Centre for Ecology & Hydrology

Air Pollution and Vegetation

ICP Vegetation

Annual Report 2015/2016

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

Air Pollution and Vegetation

ICP Vegetation[1] Annual Report 2015/2016

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September 2016

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

Acknowledgements

We wish to thank the UK Department for Environment, Food and Rural Affairs (Defra) for the continued financial support of the ICP Vegetation (Contract AQ0833). We also wish to thank the United Nations Economic Commission for Europe (UNECE) and the UK Natural Environment Research Council (NERC) for the partial funding of the ICP Vegetation Programme Coordination Centre.

We thank Marina Frontasyeva, Inga Zinicovscaia, Otilia Culicov, Tatyana Donskova, Konstantin Vergel, Alexandra Kravtsova, Pavel Nekhoroshkov, Olga Lashkova and Nikita Yushin, Joint Institute for Nuclear Research, Dubna (JINR), Russian Federation, for their support in organising and hosting the 29th ICP Vegetation Task Force meeting in Dubna; we thank JINR for their contributions in kind.

We thank Per Erik Karlsson, Gunilla Pihl Karlsson, Helena Danielson (IVL Swedish Environmental Research Institute) and Håkan Pleijel (University of Gothenburg) for their support in organising and hosting the second expert workshop on 'Epidemiological analysis of air pollution effects on vegetation' back to back with the expert workshop on 'Methodology for ozone critical levels analysis', held on 23 – 25 November 2015 in Hindås (nr. Gothenburg), Sweden. Contributions in kind for these workshops were provided by the Swedish research programmes BECC (Biodiversity and Ecosystem Services in a Changing Climate) and SCAC (Swedish Clean Air & Climate) and the Swedish Environmental Protection Agency.

We thank the Swiss Federal Office for the Environment (FOEN) for their contributions in kind to support the expert workshop on 'Dose-response functions for deriving ozone critical levels', held on 7 – 9 June 2016 in Deganwy (nr. Bangor), UK.

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We wish to thank all of the ICP Vegetation participants (see Annex 1) and their funding bodies for their continued contributions to the programme.

Front cover photo: Harry Harmens

Executive Summary

Background

The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) was established in 1987. It is led by the UK and has its Programme Coordination Centre at the Centre for Ecology & Hydrology (CEH) in Bangor. It is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. Today, the ICP Vegetation comprises an enthusiastic group of scientists from 50 countries, including scientists from outside the UNECE region. An overview of contributions to the WGE workplan and other research activities in the year 2015/16 is provided in this report.

29th ICP Vegetation Task Force meeting

The Programme Coordination Centre organised the 29th ICP Vegetation Task Force meeting, 29 February – 3 March, 2016 in Dubna, Russian Federation. The meeting was co-organised and hosted by the Joint Institute for Nuclear Research (JINR), Dubna. The meeting was attended by 90 experts from 33 countries. A book of abstracts and the minutes of the 29th Task Force meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk).

Reporting to the Convention and other publications

In addition to this report, the ICP Vegetation Programme Coordination Centre has provided a technical report on 'Effects of air pollution on natural vegetation and crops' (ECE/EB.AIR/GE.1/2016/14 - ECE/EB.AIR/WG.1/2016/7). ICP Vegetation also contributed to the joint report (ECE/EB.AIR/GE.1/2016/3 - ECE/EB.AIR/WG.1/2016/3) of the WGE and EMEP (European Monitoring and Evaluation Programme). The Programme Coordination Centre provided a co-editor and text for the WGE report on 'Trends in ecosystem and health responses to long-range transported atmospheric pollutants'. The Programme Coordination Centre contributed to the report of the LRTAP-Convention 'Towards cleaner air: Scientific Assessment Report', in particularly to key messages on recent trends in ground-level ozone concentrations, the threat of current ozone pollution to crops and (semi-)natural vegetation and the need for global action to mitigate impacts of ozone pollution in the future. The Programme Coordination Centre has published two brochures: i) 'Field evidence of ozone impacts on vegetation in ambient air (2007-2015)', and ii) 'Impacts of ozone pollution on biodiversity'; see details below.

Field evidence of ozone impacts on vegetation in ambient air (2007-2015)

It is important to demonstrate where impacts of ambient ozone have been detected in field conditions to verify predictions from ozone risk assessment modelling. The ICP Vegetation collated evidence of ozone impacts on vegetation in Europe and the rest of the world for the period 2007-2015. This provided new information to add to that previously collated for Europe for the period 1990-2006. Ad hoc field observations, epidemiological studies, biomonitoring and ambient air filtration studies provide field-based evidence for widespread damage to vegetation from current ozone levels present in ambient air. Impacts have been shown on over 60 vegetation species and include visible leaf injury symptoms, and reduced vegetation biomass and crop yield. For Europe there is good agreement between observations of leaf injury and the regions with moderate to high phytotoxic ozone dose. Although effects of ambient ozone have been frequently recorded in many European countries and parts of the USA, there is a need to broaden coverage worldwide. Much current evidence of ozone impacts on vegetation is from records of visible injury, which occur following episodic peaks of ozone. Models predict that over the coming decades the pattern of ozone exposure will continue to change in Europe and the USA, with peaks reducing and background concentrations potentially increasing. This pattern is less likely to cause visible leaf injury, but is still expected to impact on vegetation growth and crop yield. These impacts, although biologically and economically important, are more difficult to observe under field conditions and therefore there is an increasing need to establish fast and reliable methods to quantify them.

Impacts of ozone pollution on biodiversity

Although impacts of ozone on individual plant species have been studied and ozone-sensitive species have been identified, little is known about the implications for biodiversity. The existence of wide differences in sensitivity between plant species suggests that ozone stress can cause shifts in species composition in diverse plant communities. For grasslands, a new risk matrix was developed based on the phytotoxic ozone dose for grasses, calculated with the EMEP atmospheric chemistry transport model, and the percentage of grassland habitat area per 0.5º (longitude) by 0.25º (latitude) grid. Natura 2000 grassland habitats at risk from impacts of ozone pollution were mapped and shown to be scattered across many parts of central and southern Europe. Risk is highest in regions with high ozone fluxes (phytotoxic ozone dose) and relatively large grassland area, including parts of the Iberian Peninsula, the east coast of Spain, southern Italy and south-eastern Europe. There is evidence that current ambient ozone levels are sufficiently high enough to change plant community composition, flowering and seed production at the species level. Changes in plant community composition can potentially lead to changes in soil microbial communities and carbon, nutrient and water cycling. Such changes are slow, hence there is a requirement for long-term monitoring of terrestrial ecosystem responses to ozone. There is a lack of field-based evidence for the impacts of ozone on plant species diversity, especially in biodiversity hotspots such as the Mediterranean Basin. Results from European grassland field exposure experiments have been rather mixed regarding the impacts of ozone on plant growth and species composition. Whilst there is evidence that ozone might affect plant species composition, consequences for biodiversity require further study.

Recent developments of ozone critical levels for vegetation

Two expert workshops were held in preparation for the next LRTAP Convention Ozone Critical Levels. Workshop, 7 – 9 November 2016, Madrid, Spain (hosted by CIEMAT). The first workshop on ‘Methodology for ozone critical levels analysis’ was held on 24 – 25 November 2015 in Hindås (nr. Gothenburg), Sweden, and the second workshop on ‘Dose-response functions for deriving ozone critical levels’ was held on 7 – 9 June 2016 in Deganwy (nr. Bangor), UK. It was agreed to prepare two background documents by early October for the ozone critical levels workshop in November 2016 in Madrid: i) A summary document providing all of the response functions and options for critical levels for consideration for inclusion in chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention, and ii) A background document containing scientific support for decisions to be made. This will comprise a series of short sections covering various topics.

