most accurately predicted the areas where there was evidence of ozone damage. Although AOT40 worked well at the regional scale, effects frequently occurred in areas predicted to be safe from ozone damage (i.e. areas where the AOT40 was below the critical level).

3.2.3 Progress with flux-based methods for (semi-)natural vegetation

The further development of modelling methods for the assessment of risk of damage by ozone to (semi-)natural vegetation is a priority research area for the ozone sub-programme of the ICP Vegetation. Participants contribute by:

- Conducting ozone exposure experiments with grassland species;
- Measuring ozone flux, stomatal conductance and canopy characteristics such as leaf area index in naturally-occurring grasslands;
- Developing models of ozone flux to (semi-)natural vegetation;
- Linking the flux models to effects data;
- Developing methods to identify and map vegetation at potential risk of damage from ozone in Europe.

The number of groups contributing to these activities together with the links between the activities is presented in Figure 3.4

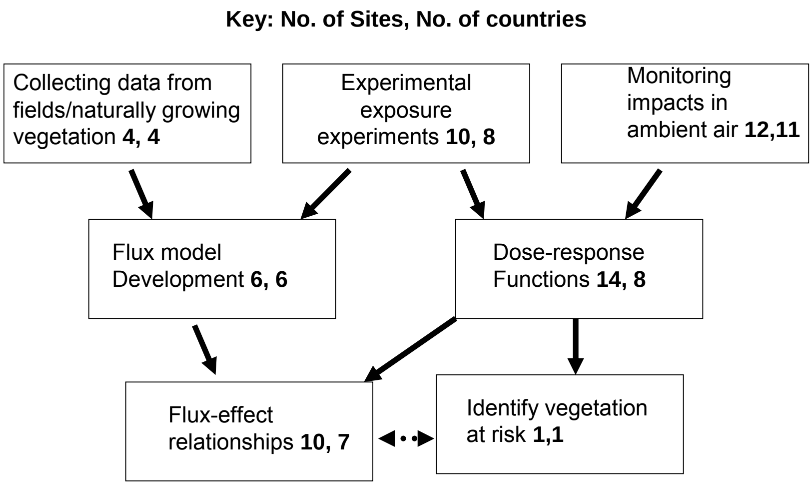

Figure 3.4. ICP Vegetation activities that are contributing to the development of flux-based methods and risk assessment for ozone effects on (semi-)natural vegetation.

Contributions were reviewed at the annual Task Force Meeting in Oulu and progress towards the development a full ozone flux-effect model suitable for deriving a flux-based critical level for this vegetation type was discussed. Ms Gina Mills (UK) presented an overview of ongoing research and listed the challenges for the group. Mr Matthias Volk (Switzerland) presented results on changes in carbon allocation and CO_2 fluxes of sub-alpine grassland under high ozone and nitrogen deposition. Ms Gina Mills (UK) reported on the impacts of increasing background ozone on competition, stomatal control and carbon turnover in grassland mesocosms, followed by a presentation from Mr Håkan Pleijel (Sweden) on visible ozone injury, ozone uptake and effects on growth of four *Phleum pratense* genotypes. Mr Ignacio González-Fernández (Spain) gave an overview of data collection and the development of flux models for Dehesa grasslands. Progress with the development of flux models for (semi-)natural vegetation was outlined by Mr Patrick Büker (UK). Results of research were presented in several posters displayed at the Task Force Meeting and were also supplied to the Programme Coordination Centre by participants that were unable to attend the meeting. The group agreed that a workshop covering progress with flux-based critical levels for crops and (semi-)natural vegetation in 2009 would be timely.

<u>Methods for assessing (semi-)natural vegetation types at risk of damage from ozone in Europe</u>

A database named OZOVEG (OZOne impacts on VEGetation) has been established at the Programme Coordination Centre incorporating all published data on the sensitivity of individual species of (semi-)natural vegetation grown in a non-competitive environment to ozone (Hayes *et al*., 2007a). Data was selected for inclusion from field-release, open-top chamber or solardome experiments involving seasonal ozone exposure and used to develop dose-response functions for over 80 species. The database has been further developed in the last year (OZOVEG2) to include newly published data, which provided sufficient data points to derive dose-response relationships for an additional six species together with information on species characteristics such plant height and canopy type for all species in the database.

Information on the responses of species to ozone when grown in a competitive environment has been added to the database using information from the ozone exposure experiments in Europe that have been conducted on whole plant communities. These experiments range from artificially sown community mixes in open-top chambers to transplant and in-situ field exposures using free air ozone exposure technology. Data were obtained from peer-reviewed journals, the “grey” literature and directly from ICP Vegetation participants. The compiled data includes experimental results from Finland, Germany, the Netherlands, Switzerland and the UK. The aim was to determine whether there was a common pattern in how much growth in a competitive environment modifies the response to ozone.

In total, there were 23 species for which an ozone dose response relationship could be compared either with and without competition, or between different competitors. Only eight of the species showed a significant ozone dose response when the data from the competition experiments were included with the single species exposures. Of these, only *Plantago lanceolata* and *Poa pratensis* showed a significant effect of competition on the ozone response. Thus, the data set is not currently large enough to derive competitor-specific ozone responses at this stage.

Work is ongoing to identify a subset of UK communities incorporating the species for which competition modifiers have been developed. Model development will incorporate the modifiers into the Ellenberg number based modelling framework developed by Jones *et al*. (2007), and test using results from the competition experiments used in this study for which species-specific biomass responses are available. Subsequent work will add in species characteristics (max height etc.) together with community characteristics (open, dense, mixed) to further develop the competition aspects of this model.

The further development of this method for assessing the risk of ozone damage from vegetation is being supported by ozone-exposure experiments being conducted by participants in countries such as the Finland, Italy, Sweden, Switzerland and the UK.

Flux-based assessment of the risk of damage to managed pasture in Europe
Research is in progress at SEI-York to develop a whole canopy flux-effect relationship for productive managed pasture that is capable of differentiating ozone flux (both stomatal and non-stomatal) to the legume and grass fractions. This model will have two uses:

i) Application under experimental conditions for use in deriving stomatal ozone flux-response relationships;
ii) Application at the regional scale to develop methods to improve a) the estimation of total ozone flux to productive grasslands by accounting for species component fractions and; b) the estimation of flux to components of grassland (legumes represented by *Trifolium repens* and grasses represented by *Lolium perenne*) to begin to develop improved risk assessments.

The (semi-)natural vegetation ozone flux model considers the changes in flux to a grassland canopy with time, taking into account changes in leaf area index and light penetration through the canopy together with ozone profiles within the canopy and the instantaneous effects of climatic conditions, soil and plant growth stage on stomatal conductance. In the first phase of development, the model was parameterised for clover and ryegrass mixtures, which was considered to be representative of managed pasture.

Only two suitable datasets for clover/ryegrass mixtures have become available so far: an open-top chamber study conducted in Switzerland by Fuhrer and colleagues in 1993 (Nussbaum *et al*., 1995) and a solardome study at CEH Bangor in 2002 (Hayes, 2007, Hayes *et al*., submitted). Preliminary results have indicated that fluxes to the grass fraction are considerably smaller than fluxes to the clover fraction, which is mainly the effect of the smaller LAI of the grass fraction as compared to the LAI of the clover fraction. Furthermore, for clover the fluxes clearly increase from the bottom to the top of the canopy, which reflects the typical structure of a clover canopy with most of the leaves being positioned in the upper part of the canopy.

