Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Air Pollution and Vegetation

ICP Vegetation

Annual Report 2014/2015

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

Air Pollution and Vegetation

ICP Vegetation[1] Annual Report 2014/2015

Harry Harmens[1], Gina Mills[1], Felicity Hayes[1], Katrina Sharps[1], Marina Frontasyeva[2], and the participants of the ICP Vegetation

[1] ICP Vegetation Programme Coordination Centre, Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW, UK
Tel: + 44 (0) 1248 374500, Fax: + 44 (0) 1248 362133, Email: hh@ceh.ac.uk
http://icpvegetation.ceh.ac.uk

[2] Moss Survey Coordination Centre, Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, Str. Joliot-Curie, 6, Dubna, Moscow Region, Russian Federation.
Tel: +7 49621 65609, Fax: +7 49621 65085, Email: mfrontasyeva@jinr.ru
http://flnp.jinr.ru/naa

September 2015

[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 Fausto Manes, Elisabetta Salvatori and Lina Fusaro, Department of Environmental Biology, Sapienza University, Rome, for their support in organising the 28th ICP Vegetation Task Force meeting in Rome, with support from the National Forest Service and the National Academy of Sciences.

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

Front cover photo: Gina Mills

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 2014/15 is provided in this report.

28th ICP Vegetation Task Force meeting

The Programme Coordination Centre organised the 28th ICP Vegetation Task Force meeting, 2 – 5 February, 2015 in Rome, Italy. The meeting was hosted by the Department of Environmental Biology, Sapienza University, Rome, with support from 'Corpo Forestale dello Stato' (National Forest Service) and 'Accademia Nazionale Delle Scienze Detta Del XL' (National Academy of Sciences). The meeting was attended by 80 experts from 22 countries, including 20 Parties to the LTRAP Convention and guests from China and Egypt. A book of abstracts and the minutes of the 28th Task Force meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk). The Programme Coordination Centre published an overview of its activities and achievements in the last 28 years in a special issue of the journal Annali di Botanica.

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/WG.1/2015/8). ICP Vegetation also contributed to the joint report (ECE/EB.AIR/WG.1/2015/3) of the WGE. 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 contributed to the Assessment Report of the LRTAP-Convention, 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. The Programme Coordination Centre has published two brochures: i) 'Changing ozone profiles in Europe: implications for vegetation', and ii) 'Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution'; see details below.

Changing ozone profiles in Europe: implications for vegetation

Background concentrations of ozone have roughly doubled between 1950 – 2000, followed by a decade with no further rise and even a reduction of ozone at some sites, particularly in the summer. Despite a more than 30% reduction in European emissions of ozone precursors during the last two decades, few trends have been observed at ICP Vegetation monitoring sites between 1999 and 2010 regarding ozone concentrations and risk of ozone impacts on vegetation. Time series much longer than 12 years are required to distinguish significant long-term trends from inter-annual variability in ozone concentrations due to climate variation. Whereas peak concentrations of ozone have declined in recent decades in some (but not all) parts of Europe, an increase in concentrations in the lower range at the same time has contributed to no change in median or average ozone concentrations across Europe. The rise in lower ozone concentrations can potentially contribute to impacts of ozone on vegetation. Ozone therefore remains a threat to crops and (semi-)natural vegetation and the services they provide to human well-being. Ozone pollution in Europe in the future is dependent on changes in both regional emissions and global transport of ozone precursors.

Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution

Interactions between air pollution and climate change are complex and responses of vegetation to a combination of changing environmental drivers cannot simply be extrapolated from responses to single drivers. Experimental and modelling evidence indicates that interactions between elevated carbon dioxide and ozone, mean temperature and extremes, water, and nitrogen are nonlinear, variable, and difficult to predict. Combined impacts of ozone and nitrogen on vegetation appear to be additive to a certain level of ozone exposure, but ozone effects dominate at high ozone exposure. Two types of interactions need to be considered differently: i) responses to gradual long-term changes in background ozone, reactive nitrogen and climate; ii) responses to extreme pollution and climate events, likely to become more frequent in the coming decades. Although heat, drought and ozone stress frequently occur together, few studies have considered their combined impacts nor the effect of additional nitrogen under these conditions.

Supporting evidence for ozone impacts on vegetation

Further field-based evidence on injury caused by ambient ozone concentrations was collated from the year 2007 onwards. Three different approaches were applied to collate and map further field-based evidence: i) Data from ICP Vegetation biomonitoring experiments; ii) Data were collated during the test phase in 2014 using a smart-phone App for recording of incidences of ozone-induced leaf injury; iii) A literature review was conducted on reported incidences of leaf injury, including those from open-air chamber studies. In addition, the ICP Vegetation developed a protocol for recording the presence/absence of ozone injury symptoms using the smart phone App or the online recording form in a systematic manner (in planted ozone gardens, parks, gardens or field) or on a more ad-hoc basis after an ozone episode.

Recent developments of ozone critical levels for vegetation

The Task Force adopted new flux-effect relationships for tomato for inclusions in Chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention. The flux-based critical levels for tomato yield and quality were set at 3 and 4 mmol m^{-2} respectively (POD_6), corresponding to a yield and quality reduction of 5%. In addition, the concentration-based critical level for yield of horticultural crops (represented by tomato) was adjusted to an AOT40 of 8 ppm h. Although other new developments in methodology, flux-effect relationships and associated critical levels were presented at the 28th Task Force meeting, the Task Force recommended to further assess the methodologies used at an Expert Group meeting in November, 2015 in readiness for proposing revised critical levels at the next ozone critical level workshop, scheduled for November 2016 in Spain.

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

Fourty and fifteen countries have confirmed to determine heavy metal and nitrogen concentrations in mosses respectively, including countries in the Eastern Europe, the Caucasus and Central Asia (EECCA) region, i.e. Azerbaijan, Belarus, Georgia, Kazakhstan, the Republic of Moldova, the Russian Federation, Uzbekistan; the South-Eastern European countries Albania, Bulgaria, Croatia, Greece, the Former Yugoslavic Republic of Macedonia, Romania, Serbia, and other Asian countries such as China, India, Mongolia, Republic of Korea, Thailand and Vietnam. Three countries (Norway, Republic of Ireland and Switzerland) will also determine POPs concentrations in mosses. Some further countries are still awaiting funding approval, hence additional countries might collect mosses in 2016.

Contributions to the WGE common workplan

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

- <u>Enhanced involvement of EECCA/SEE countries in the Eastern Europe, the Caucasus and Central Asia and cooperation with activities outside the Air Convention.</u> In 2014, ICP Vegetation transferred the coordination of the moss survey (see above) to the Russian Federation. The new Moss Survey Coordination Centre, at the Institute for Joint Nuclear Research in Dubna, has particularly stimulated the participation of EECCA countries (see previous paragraph) in the next survey in 2015/16.

- Cooperation with programmes and activities outside the region. ICP Vegetation will participate in the first Asian Air Pollution workshop, 31 October – 1 November 2015, Tokyo, Japan, and will lead discussions on air pollution impacts on crops. Some Asian (e.g. China, India, Japan, Pakistan) and African countries (e.g. Egypt, South-Africa) do attend ICP Vegetation Task Force meetings from time to time. ICP Vegetation also contributes to the 'Tropospheric Ozone Assessment Report (TOAR): Global metrics for climate change, human health and crop/ecosystem research', including leading the chapter on vegetation. This is a new activity of the International Global Atmospheric Chemistry Project (IGAC; http://www.igacproject.org).
- WGE trends report and Assessment Report of the LRTAP Convention. 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 i) past and future predicted trends in ozone pollution and its impacts on vegetation (see above), and on ii) trends in heavy metal concentrations in mosses between 1990 and 2010. The ICP Vegetation also contributed text and figures to key messages, related to ozone pollution and its impacts on vegetation, for the Assessment Report, prepared by the LRTAP Convention for presentation at the 8th Environment for Europe Ministerial Conference, Batumi, Georgia, June 2016. Recent ozone flux-based estimates show wheat yield losses to be 4.56 billion Euro in the EMEP region, equating to a mean yield loss of 13%, with the highest economic losses found in important wheat growing areas in western and central Europe.

Future activities of the ICP Vegetation

The medium-term workplan for 2016 – 2018 was adopted at the 28th Task Force Meeting of the ICP Vegetation (Rome, France, 2 – 5 February, 2015). Workplan items for 2016 - 2017 were submitted for adoption at the first joint session of EMEP and WGE in September 2015 and for final approval at the 34th session of the Executive Body of the LRTAP Convention in December 2015. Ongoing annual activities include i) report on evidence for ozone impacts on vegetation, ii) report on progress with the moss survey 2015/16, and iii) contributions to common workplan items of the WGE.

New activities include:

2016:

- Update report on field-based evidence of ozone impacts on vegetation;
- Report on ozone impacts on biodiversity;
- Ozone critical levels workshop (Autumn, Spain).

2017:

- Report on revised ozone risk assessments methods;
- Revision of Chapter 3 of the Modelling and Mapping Manual.

2018:

- Report of the European moss survey 2015/16.

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 also 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. 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[a] participating in the ICP Vegetation. In italics: country not a Party of the LRTAP Convention.

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

[a] Kosovo (United Nations administered territory, Security Council resolution 1244 (1999)) also participates.

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, 2015). 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 moss survey on heavy metals. It involves the collection of naturally-occurring mosses and determination of their heavy metal concentration at five-year intervals. European 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., 2013a,b) 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 2015

The Executive Body of the LRTAP Convention agreed on a workplan for 2014 and 2015 at its 32nd meeting in December 2013 (see ECE/EB.AIR/122/Add.2). Here we will report on the workplan items for the ICP Vegetation for 2015:

- Evaluate effects on (semi-)natural vegetation and crops due to the impact of:
  - (a) Tropospheric ozone;
  - (b) Co-occuring pollutants (ozone and nitrogen) and climatic stresses;
  - (c) Rising background ozone levels in Europe;
- Further development of the flux-based approach for setting critical levels of ground-level ozone for vegetation;
- Carry out preparatory work for the European moss survey 2015/16.

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

- Further implementation of the Guidelines on Reporting of Monitoring and Modelling of Air Pollution Effects;
- Enhance the involvement of countries in Eastern and South-Eastern Europe, the Caucasus and Central Asia, and on cooperation with activities outside the Convention;
- Cooperate with programmes and activities outside the ECE region;
- Prepare an annual report to the Executive Body for its meeting in 2015 on recent findings under Working Group on Effects and their implications for policy.

In Chapter 2, general coordination activities of the ICP Vegetation are described, including the 28th ICP Vegetation Task Force meeting and dissemination of results. In Chapter 3 and 4, we report on 'Changing ozone profiles in Europe: implications for vegetation' and 'Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution' respectively. Chapter 5 describes the progress with collating further evidence for ozone impacts on vegetation, recent developments of ozone critical levels for vegetation, progress with the 2015/2016 moss survey, and contributions to common workplan items of the WGE. Finally, planned activities of the ICP Vegetation for 2016 – 2018 are described in Chapter 6.

