Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Air Pollution and Vegetation

ICP Vegetation

Annual Report 2012/2013

wge

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

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Air Pollution and Vegetation

ICP Vegetation[1] Annual Report 2012/2013

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

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We thank Gunilla Phil-Karlsson, Helena Danielsson, Per Erik Karlsson (IVL Swedish Environmental Research Institute) and Hakan Pleijel (Departmenet of Biological Sciences, University of Gothenburg) for their support in organising the 26th ICP Vegetation Task Force meeting, with financial support from the Swedish Environmental Protection Agency.

Finallly, we wish to thank other bodies within the LRTAP Convention for their collaboration and all of the ICP Vegetation participants for their continued contributions to the programme, particularly those who have contributed to the reports on 'Ozone pollution: impacts on ecosystem services and biodiversity' and 'Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe' (see the reports for further details).

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Executive Summary

Background

The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) was established in 1987. It is led by the UK and has its Programme Coordination Centre at the Centre for Ecology and Hydrology (CEH) in Bangor. It is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. Today, the ICP Vegetation comprises an enthusiastic group of over 200 scientists from 35 countries in the UNECE region with outreach activities to other regions such as Asia, Central America and Africa. An overview of contributions to the WGE workplan and other research activities in the year 2012/13 is provided in this report.

26th ICP Vegetation Task Force meeting

The Programme Coordination Centre organised the 26th ICP Vegetation Task Force meeting, 28 – 30 January 2013 in Halmstad, Sweden, in collaboration with the local hosts IVL Swedish Environmental Research Institute and the Department of Biological Sciences, University of Gothenburg, with financial support from the Swedish Environmental Protection Agency. The meeting was attended by 63 experts from 21 countries, including 17 Parties to the LTRAP Convention and guests from Brazil, China, Japan and Pakistan. The Task Force discussed the progress with the workplan items for 2013 and updated the medium-term workplan for 2014 - 2016 for the air pollutants ozone, heavy metals, nutrient nitrogen and persistent organic pollutants (POPs). The Task Force acknowledged and encouraged further fruitful collaborations with other Convention bodies, particularly EMEP, and encouraged further development of activities in Eastern Europe, Caucasus and Central Asia (EECCA) and outreach activities to other regions in the world. A book of abstracts, details of presentations and the minutes of the 26th Task Force meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk).

Reporting to the Convention and other publications

In addition to this report, the ICP Vegetation Programme Coordination Centre has provided a technical report on 'Effects of air pollution on natural vegetation and crops' (ECE/EB.AIR/WG.1/2012/8), on 'Heavy metals and nitrogen in mosses: spatial patterns in 2010/11 and long-term temporal trends (1990-2010) in Europe' (ECE/EB.AIR/WG.1/2012/13), on 'Benefits of air pollution control for biodiversity and ecosystem services' (ECE/EB.AIR/WG.1/2012/14) in collaboration with other ICPs and contributed to the joint report (ECE/EB.AIR/WG.1/2013/3) of the WGE. It also contributed to the draft 'Guidance Document VII on heatlh and environmental improvements using new knowledge, methods and data' for the revised Gothenburg Protocol. The ICP Vegetation published glossy reports on 'Ozone pollution: impacts on ecosystem services and biodiversity' and 'Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe'. A leaflet was produced of the moss survey report and is also available in Russian. The ICP Vegetation led the publication of the WGE report on 'Benefits of air pollution control for biodiversity and ecosystem services' and the associated booklet for policy makers. The booklet was made available for the review process of the EU Thematic Strategy on Air Pollution. Three scientific papers have been published or in are press and the ICP Vegetation web site was updated regularly with new information.

Ozone pollution: impacts on ecosystem services and biodiversity

Earth's ecosystems provide an array of services upon which humans depend for food, fresh water, disease management, climate regulation, aesthetic enjoyment and spiritual fulfilment. Such 'Ecosystem Services' are currently grouped according to the benefits they provide to humans, distinguishing between provisioning, regulating, supporting and cultural services. Although humans are an integral part of ecosystems, the increased global population along with increased standards of living and other socio-political, economic, technological and societal changes, mean that our interventions can have profound negative effects on the quality of the services provided by ecosystems. The role of biodiversity in ecosystem services is often rather unclearly stated – biodiversity is sometimes considered as a separate service and yet is implicit in most ecosystem services.