Flux measurements for (semi-)natural vegetation and other flux modelling
Several groups are either measuring ozone and CO_2 fluxes or contributing data for future flux modelling for naturally-growing vegetation. For example, Mr Ben Gimeno and colleagues from Spain have been compiling measurements for two dehesa grasslands (Miraflores and Viñuelas) located only 20 km away from each other near Madrid. These grasslands have been found to have quite different CO_2 fluxes due to different canopy structure, species composition and phenology as well as differences in meteorological parameters, soil composition and livestock management. This finding draws attention to the difficulty in modelling ozone fluxes for such heterogeneous landscapes. In another example, Mr Giacomo Gerosa and Mr Angelo Finco have measured ozone, water, carbon dioxide, nitrogen oxides and energy fluxes over an area of Mediterranean macchia at Castel Porziano (Italy). Stomatal ozone flux was found to be higher at night and at dawn than during the day, and comprised only ca. 20% of the total daily ozone deposition to the vegetation.

In addition to the flux modelling described above, other groups are conducting research into ozone flux modelling methods. For example, Mr Ludger Grünhage (Germany) is further developing the PLATIN (PLant-ATmosphere INteraction) model of the biosphere/atmosphere exchange of latent and sensible heat, trace gases and aerosol constituents and Mr

Stanislaw Cieslik (Italy) is measuring and modelling ozone fluxes over wet and dry ecosystems.

Stomatal conductance and plant characteristics data (e.g. phenology, leaf area index) have been offered for use in flux modelling by several groups, including participants from France, Italy, Spain, UK and USA.

3.2.4 Flux-based maps of ozone damage risks to crop and tree species using localised parameterisations (with EMEP/MSC-W and ICP Forests)

In the last year, the flux parameterisation specialists of the ICP Vegetation have concentrated on the development of localised parameterisations for forest trees. Chaired by Ms Lisa Emberson (UK), the forest sub-group (established at the LRTAP Convention Critical Level meeting held in Obergurgl, 2006), including participants from the ICP Forests and EMEP/MSC-W, have established flux model parameterisations for coniferous, deciduous and/or Mediterranean evergreen species representative of the five main geographical regions of Europe.

In an attempt to capture the broad diversity that exists in the seasonal and diurnal ozone dose to European forest tree species, two “generic” parameterisations were defined for use in Integrated Assessment Modelling (IAM) and large-scale modelling and were incorporated into the LRTAP Convention Modelling and Mapping Manual in 2007. A generic “Deciduous” and “Mediterranean evergreen” parameterisation were selected to account for the variation in phenology and climate that are considered important drivers of stomatal ozone flux. These forest parameterisations were finalised by the forest sub-group and adopted at the 24th Task Force meeting of ICP Forests, 24-28 May 2008, Larnaca, Cyprus.

Since the establishment of the “generic” parameterisations the forest sub-group has directed efforts to defining methods to assess the stomatal ozone flux for representative “real” species. These methods have been defined to represent species in particular European regions (using regions of Europe that were previously defined in chapter 3 of the LRTAP Convention Modelling and Mapping Manual, (LRTAP Convention, 2007); and to allow the modelling of stomatal ozone flux and hence ozone risk to be more specific to local species and climatically determined forest tree physiology.

Application of these “real” species parameterisations is intended to inform the European scale Integrated Assessment Modelling (IAM) conducted using the “generic” forest parameterisations. Figure 3.5 provides an overview of how the “real” species parameterisation may be used within the LRTAP Convention ozone risk assessment modelling and mapping work. EMEP and the Centre for Integrated Assessment Modelling (CIAM) at IIASA are largely responsible for implementing the “generic” style risk assessments for use in the European scale IAM. The “real” species parameterisation is notionally to be performed at the national level using nationally specific modelling and mapping tools (e.g. national emissions data, photo-oxidant models, land-cover data etc.). This distinction is exemplary rather than definitive since EMEP may also perform the modelling and mapping using the “real” species parameterisation.

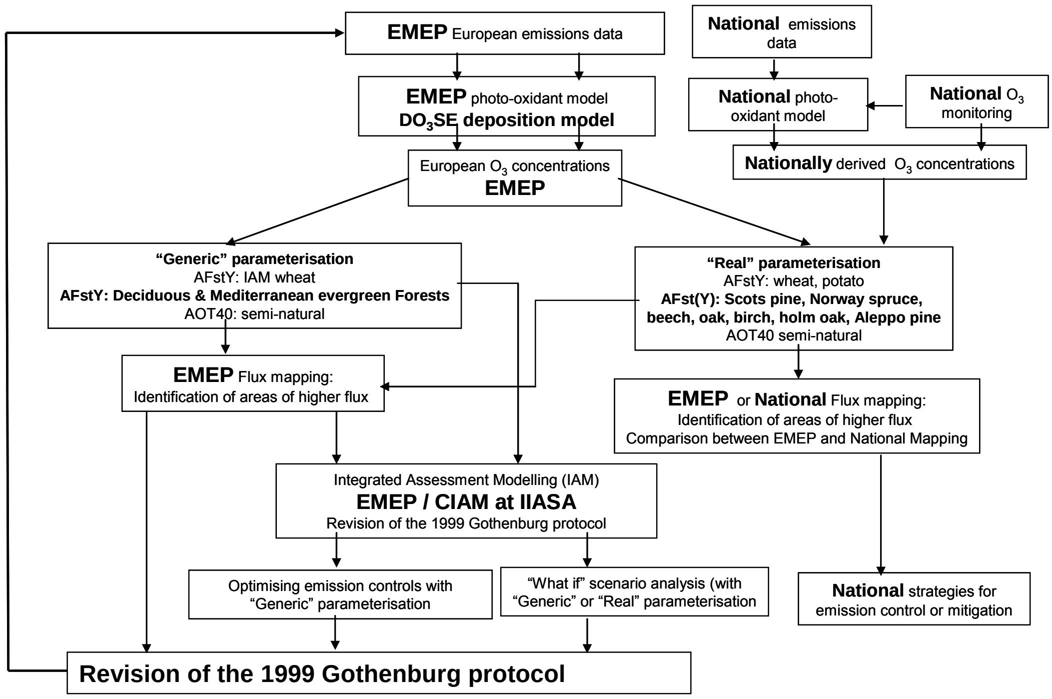

Figure 3.5. An overview of the use of "real" species parameterisation within the LRTAP Convention modelling and mapping of ozone impacts on forest trees.

Representative "real" species were defined by the forest sub-group on consideration of a number of factors, i.e., known sensitivity to ozone, importance of the species by region (e.g. economically, ecologically, geographical coverage) and forest type (i.e. to ensure both evergreen and deciduous forests were represented). In some instances, "real" species occur in more than one climatic region. In such cases, the species parameterisation represents a particular species ecotype i.e. a form or variety of the species that possesses both inherited- and genotype- determined characteristics enabling it to succeed in a particular habitat. The "real" species selected to represent each region are given in Table 3.1. Full details of the parameterisations, including consideration of whole canopy flux modelling, leaf area index development and definition of the start and end of growing season, are provided in Annex V of Chapter 3 of the Mapping Manual.

In cooperation with EMEP/MSCW, the first maps showing ozone flux to forest trees using localised parameterisations will be produced later this year.

Table 3.1. Representative "real" tree species by European region.

European region	Coniferous	Deciduous	Mediterranean broadleaf Evergreen
Northern Europe	Norway spruce	Birch	-
Atlantic Central Europe	Scots pine	Beech & temperate Oak	-
Continental Central Europe	Norway spruce	Beech	-
Mediterranean Coastal/Continental location	Aleppo pine	Beech	Holm oak

3.2.5 Heavy metal concentrations in mosses: 2005/6 European survey and trends

The results of the 2005/6 survey were published in July, 2008 together with those from previous surveys in the following report:

> Harry Harmens, David Norris and the participants of the moss survey (2008). Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990-2005). Programme Coordination Centre for the ICP Vegetation, CEH Bangor, UK.

The major findings of this report are reviewed briefly here.