2 Coordination activities

2.1 Annual Task Force meeting

The Programme Coordination Centre organised the 28th ICP Vegetation Task Force meeting, 2 – 5 February, 2015 in Rome, Italy. The meeting was hosted by the Department of Environmental Biology, Sapienza University, Rome, with support from 'Corpo Forestale dello Stato' (National Forest Service) and 'Accademia Nazionale Delle Scienze Detta Del XL' (National Academy of Sciences). The meeting was attended by 80 experts from 22 countries, including 20 Parties to the LTRAP Convention and guests from China and Egypt (**Figure 2.1**). A book of abstracts and the minutes of the 28th 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. In addition, the Programme Coordination Centre published an overview of its activities and achievements in the last 28 years in a special issue of the journal Annali di Botanica (Harmens et al., 2015a). The **29th Task Force meeting** will be held in Dubna, Russian Federation from 29 February – 4 March 2016.

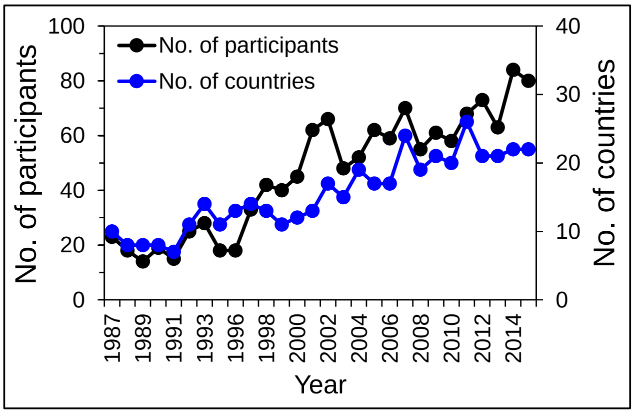


Figure 2.1 Participation in ICP Vegetation Task Force meetings since 1987 (Harmens et al., 2015a).

2.2 Other meetings

ICP Vegetation organised a joint session with the Coordination Centre for Effects (CCE)/ICP Modelling and Mapping at their 25th workshop/31st Task Force meeting, 20 – 23 April 2015, Zagreb, Croatia. The meeting was attended by 52 delegates from 19 countries. The theme of the session was nitrogen impacts on plant species diversity, including interactions between nitrogen and ozone. Presentations and discussions highlighted strong evidence for nitrogen and ozone impacts on vegetation, also showing that these pollutants sometimes worked in a synergistic or antagonistic way. At the highest ranges of ozone concentrations and nitrogen deposition in Europe, ozone reduces the potential growth enhancing effects of nitrogen and the relative effects of ozone are greater at higher than at lower nitrogen deposition. In annual Mediterranean pastures, the heterogeneous, species-specific responses to nitrogen, ozone and climate and the interaction among these factors results in a complex alteration of the competitive relationships among species, potentially affecting the structure and biodiversity of this plant community. Further details about presentations, posters and the minutes of the meeting are available from the CCE web site (http://wge-cce.org).

2.3 Reports to the LRTAP Convention

The ICP Vegetation Programme Coordination Centre has reported progress with the 2015 workplan items in the following documents for the first joint session of the Steering Body to the EMEP and the WGE, 14 - 18 September 2015, Geneva, Switzerland (http://www.unece.org/index.php?id=39872#/):

- ECE/EB.AIR/WG.1/2015/3: Joint report of the ICPs, Task Force on Health and Joint Expert Group on Dynamic Modelling;
- ECE/EB.AIR/WG.1/2015/8: 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, 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. The Assessment Report will be published in 2016 and is scheduled to be presented at the 8th Environment for Europe Ministerial Conference, Batumi, Georgia, June 2016.

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

- A glossy brochure on 'Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution' (see Chapter 3);
- A glossy brochure on 'Changing ozone profiles in Europe: implications for vegetation', see Chapter 3;
- The current annual report on line.

2.4 Scientific papers

The following papers have been published:

Feng, Z., Paoletti, E., Bynerowicz, A., Harmens, H. (2015). Ozone and plants. Environmental Pollution 202: 215-216.

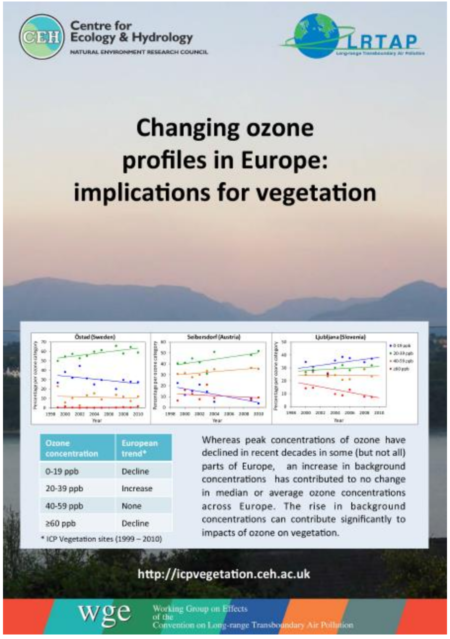
Harmens, H., Mills, G., Hayes, F., Norris, D.A., Sharps, K. (2015). Twenty eight years of ICP Vegetation: an overview of its activities. Annali di Botanica 5: 47 – 59.

Harmens, H., Norris, D.A., Sharps, K., Mills, G., Alber, R., Aleksiayenak, Y., Blum, O., Cucu-Man, S.-M., Dam, M., De Temmerman, L., Ene, A., Fernández, J.A., Martinez-Abaigar, J., Frontasyeva, M., Godzik, B., Jeran, Z., Lazo, P., Leblond, S., Liiv, S., Magnússon, S.H., Maňkovská, B., Pihl Karlsson, G., Piispanen, J., Poikolainen, J., Santamaria, J.M., Skudnik, M., Spiric, Z., Stafilov, T., Steinnes, E., Stihi, C., Suchara, I., Thöni, L., Todoran, R., Yurukova, L., Zechmeister, H.G. (2015). Heavy metal and nitrogen concentrations in mosses are declining across Europe whilst some "hotspots" remain in 2010. Environmental Pollution 200: 93-104.

3 Changing ozone profiles in Europe: implications for vegetation

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

3.1 Introduction



Background concentrations of ozone have roughly doubled between 1950 – 2000, followed by a decade with no further rise or even a reduction of ozone at some sites, particularly in the summer (Parish et al., 2012; Cooper et al., 2014). Despite a more than 30% reduction in European emissions of ozone precursors during the last two decades, a decline in mean ozone concentrations is generally not seen at EMEP (European Monitoring and Evaluation Programme) ozone monitoring sites (Torseth et al., 2012; Simpson et al., 2014). Rural background data over 1990 – 2010 show a decrease in the highest concentrations and a corresponding increase in low concentrations in the UK, the Netherlands and some other countries, but no clear trends in, for example, Switzerland or Austria. Reduced precursor emissions might well be being masked by large inter-annual variations in ozone, caused by, for example weather or biomass burning events.

Figure 3.1 Brochure on 'Changing ozone profiles in Europe: implications for vegetation'.

Applying the latest climate change scenarios, surface ozone concentrations are predicted to decline further in the future in Europe and North-America, with the magnitude of decline depending on scenario, whereas an increase is expected in South Asia. Limiting atmospheric methane growth will become more important when emissions of other ozone precursors are controlled (Wild et al., 2012).

3.2 Ozone trends (1999 – 2010) at ICP Vegetation biomonitoring sites

The ICP Vegetation biomonitoring programme has involved exposure of an ozone-sensitive variety of white clover in early years (Hayes et al., 2007; Mills et al., 2011a) and an ozone-sensitive variety of French bean in later years (Harmens et al., 2012) to ambient air between 1999 and 2010. Ozone concentration data are available from sites spanning a representative north-south and east-west gradient across Europe (see **Figure 3.2**). Here we report on temporal trends of hourly ozone concentrations and metrics indicating the risk of ozone impacts on vegetation for June, July and August.

Analysis of the European data from ICP Vegetation biomonitoring sites between 1999 and 2010 showed that in recent years the proportion of hourly ozone concentration in the lowest and highest ozone categories has declined ($P < 0.10$), whereas the proportion in the category 20 - 39 ppb has increased ($P < 0.001$) and the proportion in the category 40 - 59 ppb has not changed (**Table 3.1**). No temporal trends were found for the 24 hr mean and daylight mean ozone concentrations (**Table 3.2**). This is in agreement with trends reported for mean and median ozone concentrations at EMEP monitoring sites (Torseth et al., 2012; Simpson et al., 2014). However, night time mean and daily minimum ozone concentration have increased (0.27 ppb per year) across Europe, although only significantly ($P < 0.10$) in Tervuren, Belgium. Despite a decline in the ozone concentrations of 60 ppb or higher, the average

European daily maximum ozone concentration and AOT40[2] have not changed, although a decline (P = 0.06) was reported for Ljubljana, Slovenia.

Table 3.1 Trends (1999 – 2010) in ozone concentrations at ICP Vegetation sites.

Ozone concentration	European trend	Sites showing European trend
0-19 ppb	Decline	Tervuren (BE), Seibersdorf (AT)
20-39 ppb	Increase	Östad (SE), Ascot (GB), Tervuren (BE), Giessen (DE)
40-59 ppb	None	All, except increase in Seibersdorf (AT)
≥60 ppb	Decline	Ljubljana (SI)

Concentrations much lower than 40 ppb contribute to the accumulation of ozone flux. The ozone flux into leaves showed no trend between 1999 and 2010, indicating that the risk of ozone-induced effects on wheat has not changed with time. Considering the annual variation in ozone concentrations due to climate variation, longer time series are required to detect temporal trends in ozone concentrations and effects on vegetation across Europe. Earlier analyses have shown that there were no clear temporal trends of ozone impact on white clover leaf injury or biomass (Hayes et al., 2007; Mills et al., 2011a).

Table 3.2. Trends (1999 – 2010) in ozone concentrations and leaf fluxes at sites* across Europe.

Country	Site	24 hr mean	Daylight mean	Night mean	Daily max	Daily min	AOT40[a]	POD_3 IAM[b]
Belgium	Tervuren	None	None	Increase	None	Increase	None	None
Slovenia	Ljubljana	None	None	None	Decline	None	Decline	None
European mean		**None**	**None**	**Increase**	**None**	**Increase**	**None**	**None**

[a] The accumulated hourly mean ozone concentration above 40 ppb, during daylight hours.

[b] Phytotoxic Ozone Dose (POD) above a flux threshold of 3 nmol m^{-2} s^{-1}, accumulated during daylight hours. Parameterisation is based on wheat for application in integrated assessment modelling (IAM); adequate soil water supply was assumed.

* Data are shown for sites showing at least one significant trend (P < 0.10). No significant trends for any of the variables were observed for Östad (Sweden), Ascot (UK), Giessen (Germany), Seibersdorf (Austria) and Pisa (Italy).

3.3 Key messages

Key messages from the trend analyses are:

- Few trends have been observed at ICP Vegetation monitoring sites between 1999 and 2010 regarding ozone concentrations and risk of ozone impacts on vegetation.
- Time series much longer than 12 years are required to distinguish significant long-term trends from inter-annual variability in ozone concentrations due to climate variation.
- Whereas peak concentrations of ozone have declined in recent decades in some (but not all) parts of Europe, an increase in concentrations in the lower range at the same time has contributed to no change in median or average ozone concentrations across Europe. The rise in lower ozone concentrations can potentially contribute to impacts of ozone on vegetation. Ozone therefore remains a threat crops and (semi-)natural vegetation and the services they provide to human well-being.
- Ozone pollution in Europe in the future is dependent on changes in both regional emissions and global transport of ozone precursors.

[2] The accumulated hourly mean ozone concentration above 40 ppb, during daylight hours.