First global stomatal flux-based assessment of ozone impacts on wheat

The first global stomatal flux-based assessment of ozone impacts on wheat yield has been conducted and a manuscript describing results is nearing completion. The study has revealed a global annual yield loss due to ozone of 9.4% between 2010 and 2012, which equates to an annual economic loss of $24.3 billion globally using global average wheat prices. Economic losses were highest in Central Europe, Eastern USA, Western China and Northern India, all important wheat growing areas. Yield losses predicted with concentration-based metrics (AOT40 and M7) were much larger than those predicted with the flux-based metric.

Progress with the moss survey 2015/2016 on heavy metals, nitrogen and persistent organic pollutants

The first countries have submitted their data for the 2015-2016 moss survey to the new Moss survey Coordination Centre in the Russian Federation. Almost 40 countries are expected to submit data on heavy metal concentrations in mosses, including nine countries from South-Eastern Europe, seven countries from Eastern Europe, the Caucasus and Central Asia (Azerbaijan, Belarus, Georgia, Kazakhstan, Moldova, Russian Federation, Ukraine) and six countries from other parts of Asia and Africa (India, Mongolia, South Africa, South Korea, Thailand, Vietnam). Some countries will also report on nitrogen concentrations in mosses and on selected persistent organic pollutants.

Contributions to the WGE common workplan

The ICP Vegetation has also contributed to the following common workplan items of the WGE:

- Set up a contact group between EMEP and WGE to compare WGE exposure measurements and modelled and monitored exposure by EMEP. A group was set up between EMEP/Meteorological Synthesizing Centre-West and ICP Vegetation to discuss options for regional parameterisation of the stomatal ozone flux model incorporated in the EMEP model, to calculate the phytotoxic ozone dose for Mediterranean vegetation. First discussions were held at the second expert workshop on ozone critical levels (see above).
- Assess the long-term trends in air pollution and its adverse effects. The ICP Vegetation contributed text to and provided editorial support for the WGE report on 'Trends in ecosystem and health responses to long-range transported atmospheric pollutants'. The report describes temporal trends (primarily) between 1990 and 2012 in impacts of air pollution on ecosystems, human health and the built environment, based on the findings from the various ICPs, Task Force on Health and Joint Expert Group on Dynamic Modelling. Contributions from EMEP were also included. The ICP Vegetation reported on the lack of trends between 1999 and 2010 in ozone concentrations, fluxes and effects on vegetation. Future ozone pollution abatement requires measures at the global scale to reduce emissions of ozone precursors, including methane. It remains unclear how emission controls in Europe may be offset by global background ozone increases. The ICP Vegetation also reported on the decline in cadmium (51%), lead (77%), mercury (14%) and other metal concentrations in mosses between 1990 (1995 for mercury) and 2010. The report concluded that systematic long-term monitoring of air pollutants and the effects on the terrestrial and aquatic ecosystems, materials, crops and human health remains essential for the evaluation of the effectiveness of air pollution policies and for determining the need for further measures to reduce the emissions of air pollutants.
- Assess scientific and policy outcomes within the Convention over the past few decades, including scientific understanding, trends and achievements under the Gothenburg Protocol, and outline future challenges. The ICP Vegetation contributed to the LRTAP Convention report 'Towards Cleaner Air. Scientific Assessment Report 2016'. The report not only highlights the successes of the LRTAP Convention since its establishment in 1979, but also the problems that still exist, including ozone, nitrogen and particulate matter pollution. It concludes that international policy collaboration and coordination of air pollution science remains essential to harmonise methods for estimating emissions, monitoring air quality and impacts, and identifying cost-effective further steps, Key messages from the report were presented at the 8th Environment for Europe Ministerial Conference, 8 – 10 June 2016, Batumi, Georgia.

Future activities of the ICP Vegetation

Workplan items for 2016 - 2017 were adopted at the first joint session of EMEP and WGE in September 2015 and approved at the 34th session of the Executive Body of the LRTAP Convention in December 2015. Preliminary workplan items for 2018 and beyond were discussed at the 29th Task Force Meeting of the ICP Vegetation (Dubna, Russian Federation, 29 February – 3 March, 2016) and will be finalised at the 30th Task Force Meeting (Poznan, Poland, 14 – 17 February 2017).

Ongoing annual activities include:

- report on evidence for ozone impacts on vegetation;
- report on progress with the moss survey 2015/16 (final report to be published in 2018);
- contributions to common workplan items of the WGE.

New activities include:

2016: Ozone critical levels workshop, 7 – 9 November 2016, Madrid, Spain;

2017: Report on revised ozone risk assessments methods and revision of Chapter 3 of the Modelling and Mapping Manual.

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 1987, 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 & Hydrology (CEH) in Bangor. The ICP Vegetation is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. The Convention provides the essential framework for controlling and reducing damage to human health and the environment caused by transboundary air pollution. So far, eight international Protocols have been drafted by the Convention to deal with major long-range air pollution problems. ICP Vegetation focuses on the following air pollution problems: quantifying the risks to vegetation posed by ozone pollution and the atmospheric deposition of heavy metals, nitrogen and persistent organic pollutants (POPs) to vegetation. In addition, the ICP Vegetation studies the interactive impacts of air pollutants (e.g. ozone and nitrogen) on vegetation in a changing climate.

The ICP Vegetation is keen to enhance participation of countries in South-East Europe (SEE) and in Eastern Europe, Caucasus and Central Asia (EECCA). Hence, a new Moss Survey Coordination Centre was established in 2014 at the Joint Institute for Nuclear Research, Dubna, Russian Federation. The head of the new Moss Survey Coordination Centre is Marina Frontasyeva, who also assists the ICP Vegetation Programme Coordination Centre with the translation of various documents into Russian. The ICP Vegetation comprises an enthusiastic group of scientists from 50 countries (**Table 1.1**), including scientists from outside the UNECE region as the ICP Vegetation stimulates outreach activities to other regions in the world. Countries participate in ICP Vegetation activities or attend the annual Task Force meeting or both. 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, modelling and data synthesis procedures of the ICP Vegetation.

Table 1.1 Countries participating in the ICP Vegetation. In italics: country not a Party of the LRTAP Convention.

Albania	Greece	Russian Federation
Austria	*Guatamala*	Serbia
Azerbaijan	Hungary	Slovakia
Belarus	Iceland	Slovenia
Bulgaria	*India*	*South Africa*
China	Ireland	*South Korea*
Croatia	Italy	Spain
Cuba	*Japan*	Sweden
Czech Republic	Kazakhstan	Switzerland
Denmark	Latvia	*Thailand*
Egypt	Lithuania	Turkey
Estonia	Moldova	Ukraine
Finland	*Mongolia*	United Kingdom
France	Norway	USA
FYR of Macedonia	*Pakistan*	*Uzbekistan*
Georgia	Poland	*Vietnam*
Germany	Romania	

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 (Royal Society, 2008). Superimposed on the background tropospheric ozone are ozone episodes where elevated ozone concentrations in excess of 50-60 ppb can last for several days. Ozone episodes can cause short-term responses in plants such as the development of visible leaf injury (fine bronze or pale yellow specks on the upper surface of leaves) or reductions in photosynthesis. If episodes are frequent, longer-term responses such as reductions in growth and yield and early die-back can occur.