The heavy metals in mosses survey provides data on concentrations of ten heavy metals (arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, vanadium and zinc) in naturally-growing mosses throughout Europe. In 2005/6, the concentration of aluminium and antimony was also determined in many countries. The technique of moss analysis provides a surrogate measure of heavy metal deposition from the atmosphere to terrestrial systems, is easier and cheaper than conventional precipitation analysis, and therefore enables a high sampling density to be achieved. The aim of the survey is to identify the main polluted areas, produce European maps and further develop the understanding of long-range transboundary air pollution. An additional aim was to summarise changes in heavy metal concentrations in mosses in Europe between 1990 and 2005.

Methodology for the 2005/6 survey

In 2005/6, mosses were collected from approximately 6,000 sites in 28 countries across Europe (Figure 3.6). As in previous surveys, moss samples were collected according to a standardised protocol (ICP Vegetation, 2005) and the heavy metal concentrations were determined in the last three years' growth segments using a range of analytical techniques. *Pleurozium schreberi* was the most frequently sampled species (40.9%), followed by *Hylocomium splendens* (22.7%), *Hypnum cupressiforme* (18.0%), *Scleropodium purum* (11.6%) and other species (6.9%). For quality assurance purposes moss reference material (Steinnes *et al*., 1997) was included in the analyses and where necessary, correction factors were applied to outliers and in some cases, severe outliers were excluded from further data processing. The reported data were checked for anomalies and the format standardised before European maps were produced for the years 1990, 1995, 2000 and 2005. The maps were produced using ArcMAP, part of ArcGIS, an integrated geographical information system (GIS) and were based on the EMEP 50 x 50 km grid, displaying the mean heavy metal concentration for each cell.

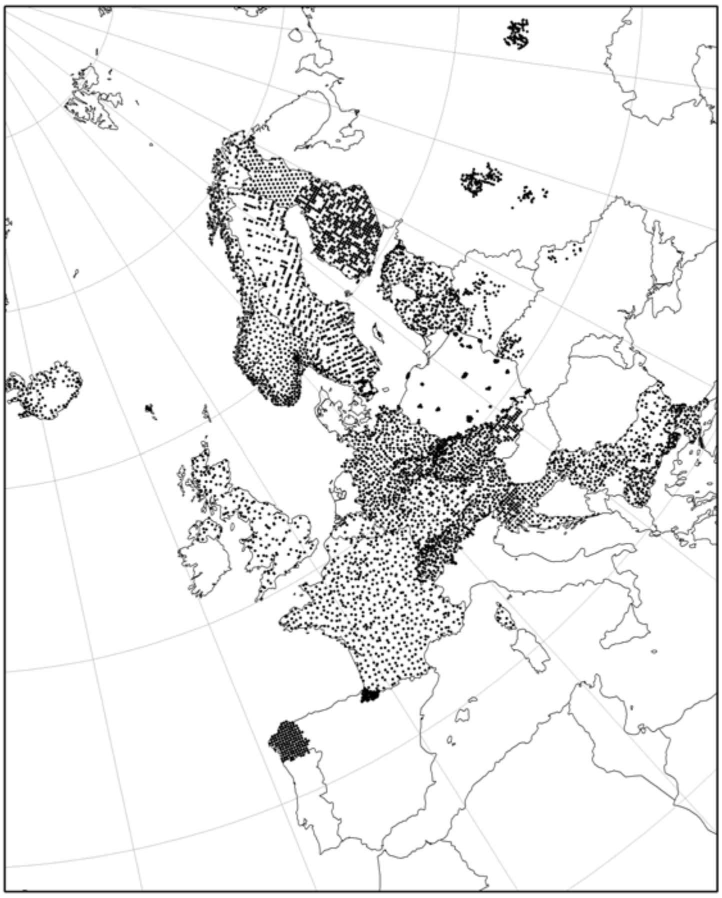

Figure 3.6. Moss sampling sites in 2005/6.

<u>Spatial and temporal trends in Europe</u>

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%, based on 16 countries), arsenic (71.8%, five countries), vanadium (60.4%, 11 countries), cadmium (52.2%, 16 countries) and iron (45.2%, 13 countries). An intermediate decrease was found for zinc (29.3%, 16 countries), copper (20.4%, 16 countries) and nickel (20.0%, 16 countries) and no significant reduction for chromium (2%, 14 countries; Figure 3.7). Few countries reported data for arsenic and mercury in 1990, but since 1995 the arsenic concentration in mosses has declined by 21.3% (14 countries), whereas mercury showed no significant decline (11.6%, eight countries). Temporal trends in heavy metal concentrations in mosses are in agreement with trends in EMEP emission data (or modelled deposition data if available) for arsenic, cadmium, copper, lead, mercury, nickel (although the decline of nickel in mosses is lower than for emissions) and zinc, but not for chromium (as emissions declined). No emission data are being reported by EMEP for iron and vanadium. 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 2005/6, the lowest concentrations of heavy metals in mosses were generally 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 the more global pollutant 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, resulting in considerable cross-border gradients with Germany and Switzerland (although less pronounced for chromium). This could indicate accumulation of a high proportion of windblown dust on mosses collected in eastern and southern France during the dry summer of 2006. Antimony concentrations were generally high in densely populated areas (e.g. central and southern United Kingdom, central Europe, North-East France and southern Norway around Oslo) and in many eastern European countries with high levels of metal pollution.