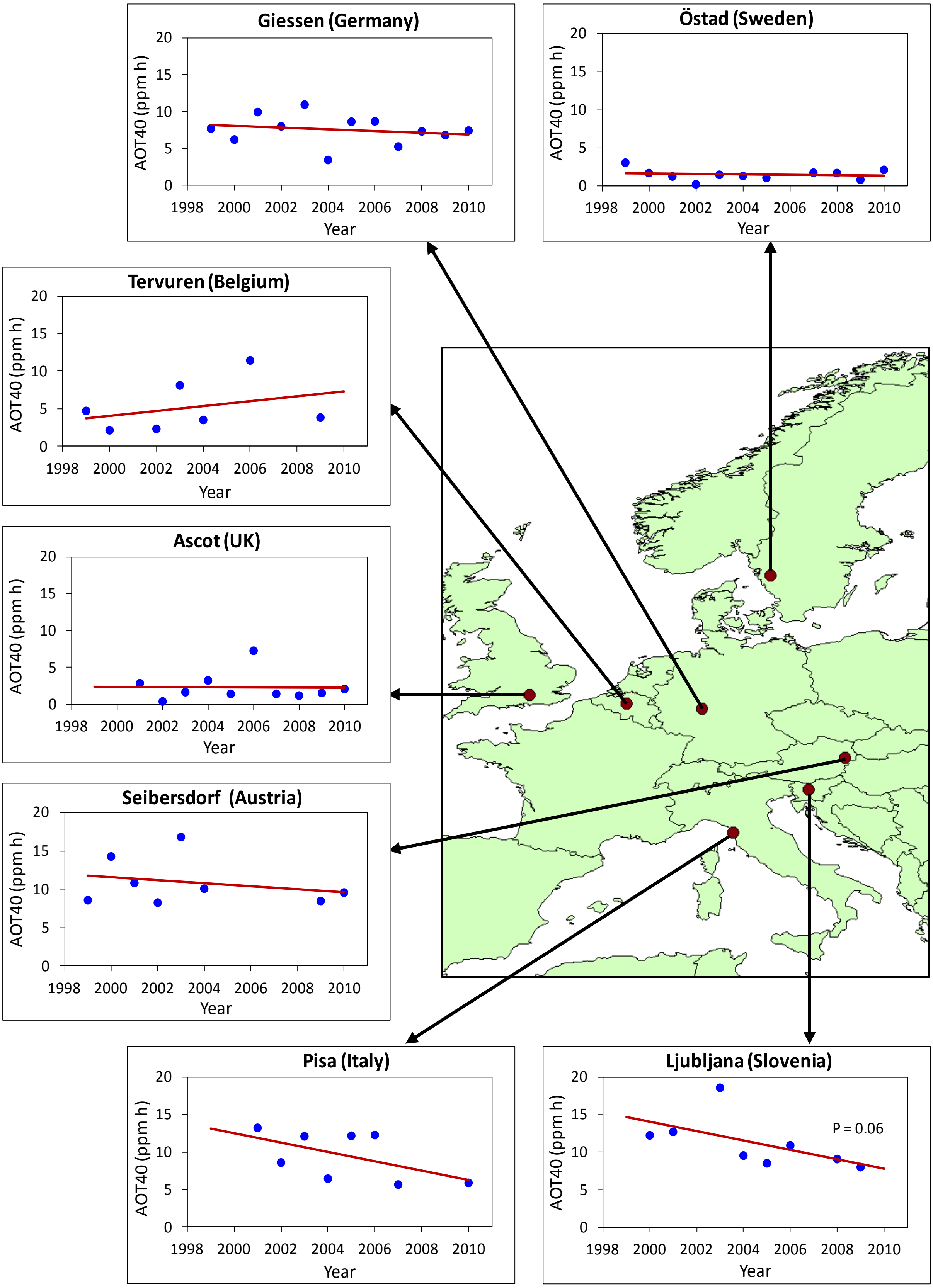
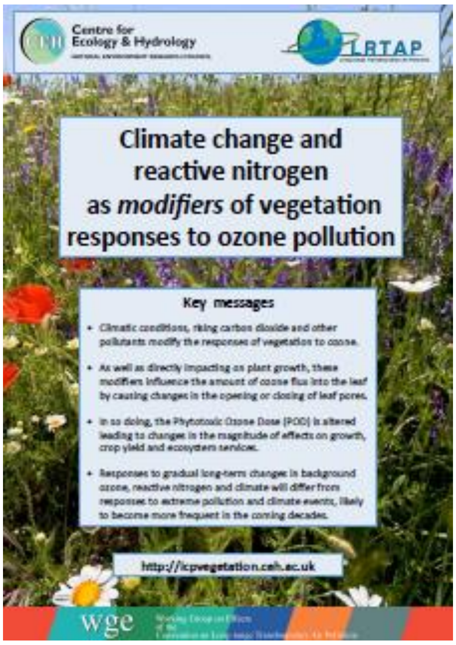


Figure 3.2 Trends (1999 – 2010) in AOT40 at representative ICP Vegetation biomonitoring sites.

4 Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution

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

4.1 Introduction



In the 20th century, ground-level ozone concentrations have more than doubled (Parish et al., 2012). At the same time, synthetic fertilizer production together with industrialisation, population growth and associated demand for food has resulted in a five-fold increase in emission of reactive nitrogen compounds (Sutton et al., 2011). Both ozone and nitrogen affect vegetation, often in contrasting ways. For example, ozone tends to reduce plant growth, whereas nitrogen tends to stimulate plant growth up to a certain level, above which detrimental effects occur. However, enhanced nitrogen deposition is known to reduce plant diversity in areas and habitats were plants are adapted to low atmospheric nitrogen input (Bobbink and Hettelingh, 2011; Dise et al., 2011). Few studies have determined their combined impacts on vegetation.

Figure 4.1 Brochure on 'Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution'.

The global climate is warming due to a considerable rise in greenhouse gases such as carbon dioxide, methane and ozone, especially in the last 50 years. Future increases in greenhouse gases and global temperature will depend on energy use and emission abatement scenarios (IPCC, 2013). A warmer climate will have fewer frost days and increased summer dryness with greater risk of drought in mid-continental areas. In addition, the frequency and duration of extreme temperatures, rainfall and drought is likely to increase. As the 'uptake' of ozone by vegetation is dependant on temperature, air humidity and soil water content (LRTAP Convention, 2015), changes in the climate will affect the impact of ozone on vegetation. Hence, it is important to study the interactive impacts of ozone, nitrogen and changing climate on vegetation to predict future trends in effects.

4.2 Climate change as a modifier of vegetation responses to ozone

4.2.1 Ozone impacts in rising carbon dioxide

In many plant species, a rise in atmospheric carbon dioxide concentrations will stimulate photosynthesis and plant growth. Ozone, however, often has the opposite effect (Ainsworth et al., 2012; Fuhrer et al., 2009; Wittig et al., 2007, 2009). Evidence confirms the positive impacts of elevated carbon dioxide and negative impacts of ozone on crop yield (IPCC, 2014). Elevated carbon dioxide might also reduce the opening of leaf pores (Curtis and Wang, 1998; Drake et al., 1997), which will provide some protection to plants from ozone (Fiscus et al., 1997; Harmens et al., 2007; McKee et al., 1997). Indeed, meta-analysis provided supportive evidence that elevated carbon dioxide counteracts the impacts of ozone on stomatal conductance and light-saturated photosynthesis in boreal and temperate forests (Wittig et al., 2007). However, some studies in forests suggest that this might not be the case at the canopy level (Uddling et al., 2010). In addition to stomatal responses, compensatory interactions between ozone and carbon dioxide have been demonstrated directly at the level of the photosynthetic machinery

(Kobayakawa and Imai, 2011), such that ozone and carbon dioxide effectively compensate for one another's effects on carbon fixation at the level of leaf physiology (Gray et al., 2010; Wittig et al., 2007, 2009). The response of vegetation to a combination of elevated carbon dioxide and ozone is finely balanced depending on their relative concentrations in the atmosphere. Whereas increasing ozone and carbon dioxide are frequently reported from controlled environment experiments as having opposite effects on leaf physiology, growth and carbon allocation, the evidence from field-based experiments does not fully support that they have compensatory effects when co-occurring (Mills et al., in press).

4.2.2 Ozone, warming and drought interactions

Whilst elevated ozone and carbon dioxide might partially compensate for each other's effects, crop yield losses might be greater when elevated ozone combines with high temperature, particularly during grain filling stages in cereals when elevated ozone causes premature leaf die-back. Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30°C, depending on crop and region (IPCC, 2014). However, little is known about the combined effect of ozone and a few degrees rise in temperature on vegetation (Vandermeiren et al., 2009). In one of the very few field experiments investigating combined effects of ozone and global warming, it was shown that ozone modifies the effects of warming on silver birch, but the response varied amongst genotypes (Kasurinen et al., 2012). The complexity of the potential interactions between global warming and ozone impacts on vegetation is illustrated by effects on the canopy uptake of ozone. When considered as a single factor, increased temperature in temperate climates is likely to increase stomatal uptake of ozone providing the optimum temperature for stomatal conductance has not been reached. However, the response to warming will also be affected by the following indirect effects of increased warming: greater tropospheric ozone formation increasing the atmospheric concentration, an increase in vapour pressure deficit, a decrease in soil water potential (soils will dry out faster due to enhanced soil evaporation and enhanced canopy transpiration), changes in seasonal patterns in the occurrence of peak episodes of ozone and earlier and enhanced plant development, resulting in a forward shift of the period within the year when plants are absorbing ozone (Mills et al., in press). In addition, a reduction in stomatal conductance due to ozone will lead to an increase in leaf temperature, therefore exaggerating the impact of global warming on leaf processes (e.g. Bernacchi et al., 2011).

It has been reported that drought-induced closure of leaf pores will limit ozone uptake and impact (Fagnano et al., 2009; Fuhrer, 2009). However, various recent studies have shown that the expected protective effect of drought on the deleterious plant responses to ozone might not occur (Mills et al., 2009, 2013; Wagg et al., 2012; Wilkinson and Davies, 2009, 2010). Ozone itself might affect the sensitivity of opening of the leaf pores (**Figure 4.1a**), which might lead to underestimation of ozone uptake if this effect is not taken into account.

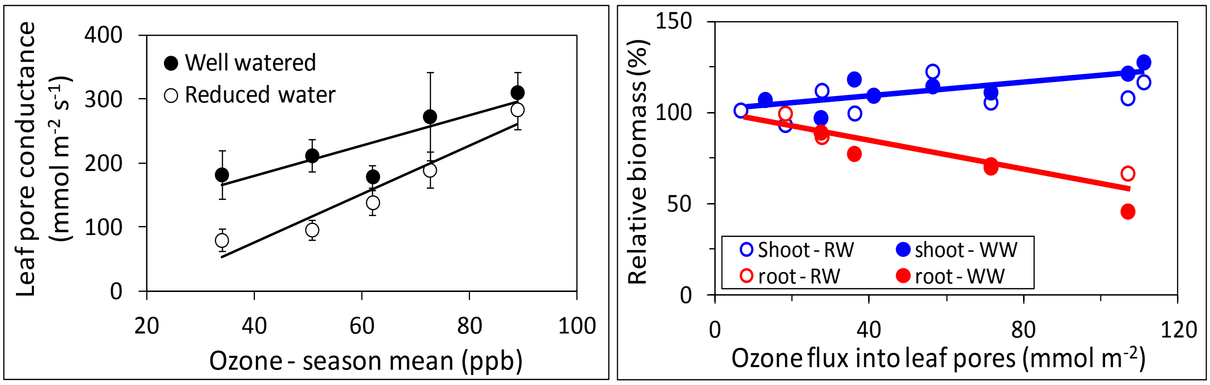


Figure 4.1 (a) Elevated ozone concentrations enhance opening of leaf pores, more so in 'drought' (reduced water) than well watered plant, and (b) ozone reduces root biomass in the grass species *Dactylis glomerata* (Modified from Hayes et al., 2012).