The 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 for policy application (Mills et al., 2011b; LRTAP Convention, 2016). In addition, the interactive impacts of ozone and nitrogen pollution and the impacts of ozone on vegetation in a changing climate (e.g. elevated carbon dioxide concentrations, warming, drought) are being studied and reported.

1.2.2 Heavy metals, nitrogen and persistent organic pollutants (POPs)

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, other manufacturing industries and construction, electricity and heat production, road transportation and petroleum refining. Whereas agricultural activities are the main source for atmospheric ammonia, fossil fuel combustion (industry, transport) is the main source for nitrogen oxides in the atmosphere. Sources and effects of atmospheric nitrogen deposition have been reviewed by Sutton et al. (2011). Reactive nitrogen poses a key threat to water, air and soil quality, ecosystems and biodiversity, and greenhouse gas balance. Too much nitrogen harms the environment and the economy (Sutton et al., 2011). POPs are organic substances that possess toxic and/or carcinogenic characteristics. They degrade very slowly in the environment, bioaccumulate in the food chain and like heavy metals and nitrogen are prone to long-range transboundary atmospheric transport and deposition. Anthropogenic sources of POPs include waste incineration, industrial production and application (such as pesticides, flame retardants, coolant fluids).

Since 2000/1, the ICP Vegetation coordinates the European network using mosses as biomonitors of atmospheric pollutants. European moss surveys have taken place every five years since 1990. Currently, the 2015/2016 moss survey is being conducted and includes participation of some Asian countries. Mosses were collected at thousands of sites across Europe and their heavy metal (since 1990; Harmens et al., 2015b), nitrogen (since 2005; Harmens et al., 2015b) and POPs concentration (pilot study in 2010; Harmens et al., 2013) were determined. The moss survey provides a complementary method to assess spatial patterns and temporal trends of atmospheric deposition of air pollutants to vegetation (based on monitoring in the field) and to identify areas at risk from air pollution at a high spatial resolution (Harmens et al., 2015b; Schröder et al., 2010a,b).

1.3 ICP Vegetation workplan for 2016

The Executive Body of the LRTAP Convention agreed on a workplan for 2016 and 2017 at its 34th meeting in December 2015 (see ECE/EB.AIR/2015/1-ECE/EB.AIR/WG.5/2015/1). Here we will report on the workplan items for the ICP Vegetation for 2016:

- Evaluate effects of ground-level ozone on (semi-)natural vegetation and crops in the current and future climate, individually or co-occurring with nitrogen:
  - (a) Update field evidence of ozone impacts on vegetation in ambient air (2007-2015);
  - (b) Impacts of ozone pollution on biodiversity;
  - (c) First flux-based global assessment of ozone impacts on wheat yield.
- Further development of the flux-based approach for setting critical levels of ground-level ozone for vegetation;
- Conduct the European moss survey 2015/16.

In addition, the ICP Vegetation was requested to report on the following common workplan items of the WGE:

- Set up contact group between EMEP and WGE to compare WGE exposure measurements and modelled and monitored exposure by EMEP;
- Assess the long-term trends in air pollution and its adverse effects;
- Assess scientific and policy outcomes within the Convention over the past few decades, including scientific understanding, trends and achievements under the Gothenburg Protocol, and outline future challenges.

In Chapter 2, general coordination activities of the ICP Vegetation are described, including the 29th ICP Vegetation Task Force meeting and dissemination of results. In Chapter 3 and 4, we report on 'field evidence of ozone impacts on vegetation in ambient air (2007-2015)' and 'Impacts of ozone pollution on biodiversity' respectively. Chapter 5 describes recent developments of ozone critical levels for vegetation, the first flux-based global assessment of ozone impacts on wheat, progress with the 2015/2016 moss survey, and contributions to common workplan items of the WGE. Remaining activities for 2016 and planned activities of the ICP Vegetation for 2017 are described in Chapter 6.

2 Coordination activities

2.1 Annual Task Force meeting

The Programme Coordination Centre organised the 29th ICP Vegetation Task Force meeting, 29 February – 3 March, 2016 in Dubna, Russian Federation. The meeting was hosted by the Joint Institute for Nuclear Research (JINR and attended by 90 experts from 33 countries (**Figure 2.1**). A book of abstracts and the minutes of the 29th Task Force meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk). Decisions and recommendations are included in the minutes of the meeting and are also described in further detail in the relevant sections in the following chapters. The **30th Task Force meeting** will be held in Poznan, Poland from 14 - 17 February 2017.

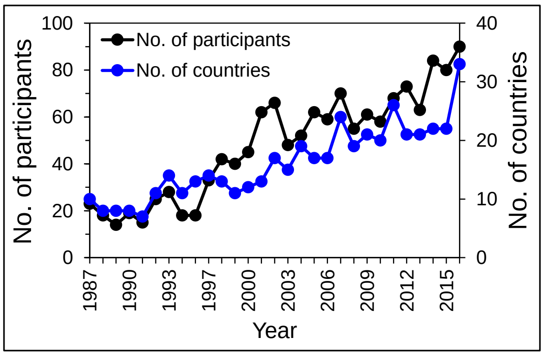


Figure 2.1 Participation in ICP Vegetation Task Force meetings since 1987.

2.2 Reports to the LRTAP Convention

The ICP Vegetation Programme Coordination Centre has reported progress with the 2016 workplan items in the following documents for the second joint session of the Steering Body to the EMEP and the WGE, 13 - 16 September 2016, Geneva, Switzerland (http://www.unece.org/index.php?id=40002#/):

- ECE/EB.AIR/GE.1/2016/3 - ECE/EB.AIR/WG.1/2016/3: Joint report of the ICPs, Task Force on Health and Joint Expert Group on Dynamic Modelling;
- ECE/EB.AIR/GE.1/2016/14 - ECE/EB.AIR/WG.1/2016/7: Effects of air pollution on natural vegetation and crops.

In addition, the Programme Coordination Centre provided a co-editor and text for the WGE report on 'Trends in ecosystem and health responses to long-range transported atmospheric pollutants'. The Programme Coordination Centre also contributed to the assessment report of the LRTAP-Convention 'Towards cleaner air: Scientific Assessment Report', particularly to key messages on recent trends in ground-level ozone concentrations, the threat of current ozone pollution to crops and (semi-)natural vegetation and the need for global action to mitigate impacts of ozone pollution. The final version of both reports were published in May 2016 (http://www.unece.org/env/lrtap/welcome.html). A summary of the Assessment Report was presented at the 8th Environment for Europe Ministerial Conference, Batumi, Georgia, 8 – 10 June 2016.

The Programme Coordination Centre for the ICP Vegetation has also published:

- A glossy brochure on 'Field evidence of ozone impacts on vegetation in ambient air (2007-2015)' (see Chapter 3);
- A glossy brochure on 'Impacts of ozone pollution on biodiversity'(see Chapter 4);
- The current annual report (available on line).

2.3 Scientific papers

The following scientific papers were published:

Harmens, H., Schröder, W., Zechmeister, H.G., Steinnes, E., Frontasyeva, M. (2015). Comments on J.A. Fernandez, M.T. Boquete, A.Carballeira, J.R. Aboal. A critical review of the protocols for moss biomonitoring of atmospheric deposition: Sampling and sample preparation. Science of the Total Environment 517: 132-150. Science of the Total Environment 538: 1024-1026.