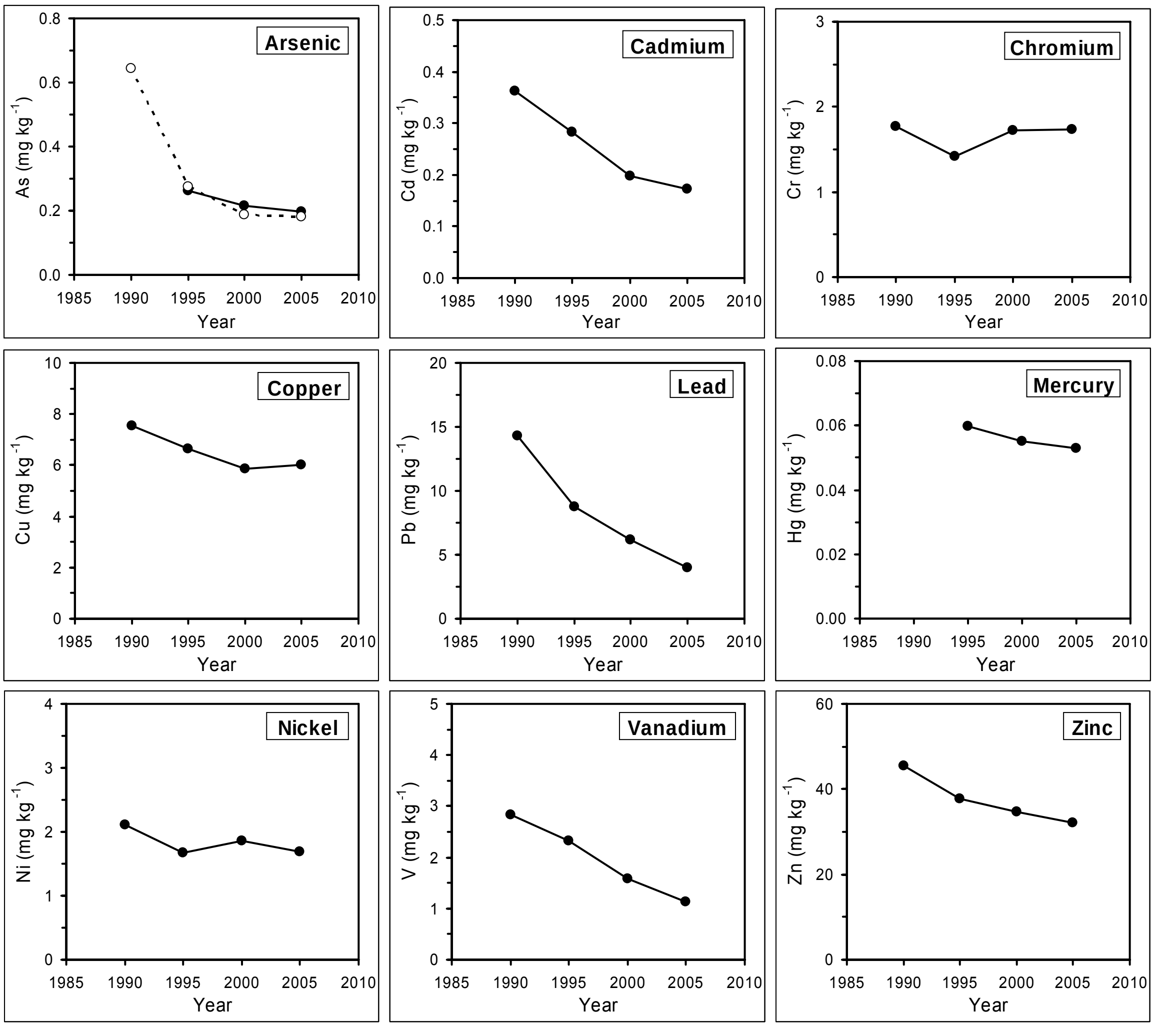

Figure 3.7. Average of median heavy metal concentrations in mosses for countries that reported data in all survey years (Harmens *et al.*, 2008a). For arsenic the broken line is based on data from only five countries (Austria, Czech Republic, Germany, Norway and Switzerland).

Conclusions

- Mosses provide an effective and cheap method for monitoring trends in heavy metals pollution in Europe at a high resolution;
- Spatial trends of heavy metal concentrations in mosses were metal-specific. However, in general the lowest concentrations were observed in (north) Scandinavia, the Baltic States and northern parts of the United Kingdom and the higher concentrations in Belgium and eastern European countries;
- Since 1990, the metal concentration in mosses has declined for arsenic, cadmium, copper, iron, nickel, lead, vanadium and zinc, but not for chromium and mercury. Despite these general European trends, country and region-specific temporal trends were observed, including increases in metal concentrations.

3.2.6 Nitrogen concentration in mosses in the 2005/6 European moss survey

A pilot study for selected Scandinavian countries had shown that there was a good linear relationship between the total nitrogen concentration in mosses and atmospheric nitrogen deposition rates (Harmens *et al*., 2005). Therefore, the mosses sampled for heavy metal analysis (see Section 3.2.5) were also analysed for total nitrogen concentration in the 2005/6 moss survey in the majority of participating countries. This provided a database of nitrogen concentrations in mosses at almost 3,000 sites across 16 European countries (Austria, Belgium, Bulgaria, Czech Republic, Estonia, Finland, France, Germany, Italy, Latvia, Slovakia, Slovenia, Spain, Switzerland, Turkey and UK). The data have been presented on an EMEP 50 x 50 km grid, and were compared with the EMEP nitrogen deposition map for 2004. In addition, a more detailed assessment has been made for the UK using a 5 x 5 km grid for nitrogen deposition. Full details of the results from the survey can be found in the following report:

> Harmens, H., Norris, D., Cooper, D., Hall, J. and the participants of the moss survey (2008). Spatial trends in nitrogen concentrations in mosses across Europe in 2005/2006. Defra contract AQ0810. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK.

The lowest total nitrogen concentrations in mosses were observed in northern Finland and northern parts of the UK, the highest concentrations were found in central and eastern Europe (Figure 3.8a). The spatial distribution of the nitrogen concentration in mosses is similar to the one of the total nitrogen deposition modelled by EMEP for 2004, except that the nitrogen deposition tended to be relatively lower in eastern Europe. However, the relationship between total nitrogen concentration in mosses and total nitrogen deposition, based on averaging all sampling site values within any one EMEP grid square, shows considerable scatter (Figure 3.9). A lot of this scatter can be explained by the fact that in many EMEP grid squares mosses were only sampled at one site. Deposition values are likely to vary considerably within each EMEP grid cell due to for example topography, local climate and vegetation. The apparent asymptotic relationship shows saturation of the total nitrogen in mosses above a nitrogen deposition rate of ca. 10 kg ha^{-1} y^{-1}. In contrast, for Switzerland the relationship was significantly linear (R^2 = 0.91) using measured site-specific total nitrogen deposition rates (Figure 3.8b; Thöni *et al*., in press). A more detailed investigation in Austria suggests that the relationship is affected by local climate, nitrogen species in deposition and possibly the pH of rain water (Zechmeister, unpublished). This might also apply to other countries and requires further investigation at the European scale.

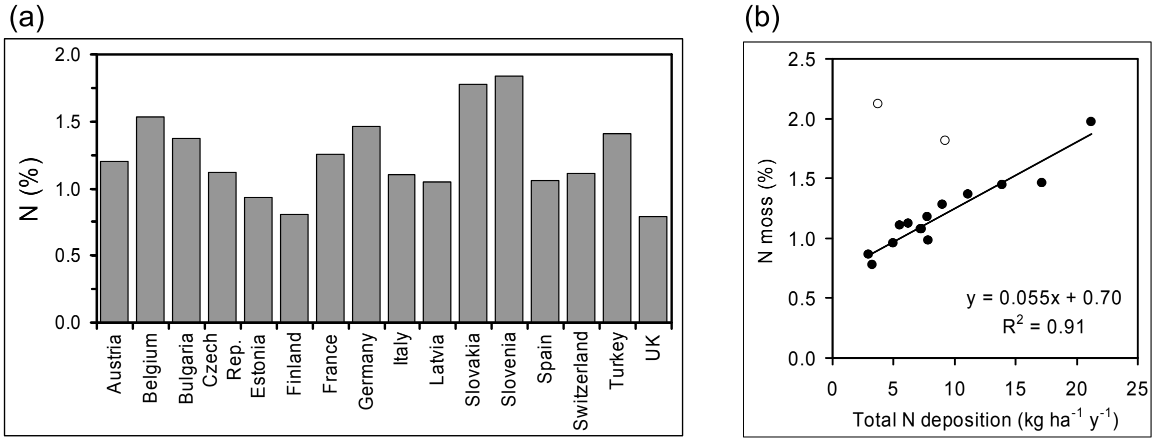

Figure 3.8. Median nitrogen concentration in mosses per country in 2005/6 (a) and relationship between measured total nitrogen deposition rate and nitrogen concentration in mosses in Switzerland (b); the open symbols were excluded from the regression.

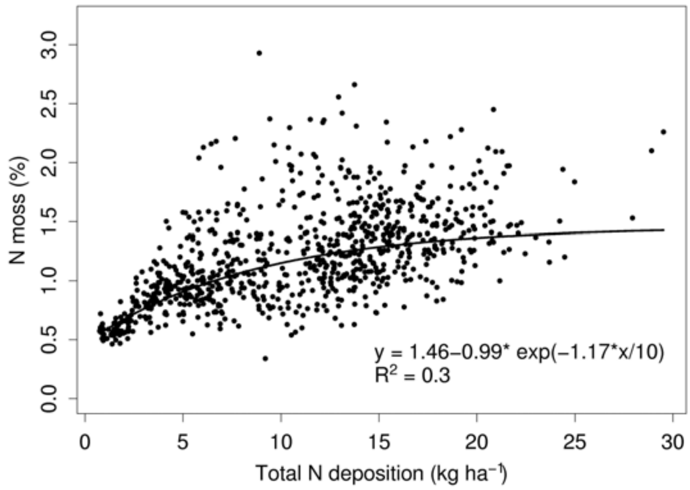

Figure 3.9. Relationship between EMEP modelled total nitrogen deposition in 2004 and averaged nitrogen concentration in mosses (2005/6) per EMEP grid square.