Extensive measurements of a Southern Appalachian forest in the USA by McLaughlin et al. (2007a, b) provide field evidence to support the concept of ozone -induced increases in stomatal conductance and hence transpiration (loss of water) by the vegetation. Exposure to increasing background ozone concentrations, as currently occurs in Europe, might make plants more susceptible to drought in the future, especially as ozone tends to reduce root biomass more than above-ground biomass (**Figure 4.1b;** Hayes et al., 2012).

4.3 Nitrogen as a modifier of vegetation responses to ozone

Few studies have looked at the combined impact of ozone and nitrogen on vegetation. Nitrogen tends to increase plant growth and crop yield, whereas ozone has the opposite effect with high concentrations tending to reduce root growth and seed production more than shoot growth. Reduced root growth will result in less nitrogen uptake from the soil and a lower nitrogen use efficiency of the plant, both in crops and (semi-)natural vegetation. A recent meta-analysis comparing responses to ozone under limiting nitrogen with those under sufficient nitrogen, indicated that negative effects of ozone on leaf area, above ground and root biomass were partially mitigated by the presence of sufficient nitrogen, although many of these effects were not significant (Yendrek et al., 2013). Mills et al. (in press) concluded that: (i) the beneficial effect of nitrogen fertilisation on root development expected for realistic nitrogen addition ranges is lost at higher ozone exposure; (ii) the proportionate effects of increasing ozone on root biomass become more pronounced at higher nitrogen supply; (iii) interactions are apparent in roots rather than shoots and (iv) generalisations on responses need to take into account the relative concentrations/deposition rates and deposition history of both pollutants. Effects on plants tend to be mainly additive, but are generally less than additive at high nitrogen and ozone exposure, when high nitrogen reduces ozone impacts and high ozone reduces the growth enhancing effect of high nitrogen (**Figure 4.2**). In wheat ozone reduces protein and starch yield (Broberg et al., 2015). Little is known about the interactive impacts of ozone and nitrogen on plant diversity.

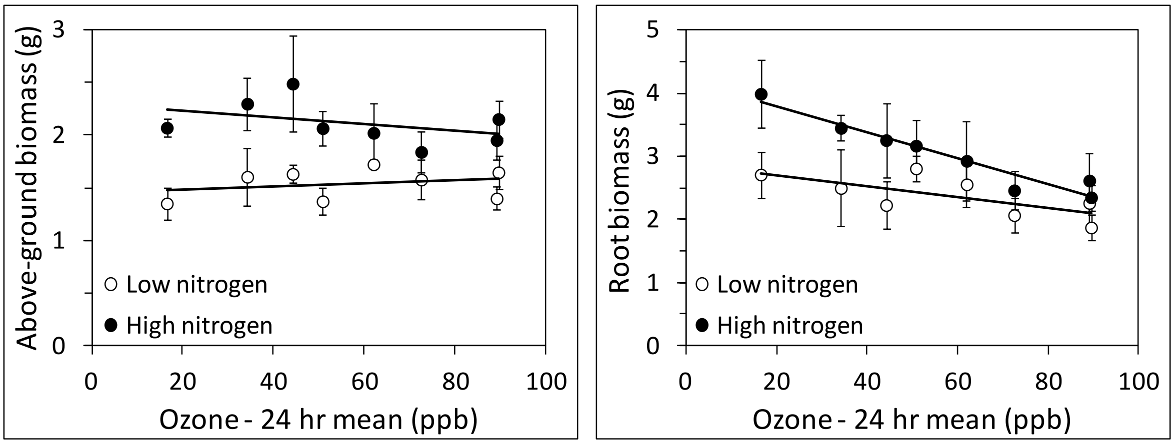


Figure 4.2 Modifying effect of nitrogen on the response to ozone of above-ground (left) and root biomass (right) of *Dactylis glomerata*. At high ozone, the stimulating effect of nitrogen on biomass is reduced (above-ground) or has even disappeared (roots); modified from Wyness et al. (2011).

Ozone might have an indirect effect on nitrogen cycling in the soil, either via a reduction of carbon allocation to roots (i.e. reduced root biomass and potentially root exudates) or via an effect on litter quality. Ozone induces early leaf die-back in sensitive plant species, resulting in early leaf fall. In the grass species *Dactylis glomerata*, nitrogen does not modify the early leaf die-back caused by ozone (Wyness et al., 2011). The nitrogen content in leaves exposed to elevated ozone is often higher due to a reduction in nitrogen re-sorption in leaves prior to leaf fall (Lindroth et al., 2001; Uddling et al., 2006). This is likely to affect nitrogen cycling in the soil where leaf litter is decomposed.

4.4 Key messages

The key message can be summarised as follows:

- Interactions between air pollution and climate change are complex and responses of vegetation to a combination of changing environmental drivers cannot simply be extrapolated from responses to single drivers.
- Experimental and modelling evidence indicates that interactions between elevated carbon dioxide and ozone, mean temperature and extremes, water, and nitrogen are nonlinear, variable, and difficult to predict.
- Combined impacts of ozone and nitrogen on vegetation appear to be additive to a certain level of ozone exposure, but ozone effects dominate at high ozone exposure.
- Two types of interactions need to be considered differently: i) responses to gradual long-term changes in background ozone, reactive nitrogen and climate; ii) responses to extreme pollution and climate events, likely to become more frequent in the coming decades. Although heat, drought and ozone stress frequently occur together, surprisingly few studies have considered their combined impacts nor the effect of additional nitrogen under these conditions.

5 Other ICP Vegetation activities in 2014/15 and common WGE workplan items

In this chapter, progress made with other ICP Vegetation and common WGE workplan items for 2014 is summarised.

5.1 Supporting evidence for ozone impacts on vegetation

To supplement the data included in the report ‘Evidence of widespread ozone damage to vegetation in Europe (1990-2006)’ (Hayes et al., 2007), further field-based evidence on injury caused by ambient ozone concentrations was collated from the year 2007 onwards. Three different approaches were applied to collate and map further field-based evidence:

1) Data from ICP Vegetation biomonitoring experiments with clover (Mills et al., 2011) and bean (Harmens et al., 2012) were reviewed, including new data received for 2014, when ozone leaf injury for bean was reported for Pisa (Italy) and Beijing (China).
2) Data were collated during the test phase in 2014 using a smart-phone App for recording of incidences of ozone-induces leaf injury (http://icpvegetation.ceh.ac.uk/record/index; Harmens et al., 2014).
3) A literature review was conducted on reported incidences of leaf injury, including those reported in non-filtered (ambient ozone) compared to filtered (reduced ozone concentration) air from open-top chamber studies.

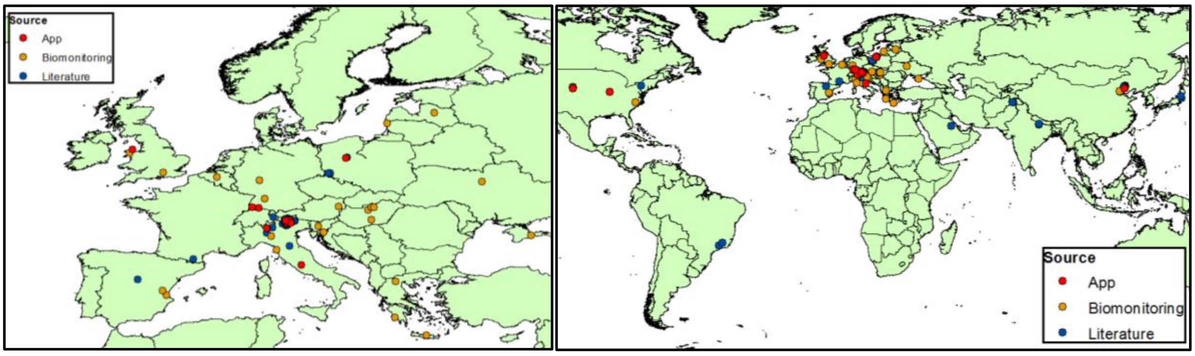


Figure 5.1 Locations in Europe (left) and the world (right) where ozone-induced leaf damage was reported between 2007 and 2015. Red dots - ozone injury recorded in 2014/15 using the smart-phone App; orange dots – ozone injury reported at ICP Vegetation biomonitoring sites; blue dots – ozone injury reported in the literature.

Figure 5.1 shows a preliminary map of where in Europe and across the globe leaf injury due to ozone has been reported since 2007. During the 2014 pilot season, records of ozone injury were recorded via the App in the USA, Northern Italy, Switzerland, the UK and Beijing (China). In the USA, leaf injury was reported at so-called ozone gardens containing ozone-sensitive species, including bean. The concept of ozone gardens was developed by NASA and the gardens were established according to a standard protocol to monitor ambient ozone-induced leaf injury (http://science-edu.larc.nasa.gov/ozonegarden/pdf/_Bio-guide-final-3_15_11.pdf). After discussions at the 28th Task Force meeting, it was decided to develop a protocol for recording the presence/absence of injury using the App or the online recording form (http://icpvegetation.ceh.ac.uk/manuals/documents/ICP%20Vegetation_Ozone%20Gardens%20and%20App%20protocol_FINAL.pdf). To gain full understanding of the extent of the ozone problem, we are as much interested in the lack of occurrence of ozone injury symptoms as the occurrence of ozone injury symptoms. We therefore would like to record injury presence or absence in a systematic manner. Hence, we encourage the establishment of ozone gardens in Europe. In addition to recording the presence/absence of ozone injury on know species plant in an ozone garden, recording could also be conducted in a systematic manner on plants growing in a park, garden or field that is visited regularly or on a more ad-hoc basis when potential symptoms might be present on vegetation after an ozone episode.

5.2 Recent developments of ozone critical levels for vegetation

Background documentation on the further development and application of risk assessment methods for ozone were submitted to the 28th Task Force meeting of the ICP Vegetation. Based on a recent review of data on the impacts of ozone on tomato yield and quality in Spain and Italy (González-Fernández et al., 2014), the Task Force decided to adopt the new flux-effect relationships for tomato for inclusions in Chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention (LRTAP Convention, 2015). The flux-based critical levels for tomato yield and quality were set at 3 and 4 mmol m^{-2} respectively (POD_6), corresponding to a yield and quality reduction of 5%. In addition, the concentration-based critical level for yield of horticultural crops (represented by tomato) was adjusted from an AOT40 of 6 ppm h to an AOT40 of 8 ppm h.