Mills, G., Harmens, H., Wagg, S., Sharps, K., Hayes, F., Fowler, D., Sutton, M., Davies, W. (2016). Ozone impacts on vegetation in a nitrogen enriched and changing climate. Environmental Pollution 208: 898-908.

Schröder W, Nickel S, Schönrock S, Meyer M, Wosniok W, Harmens H, Frontasyeva MV, Alber R, Aleksiayenak J, Barandovski L, Danielsson H, de Temmerman L, Fernández Escribano A, Godzik B, Jeran Z, Pihl Karlsson G, Lazo P, Leblond S, Lindroos AJ, Liiv S, Magnússon SH, Mankovska B, Martínez-Abaigar J, Piispanen J, Poikolainen J, Popescu IV, Qarri F, Santamaria JM, Skudnik M, Špirić Z, Stafilov T, Steinnes E, Stihi C, Thöni L, Uggerud HT, Zechmeister HG (2016). Spatially valid data of atmospheric deposition of heavy metals and nitrogen derived by moss surveys for pollution risk assessments of ecosystems. Environmental Science and Pollution Research 23:10457-76.

3 Field evidence of ozone impacts on vegetation in ambient air (2007-2015)

In this chapter we provide a summary of a brochure published on this subject. For details see http://icpvegetation.ceh.ac.uk/publications/documents/CEH_EVIDENCE_SINGLES_HIGH.pdf

3.1 Introduction

It is important to demonstrate where impacts of ambient ozone have been detected in field conditions to verify predictions from ozone risk assessment modelling. Ozone impacts on vegetation include reduced plant growth, reduced yield of crops and visible injury symptoms on leaves. Factors such as sunlight, temperature, humidity and soil moisture can influence the uptake of ozone into the leaves of the plants, and it has been shown that ozone effects on vegetation are better related to ozone uptake than ozone concentration (Hayes et al., 2007; Mills et al., 2011a). Here we provide an overview of the evidence of ozone impacts on vegetation in Europe and the rest of the world for the period 2007-2015. This gives new information to add to that previously collated for Europe for the period 1990-2006 (Hayes et al., 2007; Mills et al., 2011a).

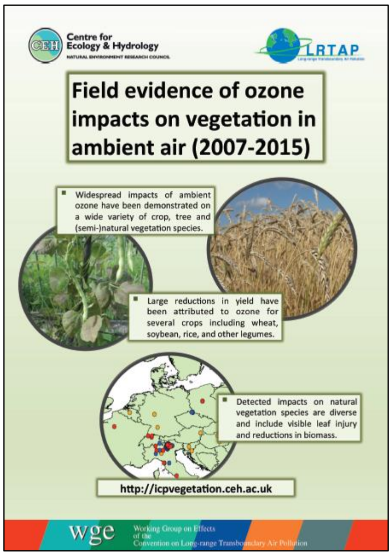


Figure 3.1 Brochure on 'Field evidence of ozone impacts on vegetation in ambient air (2007-2015)'.

3.2 Field based evidence of ozone impacts

Filtered air experiments. Open-top chambers can be used to investigate effects of reducing ambient ozone concentrations by charcoal filtration. Comparisons of responses between unfiltered and filtered air provide valuable indications of the effects of ambient ozone. Many species have been studied and a wide range of effects of ambient ozone have been reported. Reductions in crop yield have been detected on a range of crops including wheat, soybean and rice in several countries in Europe and Asia. Grain size and quality has also been affected for some crops including wheat. In Asia (China, India, Japan and Pakistan), crop yield reductions vary between 3% (for peas, beans) to 23% (for soybean). In these countries, the majority of experiments have been conducted with wheat and rice, showing an average yield reduction of 7 and 14% respectively. Reduced biomass of (semi-) natural vegetation has been found in studies covering a range of (semi-)natural vegetation types (**Table 3.1**). Other responses include reductions in greenness of leaves and seed quality.

Table 3.1 Examples of responses to ozone shown in non-filtered compared to filtered air experiments with (semi-)natural vegetation.

Country	Ozone (24h mean, ppb)	Species	Biomass reduction	Reference
Spain	28	Mediterranean pasture	8%	Calvete-Sogo et al. (2014)
Italy	37	*Quercus ilex*	17%	Gerosa et al. (2015)
Spain	35	*Quercus ilex*	1%	Alonso et al. (2014)
Spain	32	*Briza maxima*	3%	Sanz et al. (2011)
Japan	19	*Betula ermanii*	4%	Hoshika et al. (2013)

Visible leaf injury. The ICP Vegetation Biomonitoring Programme has used ozone-sensitive and ozone-resistant dwarf French bean (*Phaseolus vulgaris)* since 2008. Reductions in biomass and yield of >20% for the ozone-sensitive compared to ozone-resistant genotypes were shown in Austria, Belgium, China, France, Germany, Greece, Hungary, Italy, Latvia, Slovenia, Spain and USA. Recently, ICP Vegetation and volunteers have been recording the presence of ozone visible injury symptoms on leaves of plants within the biomonitoring programme, by use of ozone-sensitive plant species in 'ozone gardens' and in field and natural habitats using a smart-phone app (available from http://icpvegetation.ceh.ac.uk/record/index). Visible leaf injury symptoms attributed to ozone have been observed on over 60 species of crops, wild flowers, shrubs and trees over the period 2007-2015 in at least 19 countries from Europe, Asia, and North and South America. Observations of leaf injury and the regions with the highest ozone flux generally show good agreement for Europe. However, injury symptoms can still be found in regions where fluxes tend to be lower (**Figure 3.1**).

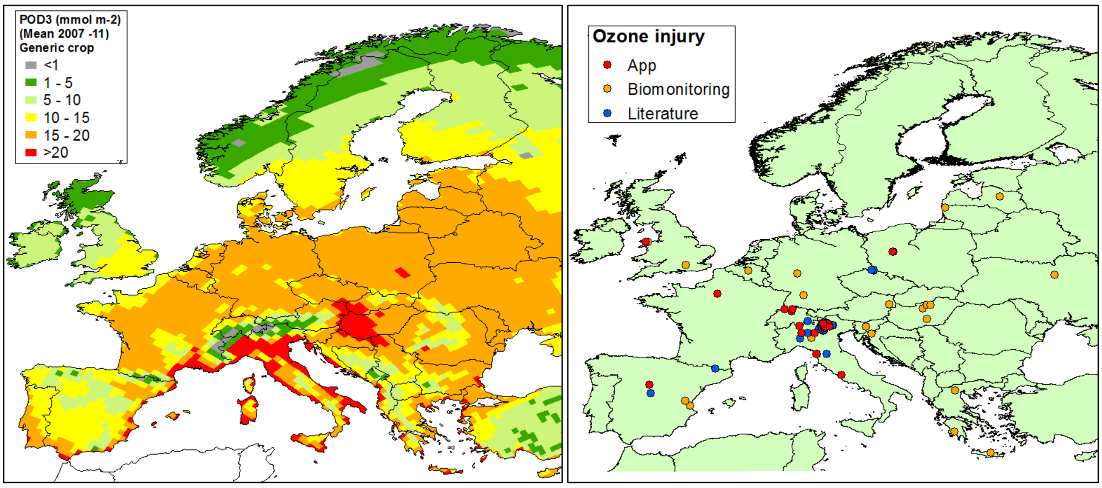


Figure 3.1. For Europe there is good agreement between regions with the highest ozone flux for crops (left map) and observations of ozone-induced leaf injury (right map). *Note: observations of ozone-induced leaf injury reflect the intensity of effort in surveying for symptoms, lack of observations in a region may not mean a lack of symptoms on vegetation.*

Epidemiology studies. Ozone impacts on mature trees in the field have been demonstrated using epidemiological analysis. The approach can disentangle and quantify the contributions of many predictor variables by utilising naturally occurring gradients of these predictors and relating these to impacts such as visible leaf injury and growth. Repeated measurements over several years are used so that location and tree-specific variations can be accounted for. For example, in Switzerland, basal area increment of forest trees was related to ozone and climatic variables. Based on measurements on approximately 4800 trees it was estimated that the reduction in annual growth rate due to ozone pollution was 19.5% for deciduous and 6.6% for coniferous forests during the period 1991–2011 (Braun et al., 2014). This agreed well with European estimates of growth reductions based on the calculated ozone uptake (Harmens and Mills, 2012). In northern Italy and southern France, epidemiological analysis has been used to show that ozone injury symptoms on forest trees were better explained by ozone uptake than ozone concentrations (Sicard et al., 2016).