<u>Spatial analysis of nitrogen concentration in mosses in relation to nitrogen deposition in the UK: a case study</u>

The total nitrogen concentration was determined in mosses collected from 170 sites distributed across the UK and compared with current national estimates of nitrogen deposition and nitrogen critical load exceedances. The Concentration Based Estimated Deposition (CBED: *Smith et al*., 2000) values for nitrogen for 2003-2005 were extracted from the national 5 x 5 km maps for each moss sample site. The CBED data consists of three sets of values:

- Average – for all vegetation types;
- Moorland – assuming all land cover is low growing vegetation;
- Woodland – assuming all land cover is woodland.

The CBED data provides separate values for oxidised, reduced and total (oxidised + reduced) nitrogen. The relationships between the nitrogen concentrations in mosses and the different nitrogen deposition values were analysed.

For the majority of the moss sites, the CORINE land cover level 3 class has been recorded by the moss surveyor, and in some cases there was additional qualifying information on the habitat type. Using information from Slootweg *et al*. (2005) and Brown (pers. comm.) the CORINE land cover classes were related to EUNIS habitat codes and UK Broad Habitat types. From this information it was possible to assign appropriate empirical nutrient nitrogen critical loads (CLnutN) to those sites with habitat information, and with habitats for which empirical critical loads are available (Bobbink *et al*., 2003). However, it should be noted that for some habitats the correspondence between different classifications is not always direct. Critical loads have not been assigned to moss sites with CORINE codes for which empirical critical loads are not available for the corresponding EUNIS classes.

In general, the moss sites with lower percent nitrogen, the lowest nitrogen deposition and small or no critical load exceedance are found in northern Scotland, whilst sites with high percent nitrogen, high nitrogen deposition and high exceedance are found in central and eastern England. However, not all sites conform to this spatial pattern, with variability from one site to another resulting in a lot of scatter in the data, reflected in the relatively low R^2 values obtained when plotting the nitrogen deposition (N_{total}, N_{ox} or N_{red}) or critical load exceedance versus the nitrogen concentration in mosses, for example as shown in Figure 3.10. This, and other analysis showed that there were poor relationships between the nitrogen concentration in mosses and the average deposition values (wet, dry, wet+dry, NO_x, NH_y, $NOx+NH_y$) for all sites (Hicks *et al*., 2008). Relationships between the nitrogen concentration in mosses and habitat specific nitrogen deposition were slightly better for moorland or woodland, and when the data were examined by individual moss species. The best results were obtained for percent nitrogen in *Hypnum cupressiforme* versus total nitrogen deposition (R^2 = 0.36); however, the R^2 values for *Pleurozium schreberi* and *Rhytidiadelphus squarrosus* were very small (<0.1). Similar results were obtained for the nitrogen concentration in mosses versus critical load exceedances for nitrogen. Critical loads for nitrogen were exceeded for 117 out of the 160 sites to which critical loads could be assigned.

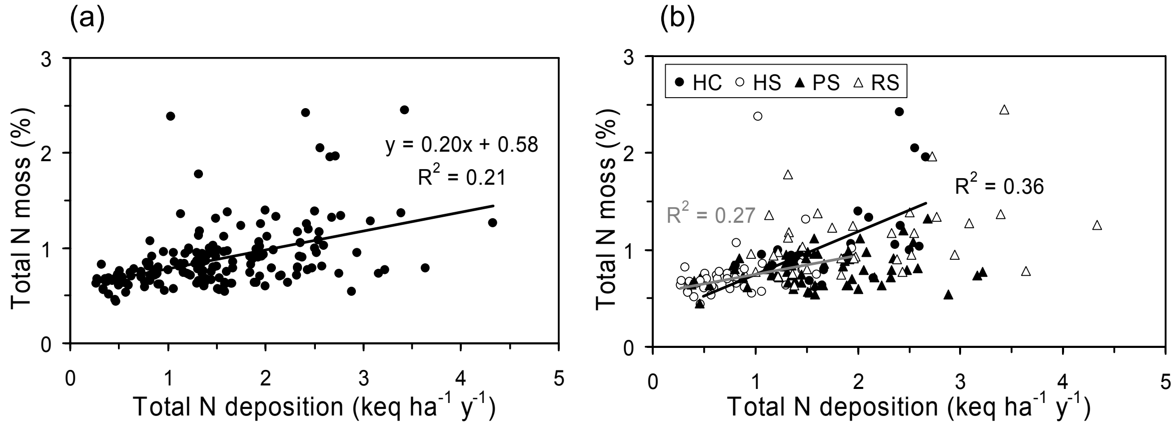

Figure 3.10. Relationship between the total nitrogen concentration in moss and habitat-specific estimated total nitrogen deposition for all moss species (a) and per individual moss species (b); HC = *Hypnum cupressiforme*, HS = *Hylocomium splendens*, PS = *Pleurozium schreberi* and RS = *Rhytidiadelphus squarrosus* (one outlier for HS was excluded from the regression equations; grey line: regression HS, black line: regression HC).

One reason for the low correspondence between the data sets may be the resolution of the deposition data; these values are taken from the national CBED maps that assume deposition is constant across each 5 x 5 km grid square. Deposition values may vary considerably within such an area due to topography, local climate and vegetation. Using habitat-specific deposition values appropriate for the CORINE land cover class at each site (i.e., where moorland or woodland deposition velocities are used to estimate the dry deposition component) improved the relationships compared to using the grid average deposition for all vegetation types. EMEP deposition values for the UK were lower than CBED deposition values and the relationship between EMEP nitrogen deposition values and nitrogen concentration in mosses showed similar scatter as shown for CBED deposition values (Hicks *et al*., 2008). In addition to the resolution of the deposition data there are other uncertainties to be considered, such as uncertainties in: a) measurement and calculation of emissions and deposition; b) critical load values; c) assignment of critical load values based on information on CORINE land cover; d) measurement of nitrogen concentration in mosses, and e) interspecies differences.

4. Newly developing activities in the ICP Vegetation

4.1 State of knowledge reviews

Following the success of the “Evidence Report”, the Task Force of the ICP Vegetation agreed that further reports that synthesise information in scientific journals, the “grey” literature and national reports would be extremely useful outputs from the ICP Vegetation. No other group has such extensive access to information on air pollution impacts on vegetation within the ECE region and beyond.

The following subjects were tentatively proposed at the 21st ICP Vegetation Task Force Meeting in Oulu:

- Comparison of SOMO35 (sum of means over 35 ppb; health indicator), AOT40 and flux-based (vegetation indicators) risk maps for Europe (see initial progress below);
- Ozone impacts on vegetation in Nordic and Baltic areas (see initial progress below);
- Ozone impacts on vegetation in the Mediterranean region;
- Review of ozone flux models and their application to different climatic regions;
- Ozone impacts on crop yield and quality (European regions, outreach to EECCA regions and Malé Declaration countries);
- Review of the 2010 biomonitoring study for ozone;
- Ozone, carbon sequestration and the linkages between climate change and air pollution policy.

In addition, the Programme Coordination Centre has initiated the following areas of study (described briefly below):

- Development of a meta-database describing national and sub-national surveys with evidence of impacts of N deposition on vegetation;
- Development of methods for mapping areas in the ECE region indicating where nitrogen critical loads are exceeded for specific EUNIS communities.

The medium-term work-plan of the ICP Vegetation is described in Chapter 5.

4.2 Comparison of AOT40, SOMO35 and $AF_{st}3_{gen}$-based risk maps for ozone

The Joint World Health Organization/Convention Task Force on the Health Aspects of Air Pollution (Task Force on Health) has recently adopted the metric SOMO35 for risk assessment. This ozone metric is defined as the yearly sum of the daily maximum 8h means that exceed 35 ppb, with the units ppb d. Since health impacts are an integral part of the negotiations related to ozone for the revision of the Gothenburg Protocol, it is timely to compare predictions using each type of effect-metric. Whilst a more in depth analysis is proposed for 2009, we present here some initial findings from the study.