Although other new developments in methodology, flux-effect relationships and associated critical levels were presented at the 28th Task Force meeting, the Task Force recommended to further assess the methodologies used at an Expert Group meeting in November, 2015 in readiness for proposing revised critical levels at the next ozone critical level workshop, scheduled for November 2016 in Spain. Other new developments presented at the Task Force meeting included:

- Based on ozone exposure experiments for Mediterranean pastures, flux models were developed for legumes and grasses and concentration-based and flux-based critical levels were proposed for above-ground biomass, seed biomass and feed values.
- Progress with new stomatal ozone flux-effect relationships and critical levels for forests trees were presented as described in Büker et al. (2015). In addition, a methodology was developed for estimating the net annual increment (NAI) of biomass laid down each year by tree species from experimental data where often only the final biomass of trees have been reported at the end of experimental exposure to ozone. This methodology was then used to develop flux-effect relationships for the NAI.
- Italian colleagues showed that the flux-based approach is more appropriated than the concentration-based approach for explaining ozone-induced visible leaf injury in forests. They proposed that no flux-threshold should be used and that the inclusion of soil water content in ozone flux-based simulations is crucial.

Five working groups were establish at the 28th Task Force meeting on the following topics to prepare for the next ozone critical level workshop, scheduled for the autumn of 2016 in Spain: methodology, evidence, crops, trees and grasslands.

An expert workshop on 'Epidemiological Analysis of Air Pollution Effects on Vegetation' was held in Basel (Switzerland) from 16-17 September, 2014. The workshop was organized by the Institute of Applied Plant Biology in cooperation with the Swiss Federal Office for the Environment. The workshop was attended by experts from Italy, Sweden, Switzerland and the United Kingdom, all involved in applying epidemiological methodologies to analyse air pollution effects, especially ozone effects on the growth of mature trees, by considering simultaneously modifying factors such as climate and nitrogen. The workshop explored how further epidemiological studies could contribute to validating ozone critical levels for vegetation (e.g. Braun et al., 2014) and the methodology on how to separate climate and direct ozone effects was discussed. Presentations and discussions focussed on statistical methods, mapping, predictors (e.g. various drought predictors) and datasets. It was concluded that epidemiological approaches can disentangle and quantify the contributions of different predictor variables to an overall effect e.g. growth. Although epidemiological analysis cannot prove causality, it can provide strong indications for causality. Plausibility and causality of exposure-response relationships have to be established with experimental studies. Further details can be downloaded from http://icpvegetation.ceh.ac.uk/events/workshop.html. A follow-on workshop is scheduled for November 2015, to be hosted by Sweden, back to back with preparations for the next critical level workshop in the autumn of 2016 in Spain.

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

Following the establishment of the new Moss survey Coordination Centre in the Russian Federation (Harmens et al., 2014), the moss survey for 2015 – 2016 has now started. Fourty and fifteen countries have confirmed to determine heavy metal and nitrogen concentrations in mosses respectively, including the EECCA countries Azerbaijan, Belarus, Georgia, Kazakhstan, the Republic of Moldova, the Russian Federation, Uzbekistan, the South-Eastern European countries Albania, Bulgaria, Croatia, Greece, the Former Yugoslavic Republic of Macedonia, Romania, Serbia, and other Asian countries such as China, India, Mongolia, Republic of Korea, Thailand and Vietnam. Three countries (Norway, Republic of Ireland and Switzerland) will also determine POPs concentrations in mosses. Some further countries are still awaiting funding approval, hence additional countries might collect mosses in 2016.

5.4 Contributions to WGE common workplan items

5.4.1 Enhanced involvement of countries in Eastern and South-Eastern Europe, the Caucasus and Central Asia, and cooperation with activities outside the Convention

In 2014, ICP Vegetation transferred the coordination of the moss survey (i.e., monitoring heavy metals, nitrogen and persistent organic pollutant (POP) concentrations in mosses every five years) to the Russian Federation. The new Moss Survey Coordination Centre, at the Institute for Joint Nuclear Research in Dubna, has particularly stimulated the participation of countries in Eastern Europe, the Caucasus and Central Asia and selected other Asian countries in the next survey in 2015/16 (see Section 5.3). Furthermore, the ICP Vegetation stimulates knowledge transfer through the publication of reports and brochures in Russian and will host the 29th ICP Vegetation Task Force meeting in 2016 in the Russian Federation.

5.4.2 Cooperation with programmes and activities outside the region

ICP Vegetation will participate in the first Asian Air Pollution workshop, 31 October – 1 November 2015, Tokyo, Japan, and will lead discussions on air pollution impacts on crops. Members of the Chinese Academy of Sciences contribute to the ozone biomonitoring programme of the ICP Vegetation and selected Asian countries (see Section 5.3) take part in the moss survey in 2015 – 2016. Some Asian (e.g. China, India, Japan, Pakistan) and African countries (e.g. Egypt, South-Africa) do also attend ICP Vegetation Task Force meetings from time to time.

ICP Vegetation also contributes to the 'Tropospheric Ozone Assessment Report (TOAR): Global metrics for climate change, human health and crop/ecosystem research', including leading the chapter on vegetation. This is a new activity of the International Global Atmospheric Chemistry Project (IGAC; http://www.igacproject.org). TOAR's mission is to provide the research community with an up-to-date global assessment of tropospheric ozone's distribution and trends from the surface to the tropopause. TOAR has two primary goals: i) Produce the first tropospheric ozone assessment report based on the peer-reviewed literature and new analyses conducted by TOAR; ii) At hundreds of measurement sites around the world (urban and non-urban), generate freely accessible ozone metrics for global-scale impact studies of ozone on human health and crop/ecosystem productivity, and generate diagnostics relevant to climate forcing by tropospheric ozone. The ICP Vegetation leads a the TOAR Fluxnet network of sites with calculated ozone stomatal flux data (Phytotoxic Ozone Dose, POD_Y; LRTAP Convention, 2015; Mills et al., 2011b).

5.4.3 WGE trends report and Assessment Report of the LRTAP Convention

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 i) past and future predicted trends in ozone pollution and its impacts on vegetation, as described in more detail in Chapter 3, and on ii) trends in heavy metal concentrations in mosses between 1990 and 2010 (Harmens et al., 2015b).

The ICP Vegetation also contributed text and figures to key messages, related to ozone pollution and its impacts on vegetation, for the Assessment Report, prepared by the LRTAP Convention for presentation at the 8th Environment for Europe Ministerial Conference, Batumi, Georgia, June 2016. Globally (based on AOT40), ozone is estimated to account for yield losses of between 3% and 12% for the major staple crops (Van Dingenen et al., 2009). More recent ozone flux-based estimates show wheat yield losses to be 4.56 billion Euro in the EMEP region, equating to a mean yield loss of 13%, with the highest economic losses found in important wheat growing areas in western and central Europe (**Figure 5.2; Table 5.1**).

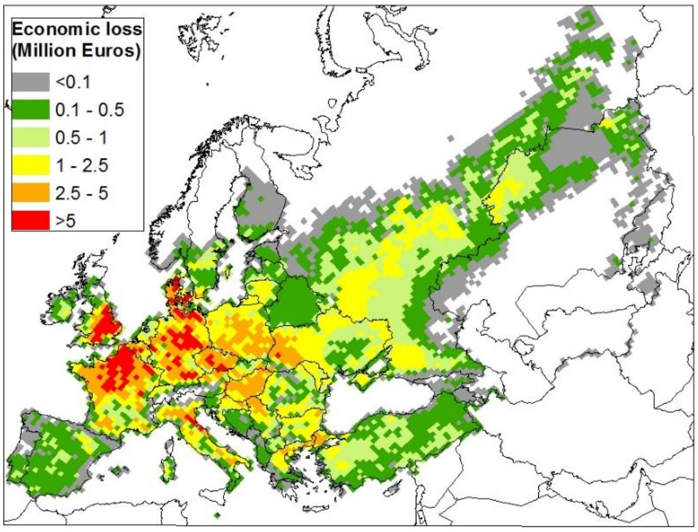


Figure 5.2 Wheat yield losses (in million Euro per 50 x 50 km grid square), using rain-fed wheat production values for 2000 (GAEZ; http://www.fao.org/nr/gaez/en/), and calculated average ozone flux for crops (EMEP; http://emep.int/mscw/index_mscw.html) and average wheat prices for the period 2007 to 2011.

Table 5.1 Wheat yield losses (in million Euro per 50 x 50 km grid square), using rain-fed wheat production values for 2000 (GAEZ; http://www.fao.org/nr/gaez/en/), and calculated average ozone flux for crops (EMEP; http://emep.int/mscw/index_mscw.html) and average wheat prices for the period 2007 to 2011.

	EMEP region	EU28+CH+NO[1]	SEE[2]	EECCA[3]
Total production loss (million t)	23.7	15.4	2.8	6.7
Economic loss (billion Euros)	4.6	3.0	0.5	1.3
Percentage yield loss	13.2	14.6	10.7	12.0

[1] CH = Switzerland, NO = Norway.
[2] South-Eastern Europe (SEE): Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Macedonia, Montenegro, Romania, Serbia, Slovenia and Turkey.
[3] Eastern Europe, Caucasus and Central Asia (EECCA): Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

6 Medium-term workplan (2016-2018)

The medium-term workplan for 2016 – 2018 was adopted at the 28th Task Force Meeting of the ICP Vegetation. Workplan items for 2016 - 2017 were submitted for adoption at the first joint session of EMEP and WGE in September 2015 and for final approval 34th session of the Executive Body of the LRTAP Convention in December 2015.

Ongoing annual activities:

- Report on supporting evidence for ozone impacts on vegetation;
- Report on progress with the moss survey 2015/2016;
- Contributions to common workplan items of the WGE.

New activities:

2016:

- Update report on field-based evidence of ozone impacts on vegetation;
- Report on ozone impacts on biodiversity;
- Ozone critical levels workshop (Autumn, Spain).

2017:

- Report on revised ozone risk assessments methods;
- Revision of Chapter 3 of the Modelling and Mapping Manual.

2018:

- Report of the European moss survey 2015/16.

References

Ainsworth, E.A., Yendrek, C.R., Sitch, S., Collins, W.J., Emberson, L.D. (2012). The effects of tropospheric ozone on net primary productivity and implications for climate change. Annual Review of Plant Biology 63: 637-661.

Bernacchi, C.J., Leakey, A.D., Kimball, B.A., Ort, D.R. (2011). Growth of soybean at future tropospheric ozone concentrations decreases canopy evapotranspiration and soil water depletion. Environmental Pollution 159: 1464-1472.

Bobbink, R., Hettelingh, J.-P. (Eds.) (2011). Review and revision of empirical critical loads and dose-response relationships. Proceeding of an expert workshop, Noordwijkerhout, 23 – 25 June 2010, the Netherlands.

Braun, S., Schindler, C., Rihm, B. (2014). Growth losses in Swiss forests caused by ozone: Epidemiological data analysis of stem increment of Fagus sylvatica L. and Picea abies Karst. Environmental Pollution 192: 129-138.

Büker, P., Feng, Z., Uddling, J., Briolat, A., Alonso, R., Braun, S., Elvira, S., Gerosa, G., Karlsson, P.E., Le Thiec, D., Marzuoli, R., Mills, G., Oksanen, E., Wieser, G., Wilkinson, M., Emberson, L.D. (2015). New flux based dose–response relationships for ozone for European forest tree species. Environmental Pollution 206: 163-174.

Cooper, O.R., Parrish, D.D., Ziemke, J., Balashov, N.V., Cupeiro, M., Galbally, I.E., Gilge, S., Horowitz, L., Jensen, N.R., Lamarque, J.F., Naik, V., Oltmans, S.J., Schwab, J., Shindell, D.T., Thompson, A.M., Thouret, V., Wang, Y., Zbinden, R.M. (2014). Global distribution and trends of tropospheric ozone: An observation-based review. Elementa Science of the Anthrosphere 2, 000029.