3.3 Conclusions, recommendations and future challenges

Conclusions:

- Ad hoc field observations, epidemiological studies, biomonitoring and ambient air filtration studies provide field-based evidence for widespread damage to vegetation from current ozone levels present in ambient air;
- Impacts have been shown on over 60 vegetation species and include visible leaf injury symptoms, and reduced vegetation biomass and crop yield;

- For Europe there is good agreement between observations of leaf injury and the regions with medium to high ozone flux.

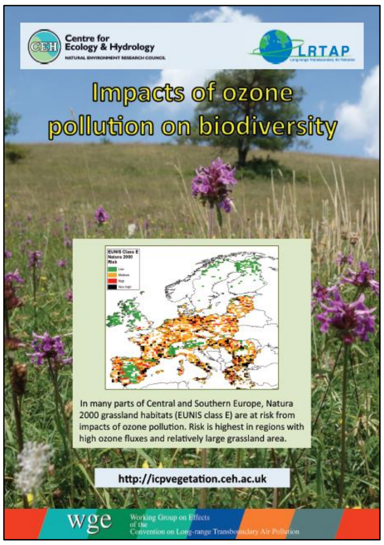
Recommendations and future challenges:

- Although effects of ambient ozone have been frequently recorded in many European countries and parts of the USA, there is a need to broaden coverage worldwide;
- Planting ozone-sensitive species ('ozone gardens') is a useful tool for demonstrating the occurrence of visible leaf injury in ambient conditions (e.g. the NASA ozone gardens, http://science-edu.larc.nasa.gov/ozonegarden/pdf/Bio-guide-final-3_15_11.pdf). The ICP Vegetation is also establishing a network of ozone gardens where ozone-sensitive species are planted to monitor ozone impacts.
- Much current evidence of ozone impacts on vegetation is from records of visible injury, which occur following episodic peaks of ozone. Models predict that over the coming decades the pattern of ozone exposure will continue to change in Europe and the USA, with peaks reducing and background concentrations potentially increasing. This pattern is less likely to cause visible leaf injury, but is still expected to impact on vegetation growth and crop yield. These impacts, although biologically and economically important, are more difficult to observe under field conditions and therefore there is an increasing need to establish fast and reliable methods to quantify them.

4 Impacts of ozone pollution on biodiversity

In this chapter we provide a summary of a brochure published on this subject. For details see http://icpvegetation.ceh.ac.uk/publications/documents/CEH_BIODIVERSITY_SINGLES_HIGH.pdf

4.1 Introduction



The rapid decline in biodiversity in recent decades triggered the establishment of the Convention on Biological Diversity at the Rio 'Earth Summit' in 1992. The main factor contributing to the loss in biodiversity is the exponential increase in human population, leading to, for example, an increased need for biomass for fuel and construction, changes in land-use towards food and fodder production, industrial and residential developments, introduction of invasive species, climate change and pollution of the air, water and soil. Although impacts of ozone on individual plant species have been studied and ozone-sensitive species have been identified, little is known about the implications for biodiversity. In spite of evidence for widespread exposure of ecosystems to ozone pollution, the potential threat to biodiversity was not included in the recent assessment by the Convention on Biological Diversity 'Global Diversity Outlook 4'.

Figure 4.1 Brochure on 'Impacts of ozone pollution on biodiversity'.

4.2 Ozone sensitivity of plant species and communities

The existence of wide differences in sensitivity between plant species (**Table 4.1**) suggests that ozone stress can cause shifts in species composition (evenness or richness) in diverse plant communities. Indeed, Payne et al. (2011) found that ozone pollution was the third strongest driver of plant community composition change in calcifuge grasslands in UK, behind inorganic nitrogen deposition and annual evapotranspiration. However, ozone exposure was not associated with a reduction in species richness or diversity. During the 1970s, high concentrations of ozone in the San Bernardino National Forests, California, had resulted in part in a replacement of the more ozone-sensitive species ponderosa pine (*Pinus ponderosa*) by the ozone-tolerant species white fir (*Abies concolor*). Field evidence is scarce, and most evidence for the impact of ozone on plant diversity is from data from controlled experiments with either artificial model communities or with intact ecosystems exposed to varying ozone concentrations. The results from field exposure studies are limited and rather mixed, with ozone affecting plant species composition in some studies but not in others (*Mills et al., 2013).*

Plant group	Reduction*	Stimulation*	No effect
Forbs	85 (68)	13 (11)	79
Grasses	27 (20)	6 (3)	42
(Bi)annuals	31 (23)	3 (2)	21
Perennials	75 (60)	16 (12)	103
Trees	70 (55)	2 (0)	37
Deciduous	40 (32)	2 (0)	19
Evergreen	34 (28)	0	23
Conifers	19 (16)	0	17
Broadleaved	56 (45)	2 (0)	25

A review by Bergmann et al. (2015) showed that forbs and deciduous trees tend to be more responsive to ozone than grasses and coniferous trees.

Table 4.1. Number of plant species per plant functional group with known ozone effects on growth. * *Values within brackets indicate number of plant species with a response of more than 15%.* Source: Bergmann et al. (2015).

4.3 Mapping Natura 2000 habitats at risk from ozone

The ICP Vegetation database for (semi-)natural vegetation contains information primarily on the response of above-ground biomass to ozone. Dose-response relationships were developed for each species based on the 24 hr mean ozone concentration. The majority of species in the database are grassland species. Using the UK National Vegetation Classification (NVC; http://jncc.defra.gov.uk/page-1425), communities for which at least 20% of the species were tested for ozone sensitivity, were converted into EUNIS (European Nature Information System) habitat code (http://eunis.eea.europa.eu/habitats.jsp) according to the methodology described by Mills et al. (2007). For grassland habitats (EUNIS class E), the percentage of tested species affected by ozone (i.e. the relative biomass was either declining or increasing with increasing 24 hr mean ozone concentration) varied between 41 and 51% for mesic grasslands (EUNIS class E2) and woodland fringes (EUNIS class E5) respectively. Hence, there is a clear potential for grassland community composition to change with increasing ozone exposure, with sensitive species being outcompeted by non-responsive or stimulated species in their competition for light, nutrients and water.

For grasslands, gridded UNECE harmonized land-cover data from the Coordination Centre for Effects (http://wge-cce.org/) were combined with gridded data on the Phytotoxic Ozone Dose above a threshold of 1 nmol m^{-1} s^{-1} (POD_1) for grasses, including a soil moisture index (Simpson et al., 2012). The risk of ozone impact on grasslands per 0.5° (longitude) by 0.25° (latitude) grid was calculated using a newly developed risk matrix (**Table 4.2**). POD_1 was given more weight than the percentage habitat area per grid by being allocated twice as many risk classes. Multiplied risk values were divided into four risk categories and mapped: low (green), medium (orange), high (red) and very high (black).