EMEP/MSC-W have kindly provided the ICP Vegetation Programme Coordination Centre with maps for each metric for the year 2006 (Figure 4.1) generated using the EMEP Eularian model (see Simpson *et al*., 2007 for details). Because this report is printed in black and white, it was only possible to show four grid categories. The ranges for these map categories have been matched to ensure comparability, with the delimiters being set at approximately 0.2, 0.4 and 0.8 times the maximum on-land values recorded for each parameter. The maps for AOT40 and SOMO35 show broadly similar patterns of increasing risk to either vegetation or health with decreasing latitude, with the highest risks being predicted in parts of Italy. Southern Europe was also identified as having high risk to ozone using $AF_{st}3_{gen}$ as the metric. However, this flux-based metric also identified others part of Europe as being of high risk of damage to vegetation, including some central areas (e.g. in Germany, western France and Austria) as well as southern Sweden and other Baltic sea countries and parts of eastern Europe.

The grid squares in which ozone injury was detected on vegetation in 2006 have been superimposed on the 2006 maps (Figure 4.1). As indicated in the "Evidence Report" (Hayes *et al*., 2007b, summarised in Section 3.2.2), the visible injury data is better described by the flux-based methodology than AOT40, with more than 80% of ozone injury in 2006 being detected in grid squares with $AF_{st}3_{gen}$ values in excess of 10 mmol m^{-2}. If it is assumed that all squares with a SOMO35 > 0 indicate a potential for effects on health, then it can be concluded that vegetation effects (visible injury) have occurred in grid squares where ambient ozone in 2006 was likely to have been damaging to health. In Figure 4.2, the SOMO35 for the 23 grid squares in Europe where ozone injury was recorded on crops and (semi-)natural vegetation in 2006 was plotted against AOT40 and $AF_{st}3_{gen}$. There was a relatively strong logarithmic relationship between SOMO35 and AOT40 (Figure 4.2a) reflecting the similarity in approach for both metrics. The non-linearity in the relationship stems from the timing of ozone accumulation (three spring/early summer months for AOT40 versus whole year for SOMO35) and the use of different thresholds and daily accumulation times for the two metrics. However, as expected from the maps in Figure 4.1 there was only a weak correlation between SOMO35 and $AF_{st}3_{gen}$ (Figure 4.2b), reflecting the very different nature of the two metrics. Generic flux values can be relatively high in areas of relatively low ozone concentration if the climatic conditions are conducive to active stomatal uptake; SOMO35 values would not be so high is such areas as the exceedance of the daily maximum 8h mean of 35 ppb would be more limited.

4.3 Ozone impacts on vegetation in Nordic and Baltic areas

In an initiative led by Sweden, ozone impacts on vegetation in the Nordic Countries and the Baltic States are being reviewed. A workshop was held in Gothenburg on 17-18 June, 2008 to assess current knowledge of ozone concentrations and impacts. Attended by 15 participants from Sweden, Finland, Estonia, Lithuania and the Russia Federation, the workshop included presentations on factors contributing to surface ozone including synoptic circulation, climate change, emissions changes and nocturnal temperature inversions together with those on impacts of near ambient ozone concentrations on crops, trees and (semi-)natural vegetation. A workshop report will be produced at the end of this year and the scientific articles will be published in a special issue of AMBIO next year.

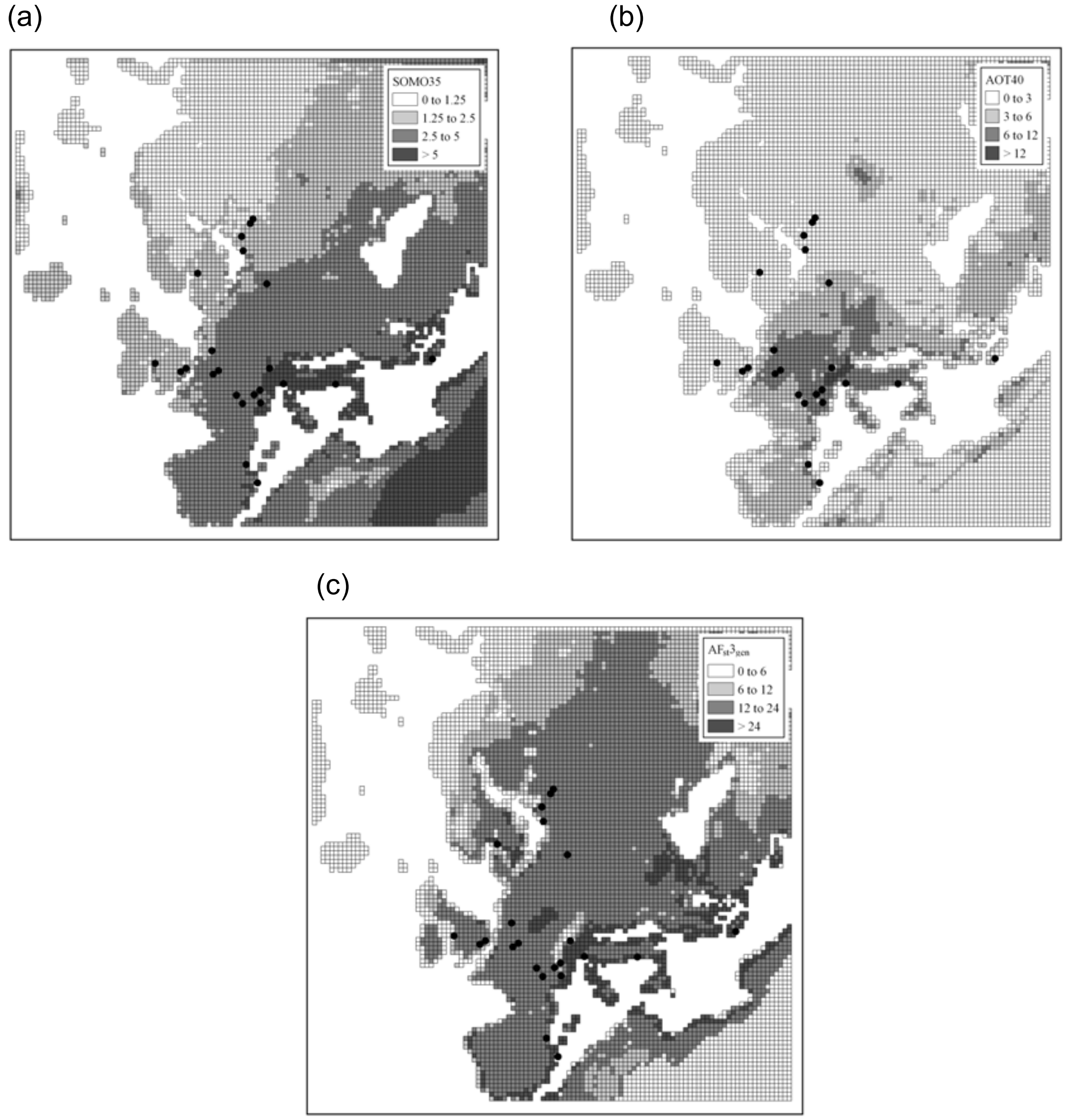

Figure 4.1. (a) SOMO35 (ppm d), (b) AOT40 (ppm h) and (c) $AF_{st}3_{gen}$ (mmol m^{-2}) for 2006 overlaid with the location of incidences of ozone injury on crops and (semi-)natural vegetation.