Dise, N., Ashmore, M., Belyazid, S. et al . (2011). Nitrogen as a threat to European terrestrial biodiversity. In: The European Nitrogen Assessment , ed. M. A. Sutton , C. M. Howard , J. W. Erisman et al. Cambridge University Press .

Fagnano, M., Maggio, A., Fumagalli, I. (2009). Crops' responses to ozone in Mediterranean environments. Environmental Pollution 157: 1438-1444.

Fuhrer, J. (2009). Ozone risk for crops and pastures in present and future climates. Naturwissenschaften 96: 173-194.

González-Fernández, I., Calvo, E., Gerosa, G., Bermejo, V., Marzuoli, R., Calatayud, V., Alonso, R. (2014). Setting ozone critical levels for protecting horticultural Mediterranean crops: Case study of tomato. Environmental Pollution 185, 178-187.

Gray, S.B., Dermody, O., DeLucia, E.H. (2010). Spectral reflectance from a soybean canopy exposed to elevated CO_2 and O_3. Journal of Experimental Botany 61: 4413-4422.

Harmens, H., Foan, L., Simon, V., Mills, G. (2013a). Terrestrial mosses as biomonitors of atmospheric POPs pollution: A review. Environmental Pollution 173: 245-254.

Harmens, H., Mills, G., Hayes, F., Norris, D. and the participants of the ICP Vegetation. (2012). Air pollution and vegetation. ICP Vegetation annual report 2011/2012. ISBN: 978-1-906698-35-5.

Harmens, H., Mills, G., Hayes, F., Norris, D. and the participants of the ICP Vegetation. (2013b). Air pollution and vegetation. ICP Vegetation annual report 2012/2013. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. ISBN: 978-1-906698-43-0.

Harmens, H., Mills, G., Hayes, F., Norris, D.A., Sharps, K. (2015a). Twenty eight years of ICP Vegetation: an overview of its activities. Annali di Botanica 5: 47 – 59.

Harmens, H., Mills, G., Hayes, F., Sharps, K., Frontasyeva, M., and the participants of the ICP Vegetation. (2014). Air pollution and vegetation. ICP Vegetation annual report 2013/2014. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. ISBN: 978-1-906698-53-9.

Harmens, H., Norris, D.A., Sharps, K., Mills, G., Alber, R., Aleksiayenak, Y., Blum, O., Cucu-Man, S.-M., Dam, M., De Temmerman, L., Ene, A., Fernández, J.A., Martinez-Abaigar, J., Frontasyeva, M., Godzik, B., Jeran, Z., Lazo, P., Leblond, S., Liiv, S., Magnússon, S.H., Maňkovská, B., Pihl Karlsson, G., Piispanen, J., Poikolainen, J., Santamaria, J.M., Skudnik, M., Spiric, Z., Stafilov, T., Steinnes, E., Stihi, C., Suchara, I., Thöni, L., Todoran, R., Yurukova, L., Zechmeister, H.G. (2015b). Heavy metal and nitrogen concentrations in mosses are declining across Europe whilst some "hotspots" remain in 2010. Environmental Pollution 200: 93-104.

Hayes, F., Wagg, S., Mills, G., Wilkinson, S., Davies, W. (2012). Ozone effects in a drier climate: implications for stomatal fluxes of reduced stomatal sensitivity to soil drying in a typical grassland species. Global Change Biology 18: 948-959.

IPCC (2013). Climate Change 2013. The Physical Science Basis. www.ipcc.ch

IPCC (2014). Climate Change, 2014. Impacts, Adaptation and Vulnerability. www.ipcc.ch.

Kasurinen, A., Biasi, C., Holopainen, T., Rousi, M., Maenpaa, M., Oksanen, E. (2012). Interactive effects of elevated ozone and temperature on carbon allocation of silver birch (*Betula pendula*) genotypes in an open-air field exposure. Tree Physiology 32: 737-751.

Kobayakawa, H., Imai, K. (2011). Effects of the interaction between ozone and carbon dioxide on gas exchange, photosystem II and antioxidants in rice leaves. Photosynthetica 49: 227-238.

LRTAP Convention (2015). Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. Chapter 3: Mapping critical levels for vegetation. http://icpvegetation.ceh.ac.uk

McLaughlin, S.B., Nosal, M., Wullschleger, S.D., Sun, G. (2007a). Interactive effects of ozone and climate on tree growth and water use in a southern Appalachian forest in the USA. New Phytologist 174: 109-124.

McLaughlin, S.B., Wullschleger, S.D., Sun, G., Nosal, M. (2007b). Interactive effects of ozone and climate on water use, soil moisture content and streamflow in a southern Appalachian forest in the USA. New Phytologist 174: 125-136.

Mills, G., Harmens, H., Wagg, S., Sharps, K., Hayes, F., Fowlwer, D., Sutton, M., Davies, B. (in press). Ozone impacts on vegetation in a nitrogen enriched and changing climate. Environmental Pollution.

Mills, G., Hayes, F., Simpson, D., Emberson, L., Norris, D., Harmens, H., Büker, P. (2011a). Evidence of widespread effects of ozone on crops and (semi-)natural vegetation in Europe (1990 - 2006) in relation to AOT40 - and flux-based risk maps. Global Change Biology 17: 592-613.

Mills, G., Hayes, F., Wilkinson, S., Davies, W.J. (2009). Chronic exposure to increasing background ozone impairs stomatal functioning in grassland species. Global Change Biology 15: 1522-1533.

Mills, G., Pleijel, H., Braun, S., Büker, P., Bermejo, V., Calvo, E., Danielsson, H., Emberson, L., Fernandez, I.G., Grunhage, L., Harmens, H., Hayes, F., Karlsson, P.E., Simpson, D. (2011b). New stomatal flux-based critical levels for ozone effects on vegetation. Atmospheric Environment 45: 5064-5068.

Mills, G., Wagg, S., Harmens, H. (2013). Ozone Pollution: Impacts on ecosystem services and biodiversity. Centre for Ecology & Hydrology. ISBN No. 978-1-906698-39-3.

Parrish, D.D., Law, K.S., Staehelin, J., Derwent, R., Cooper, O.R., Tanimoto, H., Volz-Thomas, A., Gilge, S., Scheel, H.-E., Steinbacher, M., Chan, E. (2012). Long-term changes in lower tropospheric baseline ozoneconcentrations at northern mid-latitudesAtmospheric Chemistry and Physics 12: 11485–11504

Richard L. Lindrotha,*, Brian J. Koppera, William F.J. Parsonsa,b, James G. Bockheimb, David F. Karnoskyc, George R. Hendreyd, Kurt S. Pregitzerc, J.G. Isebrandse, Jaak Soberc (2001). Consequences of elevated carbon dioxide and ozone for foliar chemical composition and dynamics in trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*). *Environmental Pollution 115: 395-404*

Royal Society (2008). Ground-level ozone in the 21st century: future trends, impacts and policy implications. Science Policy Report 15/08. ISBN 978-0-85403-713-1.

Schröder, W., Holy, M., Pesch, R., Harmens, H., Fagerli, H., et al. (2010a). First Europe-wide correlation analysis identifying factors best explaining the total nitrogen concentration in mosses. Atmospheric Environment 44: 3485-3491.

Schröder, W., Holy, M., Pesch, R., Harmens, H., Ilyin, I., et al. (2010b). Are cadmium, lead and mercury concentrations in mosses across Europe primarily determined by atmospheric deposition of these metals? Journal of Soils and Sediments 10: 1572-1584.

Simpson, D., Arneth, A., Mills, G., Solberg, S., Uddling, J. (2014). Ozone – the persistent menace: interactions with the N cycle and climate change. Current Opinion in Environmental Sustainability 9-10: 9-19.

Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., Van Grinsven, H., Grizetti, B. (2011). The European nitrogen assessment: sources, effects and policy perspectives. Cambridge University Press, UK.

Tørseth, K., Aas, W., Breivik, K., Fjæraa, A.M., Fiebig, M., Hjellbrekke, A.G., Lund Myhre, C., Solberg, S., Yttri, K.E. (2012). Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972–2009. Atmospheric Chemistry and Physics 12: 5447–5481.

Uddling J., Karlsson P.E., Glorvigen A., Selldén G. (2006) Ozone impairs autumnal resorption of nitrogen from birch (*Betula pendula*) leaves, causing an increase in whole-tree nitrogen loss through litter fall. Tree Physiology 26:113-120.

Uddling, J., Hogg, A.J., Teclaw, R.M., Carroll, M.A., Ellsworth, D.S. (2010). Stomatal uptake of O_3 in aspen and aspen-birch forests under free-air CO_2 and O_3 enrichment. Environmental Pollution 158: 2023-2031.

Vandermeiren K., Harmens H., Mills G., De Temmerman L. (2009). Impact of ground-level ozone on crop production in a changing climate. In: Climate Change and Crops (Ed. S.N. Singh), Springer-Verlag, Berlin, pp. 213 – 243. ISBN: 978-3-540-88245-9

Wagg, S., Mills, G., Hayes, F., Wilkinson, S., Cooper, D., Davies, W.J. (2012). Reduced soil water availability did not protect two competing grassland species from the negative effects of increasing background ozone. Environmental Pollution 165: 91-99.

Wild, O, Fiore, AM, Shindell, DT, Doherty, RM, Collins, WJ, Dentener, FJ, Schultz, MG, Gong, S, MacKenzie, IA, Zeng, G, Hess, P, Duncan, BN, Bergmann, DJ, Szopa, S, Jonson, JE, Keating, TJ & Zuber, A (2012). Modelling future changes in surface ozone: a parameterized approach *Atmospheric Chemistry and Physics* 12: 2037-2054.

Wilkinson, S., Davies, W.J. (2009). Ozone suppresses soil drying- and abscisic acid (ABA)-induced stomatal closure via an ethylene-dependent mechanism. Plant Cell and Environment 32: 949-959.

Wilkinson, S., Davies, W.J. (2010). Drought, ozone, ABA and ethylene: new insights from cell to plant to community. Plant Cell and Environment 33: 510-525.

Wittig, V.E., Ainsworth, E.A., Long, S.P. (2007). To what extent do current and projected increases in surface ozone affect photosynthesis and stomatal conductance of trees? A meta-analytic review of the last 3 decades of experiments. Plant Cell and Environment 30: 1150-1162.

Wittig, V.E., Ainsworth, E.A., Naidu, S.L., Karnosky, D.F., Long, S.P. (2009). Quantifying the impact of current and future tropospheric ozone on tree biomass, growth, physiology and biochemistry: a quantitative meta-analysis. Global Change Biology 1: 396-424.

Wyness, K., Mills, G., Jones, L., Barnes, J.D., Jones, D.L. (2011). Enhanced nitrogen deposition exacerbates the negative effect of increasing background ozone in Dactylis glomerata, but not Ranunculus acris. Environmental Pollution 159: 2493-2499.

Yendrek, C.R., Leisner, C.P., Ainsworth, E.A. (2013). Chronic ozone exacerbates the reduction in photosynthesis and acceleration of senescence caused by limited N availability in *Nicotiana sylvestris*. Global Change Biology 19: 3155-3166.

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.