Table 4.2. Matrix for calculating the risk of ozone impact on grasslands, based on the phytotoxic ozone dose (POD_1) for grass (Simpson et al., 2012) and the grassland area (%) per grid cell (0. 5° (longitude) by 0.25° (latitude)). POD_1 was calculated over a six months period (April – September).

Grassland area in grid cell (%)	POD_1 grass (mmol m^{-2})*	<5	5 - 15	15 - 20	20 - 25	25 - 30	>30
	RISK	**1**	**2**	**3**	**4**	**5**	**6**
0.5 – 5	**1**	**1**	**2**	**3**	**4**	**5**	**6**
5 - 10	**2**	**2**	**4**	**6**	**8**	**10**	**12**
>10	**3**	**3**	**6**	**9**	**12**	**15**	**18**

The highest annual phytotoxic ozone dose (POD_1) to grasslands (averaged for 2006 – 2010) is found in areas where ozone concentrations were intermediate and climate conditions were conducive to high ozone uptake by vegetation (Central Europe) or where ozone concentrations were high and the climate conditions (such as drought) did not limit ozone uptake by vegetation (Southern Europe; **Figure 4.1**).

Grasslands (EUNIS class E) and woodland fringes (EUNIS class E5) in Natura 2000 areas at risk from impacts of ozone were mapped by applying the developed risk matrix. Natura 2000 grassland areas at highest risk from ozone are spread across Central and Southern Europe, in those areas where grasslands are most abundant and where the phytotoxic ozone dose (POD_1 grass) is medium to high. Areas at highest risk include parts of the Iberian Peninsula, the east coast of Spain, southern Italy and south-eastern Europe. Woodland fringes are most abundant in parts of the Mediterranean, Estonia and Northern Finland, with those in the Mediterranean area being at highest risk from ozone impacts. However, it should be noted that considerable uncertainty is associated with mapping habitats at risk in Southern Europe based on the ozone responsiveness of plant species and communities that primarily occur in Western and Central Europe.

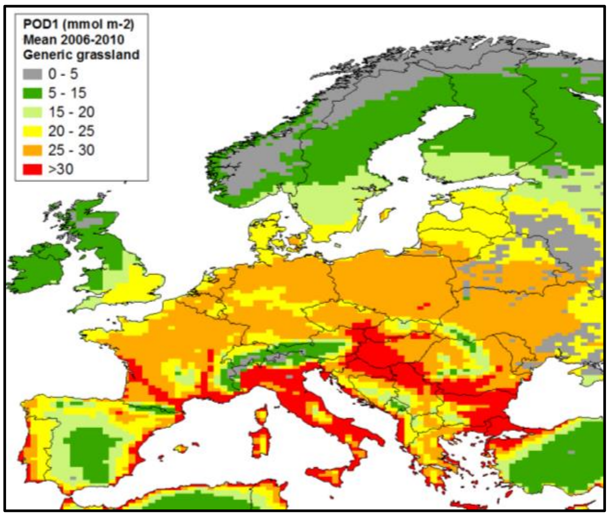


Figure 4.1. Phytotoxic ozone dose (POD_1) for grass per 0.5° x 0.25° grid, accumulated over a six months period (April – September) and averaged for 2006 – 2010.

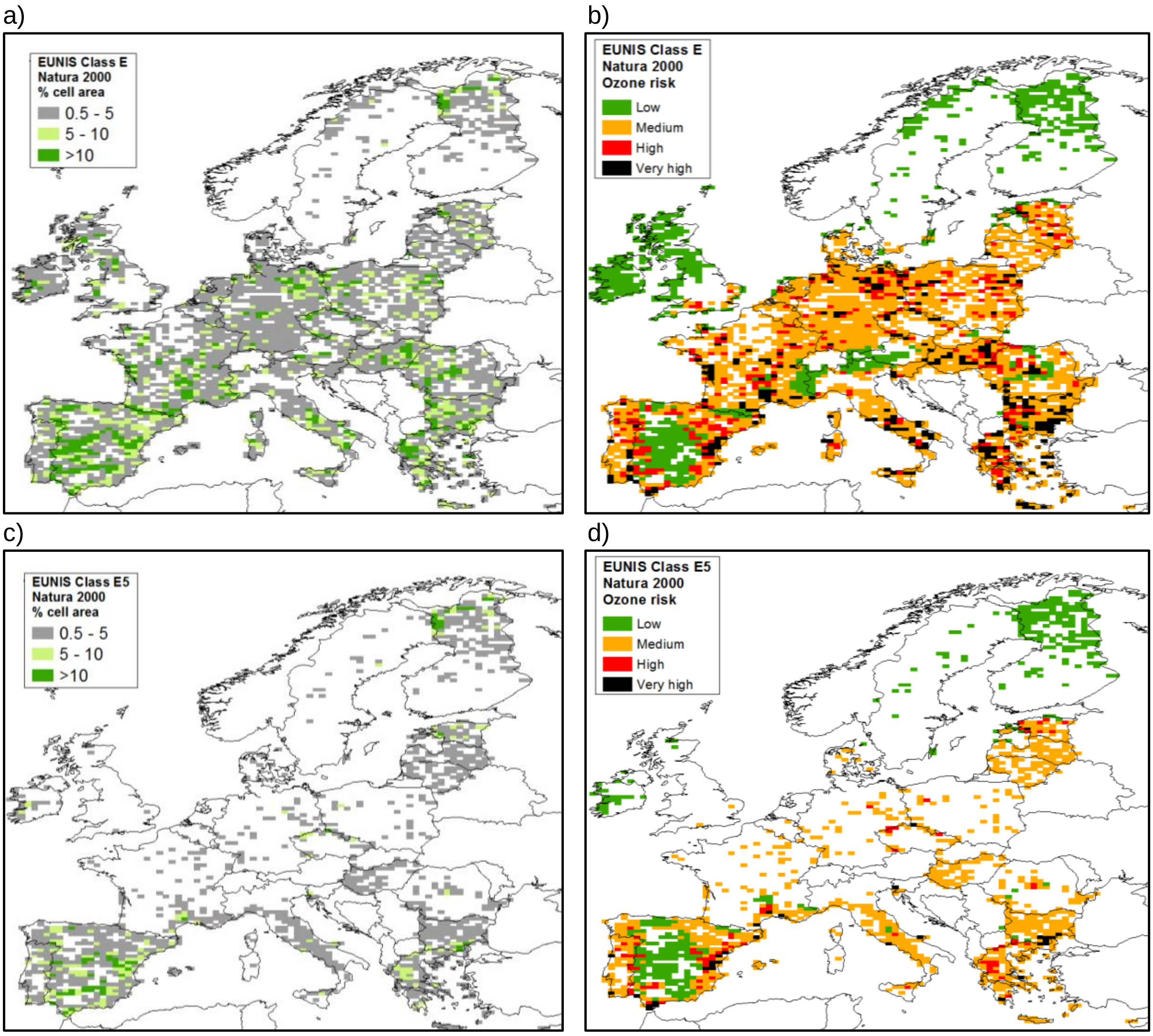


Figure 4.2. Percentage area (a, c) of grasslands (a) and woodland fringes (c) per 0.5° x 0.25° grid and the risk of ozone impact (b, d) on grasslands (b) and woodland fringes (d) in Natura 2000 areas.