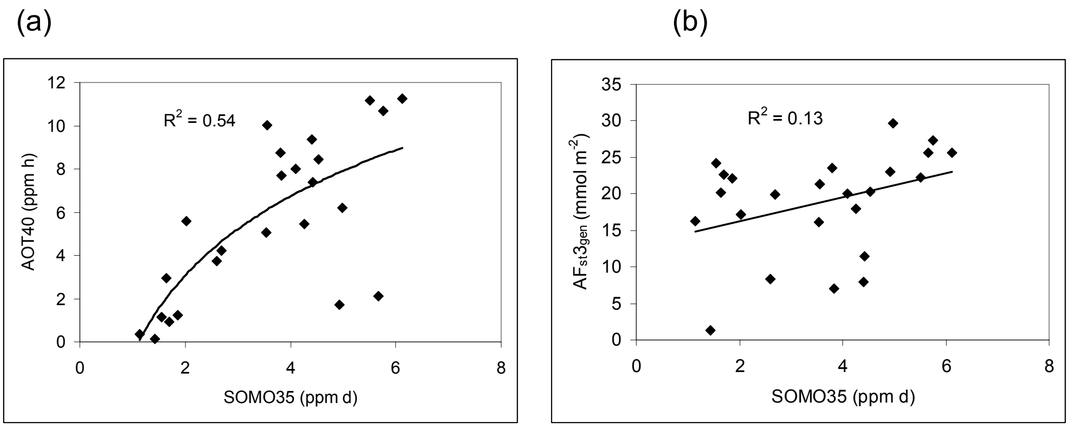

Figure 4.2. SOMO35 (ppm d) for the year 2006 against (a) AOT40 (ppm h) and (b) $AF_{st}3_{gen}$ (mmol m^{-2}) for the EMEP grid squares in which ozone injury was detected.

4.4 Development of a meta-database describing national and sub-national surveys with evidence of impacts of nitrogen deposition on vegetation

During the review of the Gothenburg Protocol the WGE identified the need for field-based evidence on the impacts of eutrophication on vegetation. In a response, the ICP Vegetation developed a first-stage meta-database describing national and sub-national surveys with evidence of impacts of nitrogen deposition on vegetation (Hicks *et al*., 2008). In December 2007, a questionnaire was circulated to 71 members of the nitrogen deposition effects on vegetation research community known to the ICP Vegetation and their network of colleagues across Europe. The returns were sorted by major ecosystem type and assessed to produce a summary of the main findings.

Responses were received for the following habitats:

- Forests (EUNIS class G, 16 responses);
- Heathland, scrub and tundra (EUNIS class F, 2 responses);
- Grasslands and tall forbs (EUNIS class E, 2 responses);
- Mire, bog and fen habitats (EUNIS class D, 3 responses);
- Across habitats (5 responses).

Although field survey data have been identified regarding nitrogen impacts on vegetation, countrywide or European-wide surveys indicate that impacts of nitrogen deposition are difficult to separate from other factors. For example, the ICP Forests has a large number of Level II monitoring plots across Europe and the potential to integrate effects assessments over a large area, but the wide range of forest types covered makes effects of nitrogen deposition difficult to disentangle from other factors, and the time series is not yet long enough to provide sufficient analytical power. Some surveys indicate increases in species with higher Ellenberg N values or a reduction in species richness with an increase in nitrogen deposition. Future work should focus on further analysis of the existing meta-database, identification of additional field surveys, in particular in areas which are currently under-represented (e.g. Mediterranean) and linking databases on for example changes in species composition with measured or modelled nitrogen deposition data in regions where this has not been done yet. Application of the database should be explored with interested parties such as dynamic modellers.

4.5 Identifying locations of specific EUNIS classes with likelihood of exceedance of empirical critical loads of nitrogen for the EMEP domain

The methodology developed was applied to ‘Heathland, scrub and tundra habitats’ (EUNIS class F; to level 2) and ‘Grasslands and tall Forbs habitats’ (EUNIS class E, to level 3). In 2002, empirical critical load ranges for nitrogen were allocated to the EUNIS E and F categories at the UNECE workshop in Bern (Bobbink *et al*., 2003). The LRTAP Convention Harmonised Land Cover Map, however, does not show all these categories. Therefore this study focussed on a more limited range of EUNIS categories and in some cases, it was necessary to condense two empirical critical load ranges, e.g. for wet and dry heathlands, using expert judgement (Hicks *et al*., 2008).

The spatial distribution of the EUNIS categories from the LRTAP land cover map was first combined with EMEP total nitrogen deposition data using a GIS overlay procedure. Minimum, mean and maximum values for the deposition in each area were compared with minimum, mean and maximum values from the relevant empirical critical load ranges. An uncertainty (± 30%) was attached to the EMEP modelled nitrogen deposition values, based on a comparison of modelled and monitored deposition fluxes of sulphur and nitrogen to ICP Forests sites in Europe (Simpson *et al.,* 2006a,b). The area of each ecosystem type for a given critical load where there is 'very likely exceedance' (i.e. minimum EMEP deposition exceeds critical load), 'likely exceedance' (i.e. mean EMEP deposition exceeds critical load), 'possible exceedance' (i.e. maximum EMEP deposition exceeds critical load), or 'no exceedance' was determined. This assessment was made for each EMEP grid square (50 x 50 km); the LRTAP Convention Harmonised Land Cover Database also provides the area of the habitat of interest in each grid square. The results were then expressed for each country as percentage areas of each habitat in each category of exceedance. The base year for EMEP deposition estimates used in this study is 2005. Results were also calculated at the individual national scales for the 2010 Gothenburg Protocol emissions targets.

Across the EMEP domain, grassland and tundra dominate the area of semi-natural habitat. Mesic grasslands, the grassland ecosystem type studied that had the highest critical load range (20-30 kg ha^{-1} y^{-1}), showed no exceedance at all for 2005 and 2010. In contrast, the Alpine and sub-alpine grasslands (E4) and Arctic, alpine and sub-alpine scrub habitats (F2) had the greatest exceedance, even though their total area is much lower. Although these arctic and alpine habitats show significant areas of likely or possible exceedance using the mean critical load value, it is the lower critical load of 5 kg ha^{-1} y^{-1} for these vegetation types that shows substantial exceedance. This result highlights these as critical habitats for further assessment, as the evidence base for the empirical critical load range that is currently used is quite limited. For the UK, the EMEP deposition data currently indicate very little exceedance for the studied habitats, however, when a similar exercise was conducted using national deposition data (2003-2005) based on a 5 x 5 km grid scale and using the UK Land Cover Map, considerable exceedances (up to 63% area) were calculated using mean deposition and mean empirical critical loads (Hicks *et al*., 2008).

There is relatively little additional benefit in terms of critical load exceedance from reaching the 2010 Gothenburg Protocol emission targets; this is largely because deposition in 2005 in most countries was already at, or close to, those under the Protocol. However, across the modelled domain, some reductions in the area of 'very likely' or 'likely' exceedance would be achieved for the most sensitive habitats with implementation of the Gothenburg Protocol targets. When these targets are met, the results suggest that little exceedance will remain if the mean of the critical load range is applied, but for sensitive habitats, substantial exceedance is likely to remain if the minimum of the critical load range is applied. There is an urgent need for improved understanding of how to apply the general guidance of empirical nitrogen critical loads for EUNIS classes to make informed choices about appropriate critical load mapping values.

5. Conclusions and future work-plan

5.1 Summary of major achievements in 2007/8

- Coordinated from CEH Bangor in the UK, the ICP Vegetation continues to comprise of an enthusiastic group of over 200 scientists from 34 countries.

- Fifty two delegates from 19 Parties to the Convention together with the chairman of the WGE, a member of the UNECE secretariat for the LRTAP Convention and a representative from ICP Modelling and Mapping attended the 21st ICP Vegetation Task Force Meeting, 26-29 February 2008 in Oulu, Finland,

- The ICP Vegetation has contributed to three ECE/EB.AIR reports of the WGE of the LRTAP Convention and provided a technical report (ECE/EB.AIR/WG.1/2008/9) on evidence of widespread ozone damage to vegetation in Europe (1990 – 2006). The programme has also contributed to the WGE consolidated report on air pollution effects and the revision of the LRTAP Convention Modelling and Mapping Manual. Four additional reports, four papers in scientific journals and a book chapter have been produced by the Programme Coordination Centre.