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Albania					
Pranvera Lazo	University of Tirana Faculty of Natural Sciences Tirana	pranveralazo@gmail.com		✓	
Flora Qarri	University of Vlora, Department of Chemistry, Vlora	flora.qarri@gmail.com		✓	
Austria					
Gerhard Soja	AIT Austrian Institute of Technology GmbH Konrad Lorenz-Str. 24 3430 Tulln	gerhard.soja@ait.ac.at	✓		
Harald Zechmeister	Dept. of Conservation Biology, Vegetation- and Landscape Ecology, University of Vienna Rennweg 14, 1030 Vienna	Harald.Zechmeister@univie.ac.at		✓	✓
Azerbaijan					
Metanet Mehrabova	Institute of Radiation Problems of the Azerbaijan Academy of Sciences, 9 B.Vahabzade str., Baku, AZ1143	mehrabova@mail.ru		✓	
Zakir Ibrahimov	Azerbaijan State Agrarian University, Gjanga	za.ibrahim-ecoforest.az@rambler.ru		✓	
Elshad Mammadov	Azerbaijan Technological University, Ganja, 62 avenue Ataturk	elshad1952@mail.ru		✓	
Belarus					
Yulia Aleksiayenak	International Sakharov Environmental University, Minsk	beataa@gmail.com		✓	
Belgium					
Karine Vandermeiren Nadia Waegeneers Ann Ruttens	Veterinary and Agrochemical Research Centre CODA-CERVA Leuvensesteenweg 17 B-3080 Tervuren	karine.vandermeiren@coda-cerva.be nadia.waegeneers@coda-cerva.be ann.ruttens@coda-cerva.be	✓	✓	✓
Bulgaria					
Gana Minkova Gecheva Savka Miranova	University of Plovdiv 24, Tzar Assen Str. 4000 Plovdiv	ggecheva@mail.bg savmar@pu.acad.bg		✓	
Croatia					
Zdravko Spiric	Oikon Ltd. Institute for Applied Ecology Trg senjskih uskoka 1-2 10020 Zagreb	zspiric@oikon.hr	✓	✓	✓
Grahek Zeiko Ivana Milanovic	Institute of Radioecology, Bijenička Cesta 54 10 002 Zagreb	zgrahek@irb.hr		✓	
Czech Republic					
Ivan Suchara Julie Sucharová	Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Kvetnove namesti 391,CZ-252 43 Pruhonice	suchara@vukoz.cz sucharova@vukoz.cz		✓	✓
Petr Jančík Irena Pavlikova	Technical University of Ostrava, Institute of Environmental Technology, 17 listopadu 15/2172, 708 33 Ostrava	petr.jancik@vsb.cz irena.pavlikova@vsb.cz		✓	

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Denmark (Faroe Islands)					
Maria Dam Katrin Hoydal	Environment Agency Traðagøta 38 FO-165 Argir	mariad@us.fo katrinh@us.fo		✓	
Estonia					
Siiri Liiv	Tallinn Botanic Garden Kloostrimetsa tee 52 11913 Tallinn	siiri.liiv@botaanikaaed.ee		✓	✓
Finland					
Eero Kubin Juha Piispanen Jarmo Poikolainen	Finnish Forest Research Institute Oulu, PO Box 413, 90014 University of Oulu	Eero.Kubin@metla.fi Juha.Piispanen@metla.fi Jarmo.Poikolainen@metla.fi		✓	✓
Sirkku Manninen	Department of Environmental Sciences, P.O. Box 56 00014 University of Helsinki	sirkku.manninen@helsinki.fi	✓		
Former Yugoslav Republic of Macedonia					
Trajce Stafilov Lambe Barandovski	Institute of Chemistry, Faculty of Science, SS. Cyril and Methodius University Arhimedova 5, Skopje	trajcest@pmf.ukim.mk lambe@pmf.ukim.mk		✓	
France					
Jean-François Castell Olivier Bethenod	UMR EGC/AgroParisTech-INRA 78850 Thiverval-Grignon	castell@grignon.inra.fr bethenod@grignon.inra.fr	✓		
Laurence Galsomiès	ADEME, Deptartment Air 27 rue Louis Vicat 75737 Paris Cedex 15	laurence.galsomies@ademe.fr		✓	✓
Jean-Paul Garrec Didier le Thiec	INRA-Nancy F-54280 Champenoux	garrec@nancy.inra.fr lethiec@nancy.inra.fr	✓		
Sebastien Leblond	Muséum National d'Histoire Naturelle France, CP 39 57 rue Cuvier, 75005 Paris	sleblond@mnhn.fr		✓	✓
Pierre Louis Sicard	ACRI-ST, 260 route du Pin Montard, BP 234 06904 Sophia-Antipolis Cedex	pierre.sicard@acri-st.fr	✓		
Matthieu Baggard Anne Repellin	Université Paris Est Créteil	matthieu.bagard@u-pec.fr repellin@u-pec.fr	✓		
Georgia					
Shamil Shetekauri Omar Chaligava	I. Javakhishvili Tbilisi State University, Chavchavadze ave 3, Tbilisi 0129	shetekauri@yahoo.com omar.chaligava@ens.tsu.edu.ge		✓	
Elena Kirkesali Tamaz Kalabegeshvili	I. Javakhishvili State University, E. Andronikashvili Institute of Physics, 6 Tamarashvili str., Tbilisi 0177	kirkesali@gmail.com		✓	
Germany					
Jürgen Bender	Institute of Biodiversity Johann Heinrich von Thünen-Institute (vTI), Bundesallee 50 D-38116 Braunschweig	juergen.bender@vti.bund.de	✓		
Ludger Grünhage	Institute for Plant Ecology Justus-Liebig-University, Heinrich-Buff-Ring 26-32 D-35392 Giessen	Ludger.Gruenhage@bot2.bio.uni-giessen.de	✓		
Winfried Schröder Michaela Meyer Stefan Nickel	Hochschule Vechta, Institute für Umweltwissenschaften Postfach 1553 D-49364 Vechta	wschroeder@iuw.uni-vechta.de michaela.meyer@uni-vechta.de stefan.nickel@uni-vechta.de		✓	✓
Willy Werner Stephanie Boltersdorf	University Trier, Department of Geobotany, Behringstr. 5 54286 Trier	werner@uni-trier.de Stefanie.Boltersdorf@gmx.de	✓		✓

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Stefan Fränzle	Internationales Hochschulinstitut Zittau, Markt 23 D Zittau, Saxony	fraenzle@ihi-zittau.de		✓	
Greece					
Dimitris Velissariou	Technological Educational Institute of Kalamata Antikalamos 241 00, Kalamata	d.velissariou@teikal.gr	✓		
Costas Saitanis	Agricultural University of Athens Laboratory of Ecology & Environmental Sciences Iera Odos 75 Botanikos 11855, Athens	saitanis@aua.gr	✓	✓	
Hungary					
Agnes Balint	Victor Babeș University *of* Medicine and Pharmacy Budapest	balintagnes@gmail.com		✓	
Kovac Tibor	Institute of Radiochemistry and Radioecology, University of Pannonia	kt@almos.uni-pannon.hu		✓	
Iceland					
Sigurður Magnússon	Icelandic Institute of Natural History, Hlemmur 3, 125 Reykjavík	sigurdur@ni.is		✓	
Ireland					
Julian Aherne	Trent University, 1600 West Bank Drive, Peterborough, ON K9J 7B8, Canada	jaherne@trentu.ca		✓ P	✓
David Dott	Environmental Protection Agency, McCumiskey House Richview Clonskeagh Road Dublin 14, Dublin	d.dodd@epa.ie		✓ P	✓
Italy					
Stanislaw Cieslik Ivano Fumagalli	European Commission, Joint Research Centre - Institute for Environment and Sustainability Via E. Fermi, 2749, I-21027 Ispra (VA)	stanislaw.cieslik@yahoo.it ivan.fumagalli@jrc.it	✓		
Gianfranco Rana Marcello Mastrorilli	CRA-Research Unit for Agriculture in Dry Environments via C. Ulpiani, 5 70125 Bari	gianfranco.rana@entecra.it marcello.mastrorilli@entecra.it	✓		
Fausto Manes Marcello Vitale Elisabetta Salvatori Lina Fusaro	Dipartimento di Biologia Vegetale, Università di Roma “La Sapienza”, Piazzale Aldo Moro 5, 00185 Rome	fausto.manes@uniroma1.it marcello.vitale@uniromal.it elisabetta.salvatori@uniroma1.it lina.fusaro@uniroma1.it	✓		
Renate Alber	Environmental Agency of Bolzano, Biological Laboratory Via Sottomonte 2 I-39055 Laives	Renate.Alber@provinz.bz.it		✓	✓
Alessandra de Marco	ENEA, CR Casaccia Via Anguillarese 301 00060 S. Maria di Galeria, Rome	alessandra.demarco@enea.it	✓		
Giacomo Gerosa Angelo Finco Riccardo Marzuoli	Universita’ Cattolica del S.c. di Brescia, Via Pertini 11 24035 Curno	giacomo.gerosa@unicatt.it angelo.finco@unicatt.it riccardo.marzuoli@unicatt.it	✓		
Silvano Fares	Agricultural Research Council Research Centre for the Soil-Plant System Via della Navicella 2-4 00184 Rome, Italy	silvano.fares@entecra.it	✓		

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Elena Paoletti	Istituto Protezione Piante Cons. Nazionale delle Ricerche Via Madonna del Piano 10 50019 Sesto Fiorentino (Firenze)	e.paoletti@ipp.cnr.it	✓		
Cristina Nali Lorenzo Cotrozzi	University of Pisa Via del Borghetto 80 56124 Pisa	cristina.nali@unipi.it lorenzo.cotrozzi@for.unipi.it	✓		
Kazakhstan					
Victor Gluschenko Vladimir Solodukhin	Center of Complex Ecological Research, Unstitute of Nuclear Physics, str. Ibragimov, 1, Almaty	vik@inp.kz Solodukhin@inp.kz		✓	
Nurija Omarova	L.N.Gumilyov Eurasian National University, Astana	Omarova_nm@enu.kz		✓	
Anatoly Chursin	Research Environmental Centre, S.Amandjolov University, str. Amurskaya, 18/1, Ust'-Kamenogorsk	eko.chursin@mail.ru		✓	
Kosovo (United Nations administered territory, Security Council resolution 1244 (1999))					
Albert Maxhuni	University of Pristina	contact: pranveralazo@gmail.com		✓	
Latvia					
Marina Frolova	Latvian Environment, Geology and Meteorology Agency Maskavas Str. 165 Riga, LV 1019	marina.frolova@lvgma.gov.lv		✓	✓
Inara Melece	University of Latvia	inaramelece@inbox.lv	✓		
Lithuania					
Kestutis Kvietkus	Institute of Physics Savanoriu Ave 231 LT-02300 Vilnius	kvietkus@ktl.mii.lt		✓	
Norway					
Eiliv Steinnes Torunn Berg	Norwegian University of Science and Technology NO-7491 Trondheim	eiliv.steinnes@chem.ntnu.no torunn.berg@chem.ntnu.no		✓ P	
Hilde Uggerud Martin Schlabach	Norwegian Institute for Air Research (NILU), 2027 Kjeller	hilde.thelle.uggerud@nilu.no martin.schlabach@nilu.no		✓	
Poland					
Barbara Godzik, Grażyna Szarek-Łukaszewska, Pawel Kapusta	W. Szafer Institute of Botany Polish Academy of Sciences Lubicz Str. 46, 31-512 Krakow	b.godzik@botany.pl p.kapusta@botany.pl	✓	✓	✓
Klaudine Borowiak Justyna Urbaniak	August Cieszkowski Agricultural University of Poznan, ul. Piatkowska 94C, 61-691 Poznan	klaudine@up.poznan.pl justurb@up.poznan.pl	✓		
Grgegorz Kosior	Departament of Ecology, Biogeochemistry and Environment Protection, Faculty of Biological Science, University of Wroclaw, plac Uniwersytecki 1, 50-137 Wrocław	grzegorz.kosior@uni.wroc.pl		✓	
Romania					
Ion V. Popescu Claudia Stihi Cristiana Radulescu	Valahia University of Targoviste Faculty of Sciences and Arts, 2 Carol I street 130024 Targoviste	lucaciuadriana@yahoo.com stihi@valahia.ro radulescucristiana@yahoo.com		✓	
Simona-Maria Cucu-Man	Alexandru Ioan Cuza University of Iasi	sman@uaic.ro		✓	
Antoaneta Ene	Dunarea de Jos University of Galati	aene@ugal.ro		✓	
Radu Todoran	Tech. University of Cluj-Napoca North Center, Baia Mare	Todoran_radu@yahoo.com		✓	