The Mediterranean Basin is recognized as one of the top 25 Global Biodiversity Hotspots for conservation priorities. In Spain alone, the biodiversity of fungi, lichens, mosses and vascular plants represents 80% of the EU biodiversity and almost 60% of that of the European continent. However, very limited information is available on the ozone sensitivity of individual species or communities taking into account the huge plant biodiversity present in this area. Dehesas are high biodiversity Mediterranean ecosystems that are protected under the EU Habitats Directive. Recent research has shown that ozone may induce changes in plant species composition of Dehesa pastures by changing competitive relationships, causing a decline in the abundance of ozone-sensitive species (Calvete-Sogo et al., 2016). Ozone has shown also to affect differently the seed production of different pastures species which can result in long-term effects on the species composition of the pasture, thus altering the biodiversity of this valuable ecosystem (Calvete-Sogo et al., in prep). The effect of ozone pollution on seed production might be modified by the amount of nitrogen pollution (Sanz et al., 2007). However, field validation of effects observed under experimental conditions is still lacking for many plant species and communities.

4.4 Conclusions and recommendations

Conclusions and recommendations from the current study are:

- Natura 2000 grassland habitats are at risk from impacts of ozone pollution in many parts of central and southern Europe. Risk is highest in regions with high ozone fluxes (Phytotoxic Ozone Dose) and relatively large grassland area.
- There is evidence that current ambient ozone levels are sufficiently high enough to change plant community composition, flowering and seed production at the species level. Changes in plant community composition can potentially lead to changes in soil microbial communities and carbon, nutrient and water cycling. Such changes are slow, hence there is a requirement for long-term monitoring of terrestrial ecosystem responses to ozone.
- There is a lack of field-based evidence for the impacts of ozone on plant species diversity, especially in biodiversity hotspots such as the Mediterranean Basin. Results from European grassland field exposure experiments have been rather mixed regarding the impacts of ozone on plant growth and species composition. Whilst there is evidence that ozone might affect plant species composition, consequences for biodiversity require further study.

5 Other ICP Vegetation activities in 2015/16 and common WGE workplan items

In this chapter, progress made with other ICP Vegetation and common WGE workplan items for 2016 is summarised.

5.1 Recent developments of ozone critical levels for vegetation

Two expert workshops were held in preparation for the next LRTAP Convention Ozone Critical Levels Workshop, 7 – 9 November 2016, Madrid, Spain (host institute: CIEMAT).

The first workshop on ‘Methodology for ozone critical levels analysis’ was held on 24 – 25 November 2015 in Hindås (nr. Gothenburg), Sweden, and was jointly hosted by IVL Swedish Environmental Research Institute and the University of Gothenburg. Contributions in kind were provided by the Swedish research programmes BECC (Biodiversity and Ecosystem Services in a Changing Climate) and SCAC (Swedish Clean Air & Climate) and the Swedish Environmental Protection Agency. The workshop was attended by 27 representatives from ICP Vegetation, ICP Forests, WGE and EMEP from Finland, Germany, Italy, Spain, Sweden, Switzerland and the UK. There were a series of methodology discussions in plenary. In addition, break-out groups considered methodology of particular relevance for crops, (semi-)natural vegetation and trees and planned activities for the next 12 months. The workshop was held back-to-back with the second expert workshop on ‘Epidemiological analysis of air pollution effects on vegetation’, hosted and funded by the same instititutes and research programmes mentioned above. The epidemiology workshop was attended by 24 scientists from Finland, Italy, Sweden, Spain, Switzerland, and United Kingdom. The workshop explored how further epidemiological studies could contribute to validating ozone critical levels for vegetation. Presentations of new epidemiological data and analyses confirmed the general conclusions and recommendation from the first expert workshop (Harmens et al., 2015).

The second workshop on ‘Dose-response functions for deriving ozone critical levels’ was held on 7 – 9 June 2016 in Deganwy (nr. Bangor), UK, and was hosted by the ICP Vegetation Programme Coordination Centre at CEH Bangor. Contributions in kind were provided by the Swiss Federal Office for the Environment. The workshop was attended by 16 experts from ICP Vegetation, ICP Forests and EMEP from Italy, Spain, Sweden, Switzerland and the UK. It was agreed to prepare two background documents by early October for the ozone critical levels workshop in November 2016 in Madrid:

1. Summary document providing all of the response functions and options for critical levels for consideration for inclusion in chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention (LRTAP Convention, 2016);
2. Background document containing scientific support for decisions to be made. This will comprise a series of short sections covering the following subjects:
    - Ozone gradient calculations;
    - Net annual increment in trees;
    - Y flux threshold selection, choices made;
    - Choice of 15 ppb as pre-industrial ozone and examples of flux calculations;
    - Defining growing seasons, potential approaches;
    - Defining ozone sensitivity in (semi-)natural vegetation;
    - Representing certainty in the critical levels.

The aim is to substantially revise the structure of Chapter 3 of the Modelling and Mapping Manual and cut in length to ca. 30 pages. Chapter 3 will be supported by a Scientific Background Document (name to be decided) to be hosted on the ICP Vegetation web site. This will include scientific support for the critical levels included in Chapter 3 and associated methodology together with forward-looking research. This Scientific Background Document will be updated annually (if needed) after each ICP Vegetation Task Force Meeting and will contain active links to, for example the DO_3SE model (https://www.sei-international.org/do3se) and relevant publications.

5.2 First global stomatal flux-based assessment of ozone impacts on wheat

The first global stomatal flux-based assessment of ozone impacts on wheat yield has been conducted and a manuscript describing results is nearing completion. The study has revealed a global annual yield loss due to ozone of 9.4% between 2010 and 2012, which equates to an annual economic loss of $24.3 billion globally using global average wheat prices. Economic losses were highest in Central Europe, Eastern USA, Western China and Northern India, all important wheat growing areas. Yield losses predicted with concentration-based metrics (AOT40 and M7) were much larger than those predicted with the flux-based metric.

5.3 Progress with the moss survey 2015/2016 on heavy metals, nitrogen and persistent organic pollutants

The first countries have submitted their data for the 2015-2016 moss survey to the new Moss survey Coordination Centre in the Russian Federation. Almost 40 countries are expected to submit data on heavy metal concentrations in mosses, including nine countries from South-Eastern Europe, seven countries from Eastern Europe, the Caucasus and Central Asia (Azerbaijan, Belarus, Georgia, Kazakhstan, Moldova, Russian Federation, Ukraine) and six countries from other parts of Asia and Africa (India, Mongolia, South Africa, South Korea, Thailand, Vietnam). Some countries will also report on nitrogen concentrations in mosses and on selected persistent organic pollutants (POPs; Harmens et al., 2013; 2015a).

5.4 Contributions to WGE common workplan items

5.4.1 Set up a contact group between EMEP and WGE to compare WGE exposure measurements and modelled and monitored exposure by EMEP

A group was set up between EMEP/Meteorological Synthesizing Centre-West and ICP Vegetation to discuss options for regional parameterisation of the stomatal ozone flux model incorporated in the EMEP model, to calculate the phytotoxic ozone dose for Mediterranean vegetation. Outcomes of the EMEP model will be compared with national scale modelling in the Mediterranean region. First discussions were held at the second workshop ozone critical levels expert workshop, 7 – 9 June 2016, Deganwy (nr. Bangor), UK (see Section 5.1).