- The ozone experimental programme of the ICP Vegetation is undergoing further development. Participants are increasingly contributing data from ozone exposure experiments together with field observations, a new biomonitoring method using beans is being trialled this summer, and a large-scale biomonitoring exercise is planned for 2010.

- A review of the evidence of ozone damage to vegetation in ambient air (1990 – 2006) has shown that effects have been found on over 30 crops and 80 species of (semi-) natural vegetation growing in commercial fields, experimental sites or (semi-)natural ecosystems, with effects reported in 14 countries. The highest impacts were reported in Greece, Italy and Switzerland although effects in northern countries such as Sweden were also frequently reported. AOT40-based maps consistently under-reported detected effects whilst ozone-flux based risk maps accurately identified those areas where effects had been detected.

- Whilst a more in depth analysis is proposed for 2009, initial findings from a study of the location of vegetation effects in relation to SOMO35, AOT40 and $AF_{st}3_{gen}$ for the year 2006 indicate that vegetation effects (visible injury) occurred in grid squares where ambient ozone in 2006 was predicted to have been damaging to health.

- A methodology has been developed for flux-based risk assessments for forest trees using regionally-specific parameterisations for coniferous, deciduous and/or Mediterranean evergreen species representative of the five main geographical regions of Europe.

- Using experimental and monitoring data provided by ICP Vegetation participants, whole canopy flux models are being developed for grassland communities that incorporate stomatal and non-stomatal flux to grass, legume and other forb fractions.

- In 2005/6, the lowest concentrations of heavy metals in mosses were generally found in (north) Scandinavia, the Baltic States and northern parts of the UK and the highest concentrations in Belgium and eastern Europe. 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. However, country-specific temporal trends were observed.

- 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. This spatial distribution was similar to that of the total nitrogen deposition modelled by EMEP for 2004, except that the nitrogen deposition tended to be relatively lower in eastern Europe.

- The ICP Vegetation has compiled a meta-database of field-surveys describing field-based evidence of the impacts of eutrophication on vegetation within Europe. Although some surveys indicate increases in species with higher Ellenberg N values or a reduction in species richness with an increase in nitrogen deposition, impacts of nitrogen are often difficult to separate from other factors.

- Using EMEP deposition data and the LRTAP Convention Harmonised Land Cover Map, Alpine and sub-alpine grasslands (E4) and Arctic, alpine and sub-alpine scrub habitats (F2) were identified as sensitive 'Heathland' and 'Grassland' EUNIS classes with the highest likelihood of exceedance of empirical nitrogen critical loads (although their land cover is relatively low in Europe). However, a case study in the UK showed that exceedances (percent area) were considerably greater for selected habitats when based on a 5 x 5 km national deposition grid and the UK Land Cover Map than predicted using the EMEP model and the Convention's Land Cover Map.

5.2 Future work-plan (2009-2011) for the ICP Vegetation

The following work-plan was proposed at the 21st Task Force Meeting of the ICP Vegetation (Oulu, Finland, 26-29 February 2008).

2009

- Report on the risk of damage to (semi-)natural vegetation communities in Europe [O];
- Report on flux-based assessment of risk of damage to managed pastures in Europe [O];
- Report on ozone exposure and impacts on vegetation in the Nordic Countries and the Baltic States [O];
- A glossy brochure and associated web page for the general public and other interested parties on field-based evidence for impacts of ozone on vegetation [O];*
- Report on the temporal trends in heavy metal concentrations in mosses between 1990 and 2005 [HM];
- Report on the spatial variation in heavy metal and nitrogen concentrations in mosses [HM, N].

* not included in official WGE work-plan for 2009.

2010

- Report on ozone impacts in Mediterranean areas [O];
- Report on ozone, carbon sequestration, and linkages between ozone and climate change [O];

- Report of workshop on quanitification of ozone impacts on crops and (semi-)natural vegetation, tentatively planned for the autumn of 2009 [O];
- Progress report on European heavy metals and nitrogen in mosses survey 2010 [HM, N];
- Review of the relationship between heavy metal and nitrogen concentrations in mosses and impacts on ecosystems [HM, N].

2011

- Review of ozone flux modelling methods and their application to different climatic regions [O];
- Report on the 2010 biomonitoring exercise for ozone [O];
- Report on progress with a review of ozone impacts on crop yield and quality (includes outreach to EECCA countries, Malé Declaration countries etc.);
- Progress report on European heavy metals and nitrogen in mosses survey 2010 [HM; N].

[N]: Nutrient nitrogen, [O]: Ozone and [HM]: Heavy metals.

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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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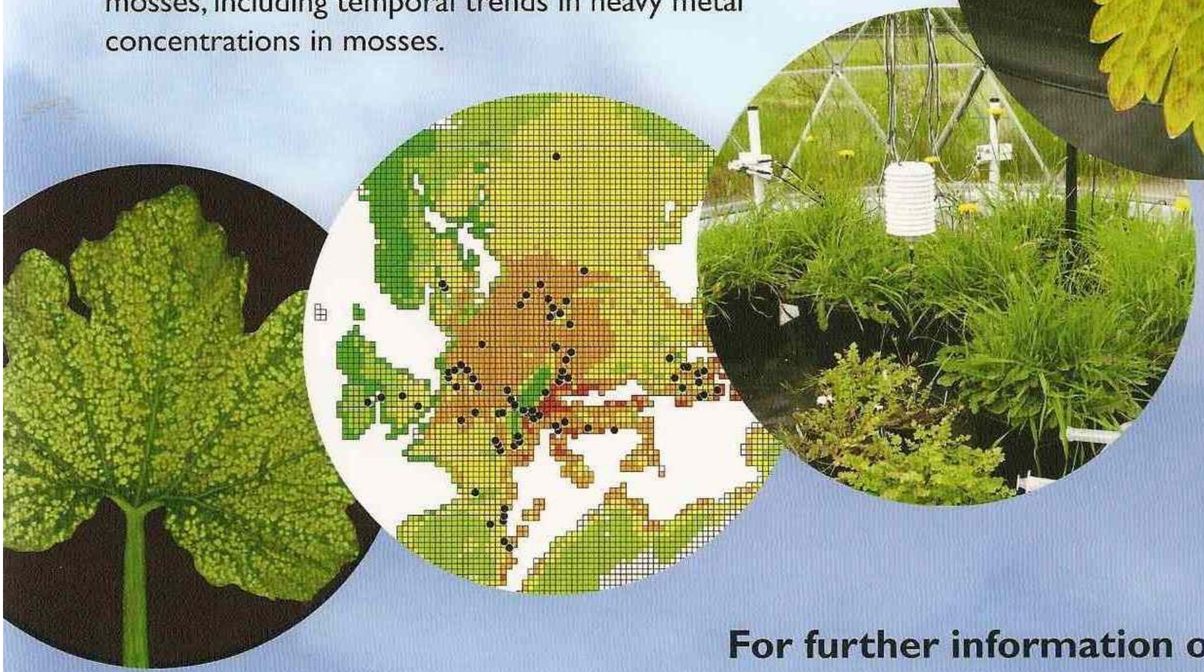
Air Pollution and Vegetation
ICP Vegetation
Annual Report 2007/2008

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 34 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, including biomonitoring programmes that indicate the geographical extent of ozone damage on sensitive species.
- Studies into further developing and applying flux-based critical levels of ozone for vegetation.
- Monitoring heavy metal and nitrogen deposition to mosses, including temporal trends in heavy metal concentrations in mosses.



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