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Russian Federation					
Marina Frontasyeva (Head Moss Survey Coordination Centre) Konstantin Vergel (& 10 more teams in Central Russia)	Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research str. Joliot Curie, 6 141980 Dubna Moscow Region	marina@nf.jinr.ru verkn@mail.ru		✓	
Aleksandr Alekseev	St. Petersburg State Forest Technical University	a_s_alekseev@mail.ru		✓	
Anatoly Dunaev	Chemical Technological University of Ivanovo	kannikkiy@inbox.ru		✓	
Nina Lebedeva	Liceum # 1, Volgorechensk, Kostromskaya	ninal1964@mail.ru		✓	
Inna V. Vikhrova	Municipal Educational Centre, Tikhvin, Leningradskaya	vix-inna@yandex.ru		✓	
Vladislav Zlobin	South Urals	zvv1210@yandex.ru		✓	
Natalia Goltsova	Biological Research Institute St.Petersburg State University St Peterhof 198504 St. Petersburg	Natalia.Goltsova@pobox.spbu.ru		✓	
Yuliya Koroleva	Immanuel Kant Baltic Federal University, Kaliningrad	yu.koroleff@yandex.ru		✓	
Serbia					
Miodrag Krmar Dragan Radnovich	Faculty of Science University Novi Sad Trg Dositeja Obradovica 4 21000 Novi Sad	miodrag.krmar@dbe.uns.ac.rs draganradnovic@gmail.com		✓	
Mira Anicic	Institute pf Physics, Pregrevica 118, 11080 Belgrade	mira.anicic@ipb.ac.rs		✓	
Slovakia					
Blanka Maňkovská	Institute of Landscape Ecology Slovak Academy of Science, Štefánikova str. 3, 814 99 Bratislava, Slovakia	bmankov@stonline.sk		✓	✓
Slovenia					
Franc Batic Boris Turk Klemen Eler	University of Ljubljana, Biotechnical Faculty, Agronomy Department, Jamnikarjeva 101, 1000 Ljubljana	franc.batic@bf.uni-lj.si boris.turk@bf.uni-lj.si klemen.eler@bf.uni-lj.si	✓		
Zvonka Jeran	Jožef Stefan Institute Dep. of Environmental Sciences, Jamova 39, 1000 Ljubljana	zvonka.jeran@ijs.si		✓	✓
Mitja Skudnik	Slovenian Forestry Institute Vecna pot 2, 1000 Ljubljana	mitja.skudnik@gozdis.si		✓	✓
Spain					
J. Angel Fernández Escribano Alejo Carballeira Ocaña J.R. Aboal	Ecologia Facultad De Biologia Univ. Santiago de Compostela 15782 Santiago de Compostela	bfjafe@usc.es bfalejo@usc.es bfjaboal@usc.es		✓	✓
Vicent Calatayud	Fundacion CEAM, Parque Tech. C/Charles R Darwin 14 Paterna, E-46980 Valencia	vicent@ceam.es	✓		
Victoria Bermejo, Rocio Alonso, Ignacio González Fernández, Héctor Calvete Sogo	Departamento de Impacto Ambiental de la Energía CIEMAT, Ed 70 Avda. Complutense 22 28040 Madrid	victoria.bermejo@ciemat.es rocio.alonso@ciemat.es ignacio.gonzalez@ciemat.es hector.calvete@ciemat.es	✓		✓
Jesús Santamaria Sheila Izquieta	Universidad de Navarra Facultad de Ciencias Irunlarrea No 1 31008 Pamplona I, Navarra	chusmi@unav.es sizquieta@alumni.unav.es	✓	✓	✓

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Javier Martínez Abaigar Encarnación Núñez Olivera Rafael Tomás Las Heras	CCT, Madre de Dios 51 Universidad de La Rioja 26006 Logroño, La Rioja	javier.martinez@unirioja.es		✓	✓
J. María Infante Olarte	Gobierno de La Rioja Dirección General de Calidad Ambiental y Agua Prado Viejo, 62 bis 26071 Logroño, La Rioja	dg.calidadambiental@larioja.org		✓	✓
Sweden					
Per-Erik Karlsson Gunilla Pihl Karlsson Helena Danielsson	IVL Swedish Environmental Research Institute PO Box 5302, SE-400 14 Göteborg	pererik.karlsson@ivl.se gunilla.pihl.karlsson@ivl.se helena.danielsson@ivl.se	✓	✓	
Håkan Pleijel	Environmental Science and Conservation, Göteborg University PO Box 464, S-40530 Göteborg	hakan.pleijel@dpes.gu.se	✓		
Switzerland					
Jürg Fuhrer Seraina Bassin Matthias Volk	Agroscope Research Station ART, Reckenholzstr. 191 CH-8046 Zurich	juerg.fuhrer@art.admin.ch seraina.bassin@art.admin.ch matthias.volk@art.admin.ch	✓		✓
Sabine Braun	Institute for Applied Plant Biology Sangrubenstrasse 25 CH-4124 Schönenbuch	sabine.braun@iap.ch	✓		
Lotti Thöni	FUB-Research Group for Environmental Monitoring Alte Jonastrasse 83 CH-8640 Rapperswil-Jona	lotti.thoeni@fub-ag.ch		✓ P	✓
Marcus Schaub	Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111, 8903 Birmensdorf	marcus.schaub@wsl.ch	✓		
Turkey					
Mahmut Coskun	Canakkale Onsekiz Mart University, Health Service Vocational College 17100 Çanakkale	coskunafm@yahoo.com		✓	✓
Ukraine					
Oleg Blum	National Botanical Garden Academy of Science of Ukraine Timiryazevska St. 1, 01014 Kyiv	blum@nbg.kiev.ua	✓	✓	
United Kingdom					
Harry Harmens (Chairman), **Gina Mills** (Head of Programme Centre), Felicity Hayes, Katrina Sharps, Laurence Jones, David Norris, Jane Hall, David Cooper	Centre for Ecology and Hydrology Environment Centre Wales Deiniol Road Bangor Gwynedd LL57 2UW	hh@ceh.ac.uk, gmi@ceh.ac.uk fhay@ceh.ac.uk, katshar@ceh.ac.uk lj@ceh.ac.uk, danor@ceh.ac.uk jrha@ceh.ac.uk cooper@ceh.ac.uk	✓	✓	✓
Lisa Emberson Patrick Büker Alan Briolat Steve Cinderby Howard Cambridge	Stockholm Environment Institute, Biology Department University of York Heslington, York YO10 5DD	l.emberson@york.ac.uk patrick.bueker@york.ac.uk alan.briolat@sei-international.org sc9@york.ac.uk hmc4@york.ac.uk	✓		
William Purvis	Freelance, Natural History Museum, London	owpurvis@aol.com		✓	

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Bill Davies	Lancaster Environment Centre Lancaster University Lancaster LA1 4YQ	w.davies@lancaster.ac.uk	✓		
USA					
Kent Burkey	US Department of Agriculture ARS, N.C. State University 3908 Inwood Road Raleigh, North Carolina 27603	Kent.Burkey@ars.usda.gov	✓		
Not a Party of the LRTAP Convention:					
China					
Zhaozhong Feng	Research Center for Eco-Environmental Sciences (RCEES), Chinese Academy of Sciences, 18 Shuangqing Road Haidian District, Beijing 100085	zhzhfeng201@hotmail.com	✓		
Cuba					
Jesús Ramirez	Institute of Meteorology, Cuba	jramirez_cu@yahoo.com	✓		
Egypt					
Samia Madkour	University of Alexandria, Damanhour	samiamadkour@yahoo.co.uk	✓		
India					
Dinesh Saxena	Department of Botany Bareilly College, Bareilly	dinesh.botany@gmail.com		✓	
Fakir-Mohammad Dastagir Attar	Department of Physics, University of Pune, Pune-411007	fmdattar@gmail.com		✓	
Japan					
Yoshihisa Kohno	Central Research Institute of Electric Power Industry (CRIEPI	kohno@criepi.denken.or.jp	✓		
Moldova					
Tudor Lupaşcu Inga Zinicovscaia	Institute of Chemistry of the Avademy of Sciences of Moldova	lupascut@gmail.com		✓	
Mongolia					
Nyamsuren Baljinnyam	Central Geological Laboratory, Ulaanbaatar, Mongolia Trade Union str., Songinokhaikhan District, Ulaanbaaroar 211137	nn_baljka@yahoo.com		✓	
Pakistan					
Sheikh Saeed Ahmad	Environ. Sciences Department Fatima Jinnah Women University The Mall, Rawalpindi	drsaeed@fjwu.edu.pk	✓		
Muhammad Andrees	Government College University Faisalabad	madrees@gcuf.edu.pk	✓		
South Africa					
Gert Krüger Jacques Berner	School of Environmental Sciences, North-West University, Potchefstroom, 2520	Gert.Kruger@nwu.ac.za jacques.berner@nwu.ac.za	✓		
Richard Newman Ntombizikhona Ndlovu	Stellenbosch University Private Bag X1 7602 Matieland	rtnewman@sun.ac.za nbndlovu@tlabs.ac.za		✓	
South Korea					
Jong Park	Postech University, Pohang	jmpark@postech.ac.kr		✓	
Thailand					
Tripob Bhongsuwan	Prince of Songkla University, 15 Karnjanawanitch road, Khohong, Hat Yai, Songkhla 90112	Tripop.b@psu.ac.th		✓	

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Uzbekistan					
Aleksander Kist	Institute of Nuclear Physics AS RUz, Ulugbek, Tashkent 100214	a.kist@inp.uz		✓	
Vietnam					
Le Hong Khiem	10 Dao Tan, Ba Dinh, Ha Noi	lhkhiem@iop.vast.ac.vn		✓	
My Trinh	Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research	trinh@nf.jinr.ru		✓	

Air Pollution and Vegetation
ICP Vegetation
Annual Report 2014/2015

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:

- Further supporting evidence for ozone impacts on vegetation and recent developments in setting ozone critical levels.
- Changing oozne profiles in Europe: implications for vegetation.
- Climate change and reactive nitrogen as modifiers of vegetation responses to ozone pollution.
- Progress with the heavy metals and nitrogen in mosses survey 2015/2016.

<u>*For further information please contact:*</u>

Harry Harmens
Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor
Gwynedd LL57 2UW
United Kingdom
Tel: +44 (0) 1248 374500
Fax: +44 (0) 1248 362133
Email: hh@ceh.ac.uk

ISBN: 978-1-906698-55-3