5.4.2 Assess the long-term trends in air pollution and its adverse effects

The ICP Vegetation contributed text to and provided editorial support for the WGE report on 'Trends in ecosystem and health responses to long-range transported atmospheric pollutants' (De Wit et al., 2016; http://www.unece.org/env/lrtap/welcome.html). The report describes temporal trends (primarily) between 1990 and 2012 in impacts of air pollution on ecosystems, human health and the built environment, based on the findings from the various ICPs, Task Force on Health and Joint Expert Group on Dynamic Modelling. Contributions from EMEP were also included. The ICP Vegetation reported on the lack of trends between 1999 and 2010 in ozone concentrations, fluxes and effects on vegetation, as described in further detail in the brochure "Changing ozone profiles in Europe: implications for vegetation" (Harmens et al., 2015b). Similarly, the Task Force on Health reported on the lack of clear trends in the risk of population exposure to ozone for the period 2000 – 2012. Hence, both human health and vegetation (including crops) remain currently at considerable risk of adverse impacts of ozone. Ozone pollution in the future is critically dependent on changes in regional emissions and global transport of ozone precursors. Further ozone pollution abatement requires measures at the global scale to reduce emissions of ozone precursors, including methane. It remains unclear how emission controls in Europe may be offset by global background ozone increases, by changes in longer-lived ozone precursors such as methane or by changes in chemical processing or transport driven by future shifts in climate. Applying the latest climate change scenarios, in the absence of changes in emission of precursors, surface ozone concentrations are predicted to increase in the future in Europe. Limiting atmospheric methane increases is becoming more important as emissions of other ozone precursors are controlled.

The ICP Vegetation also reported on the decline in cadmium (51%), lead (77%), mercury (14%) and other metal concentrations in mosses between 1990 (1995 for mercury) and 2010 (Harmens et al., 2015a). For lead and cadmium, these trends are primarily driven by reductions of anthropogenic emissions of lead and cadmium in Europe. For mercury, secondary emission sources and emission sources outside of Europe lead to a lower decline in deposition than in anthropogenic emissions. Hemispheric transport of mercury results in a considerable contribution of mercury pollution from other continents to mercury deposition in Europe. Air pollution policy for heavy metals has been effective in reducing emissions, deposition and accumulation rates in the environment, although less for mercury than for cadmium and lead. For lead, the ecosystem area at risk in Europe declined from 67% to 20% between 1990 and 2010. For mercury, the ecosystem area at risk of exceedance of mercury critical loads declined only from 69% to 56% between 1990 and 2010. However, heavy metal accumulation in soils continues, with possible consequences for export to aquatic ecosystems. Hence, there is still a long-term risk of harmful effects to human health and ecosystems by the atmospheric deposition of lead and mercury in certain areas in Europe.

Systematic long-term monitoring of air pollutants and the effects on the terrestrial and aquatic ecosystems, materials, crops and human health remains essential for the evaluation of the effectiveness of air pollution policies and for determining the need for further measures to reduce the emissions of air pollutants.

5.4.3 Assess scientific and policy outcomes within the Convention over the past few decades, including scientific understanding, trends and achievements under the Gothenburg Protocol, and outline future challenges

The ICP Vegetation contributed to chapter 4 and 8 of the LRTAP Convention report 'Towards Cleaner Air. Scientific Assessment Report 2016' (http://www.unece.org/env/lrtap/welcome.html; Maas and Grennfelt, 2016). Key findings from the report are:

- Abatement measures under the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) and its protocols have achieved significant success. There has been a sharp decline in emissions, especially for sulphur, and economic growth and trends in air pollution have been progressively decoupled.

- Despite successes problems still exist. A significant proportion of the urban population in Europe and North America is exposed to concentrations of fine particles and ozone that are near or above the WHO guideline level and, despite soils and lakes recovering from acidification across large parts of Europe, nitrogen deposition in many parts still exceeds the level below which harmful effects do not occur.

- Because transboundary sources are often major contributors to urban pollution, many European cities will be unable to meet WHO guideline levels for air pollutants through local action alone. Even national and Europewide action may not be enough in some cases.

- Long-term risks due to ozone, heavy metals and persistent organic pollutants continue to exist in many UNECE countries. In addition to implementing CLRTAP Protocols, reducing background levels and exposure will require broader coordination beyond the European or North American scale, as well as coordination with other international fora.

- Technical measures are available to reduce fine particles and ozone to levels below the WHO guidelines in most parts of Europe and North America and to avoid excess nitrogen in most nature areas. Successful examples of healthy lifestyles that contribute to cleaner air are also available.

- Air pollution control costs are generally significantly lower than the costs of damage to health and the environment. In many countries the net impact of abatement measures on national income and employment will be neutral because production of the technologies required will also create employment.

- An integrated approach to climate change and air pollution could lead to significant co-benefits, as well as to reducing the risk of applying climate change measures with significant negative impacts on air quality.

- Ratification and implementation of the 2012 revision of the Gothenburg Protocol would reduce emissions of sulphur dioxide, nitrogen oxides and particulate matter by 40–45% between 2005 and 2020, according to estimates made in 2011. For ammonia the reduction would be 17%.

- International policy collaboration and coordination of air pollution science remains essential to harmonise methods for estimating emissions, monitoring air quality and impacts, and identifying cost-effective further steps.

These key messages were presented at the 8th Environment for Europe Ministerial Conference, 8 – 10 June 2016, Batumi, Georgia.

6 Future activities

Workplan items for 2016 - 2017 were adopted at the first joint session of EMEP and WGE in September 2015 and approved at the 34th session of the Executive Body of the LRTAP Convention in December 2015 (ECE/EB.AIR/2015/1-ECE/EB.AIR/WG.5/2015/1). Preliminary workplan items for 2018 and beyond were discussed at the 29th Task Force Meeting of the ICP Vegetation (Dubna, Russian Federation, 29 February – 3 March, 2016) and will be finalised at the 30th Task Force Meeting (Poznan, Poland, 14 – 17 February 2017). These include ongoing and new ozone-related activities and preparations for the next moss survey scheduled for 2020.

Ongoing annual activities include:

- Report on supporting evidence for ozone impacts on vegetation, including establishment of ozone gardens;
- Report on progress with the moss survey 2015/2016 (final report to be published in 2018);
- Contributions to common workplan items of the WGE, including discussions on future data access and usage.

Remaining activity for 2016:

- Ozone critical levels workshop, 7 – 9 November 2016, Madrid, Spain.

New activities for 2017:

- Report on revised ozone risk assessments methods based on outcomes of the ozone critical level workshop;
- Revision of Chapter 3 of the Modelling and Mapping Manual.

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Annex 1. Participation in the ICP Vegetation

In many countries, several other scientists (too numerous to include here) also contribute to the work programme of the ICP Vegetation. P in heavy metals column indicates involvement in POPs research.

Party of the LRTAP Convention	Institute	Email	Ozone	Heavy metals	Nitrogen
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Air Pollution and Vegetation
ICP Vegetation
Annual Report 2015/2016

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 50 countries, in the UNECE region and with outreach activities to other regions. 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 ground-level ozone, heavy metals, nitrogen and persistent organic pollutants (POPs). Progress and recent results from the following activities are reported:

- Field evidence of ozone impacts on vegetation in ambient air (2007-2015).
- Impacts of ozone pollution on biodiversity.
- Global stomatal flux-based assessment of ozone impacts on wheat.
- Recent developments of ozone critical levels for vegetation.
- Progress with the moss survey 2015/2016 on heavy metals, nitrogen and POPs.

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ISBN: 978-1-906698-58-4