The ICP Vegetation reviewed the current available knowledge on the impacts of ozone on:

- **Supporting services**, such as primary productivity and carbon cycling, nutrient cycling, stomatal functioning and associated water cycling;
- **Provisioning services,** such as crop and timber production;
- **Regulating services,** such as climate regulation (including global warming), air quality, methane emissions, water cycling, pollination and insect signalling;
- **Cultural services,** such as enjoyment of the natural environment. Little is known about the impact on ozone on cultural services.

In the review the potential impacts of ozone on (plant)biodiversity and species balances was also discussed and a case study on the impacts on (plant)biodiversity in the Mediterranean was presented.

Finally, approaches for valuing ozone impacts on ecosystem services were discussed and recommendations for future research were presented to enable a more comprehensive quantitative assessment of ozone impacts on ecosystem services, including an economic valuation (currently not possible for most services), in the future.

European moss survey 2010/2011 on heavy metals, nitrogen and persistent organic pollutants (POPs)

The first European moss survey was conducted in 1990/1991 for heavy metals, and has since then been repeated every five years with the most recent survey being conducted in 2010/2011. In 2005/2006, nitrogen concentrations in mosses were determined for the first time at the European scale and in 2010/2011 six countries conducted a pilot study for POPs, particularly polycyclic aromatic hydrocarbons (PAHs). Elemental or compound concentrations in mosses provide a complementary measure of elemental or compound deposition from the atmosphere to terrestrial systems, it is easier and cheaper than conventional precipitation analysis, and therefore enables a high sampling density to be achieved. This method allows the identification of areas at risk of high atmospheric deposition fluxes of heavy metals, nitrogen and POPs and for monitoring changes with time.

Heavy metals

The decline in emission and subsequent deposition of heavy metals across Europe in recent decades has resulted in a decrease in the heavy metal concentration in mosses since 1990, with the decline continuing since the previous moss survey in 2005. In general, the decline in metal concentrations in mosses was higher between 1990 and 1995 (or 2000) than in later years. The metal concentration in mosses has declined the most for lead, due to the abolishment of leaded petrol, and the least for copper. For cadmium, lead and mercury, the temporal trends in concentrations in mosses are in good agreement with trends reported for atmospheric deposition modelled by EMEP. Between 1990 and 2010, the average cadmium and lead concentration in mosses has declined by 51% and 77% respectively, whereas the average mercury concentration in mosses has declined by 23% since 1995. For other metals, the decline in concentrations in mosses also follows the decline in reported emissions since 1990, however, temporal trends can be different for different geographical scales, with no changes or even increases being observed at the (sub)country scale.

As in previous surveys, in 2010/2011 the lowest concentrations of heavy metals in mosses were generally found in northern Europe, although higher concentrations were reported near local sources. Low to intermediate heavy metal concentrations in mosses were generally observed in western and central Europe. The highest concentrations were often found in (south-)eastern Europe, with localised lower concentrations being observed.

Nitrogen

The spatial pattern of the nitrogen concentration in mosses in 2010/11 was similar to the spatial pattern in 2005/2006, with lower values being observed for Finland than the rest of Europe. Generally, high concentrations of nitrogen were found in western and central Europe. The small decline (5%) in the average median nitrogen concentration in mosses is in agreement with the 7% decline reported by EMEP for modelled total nitrogen deposition in the EU27 since 2005. Previous analysis of the relationship between nitrogen concentration in mosses and EMEP-modelled total nitrogen deposition showed considerable scatter with saturation occurring at a total nitrogen deposition rate of ca. 15 kg N ha^{-1} y^{-1}. However, in some countries a linear relationship has been observed between the total nitrogen concentration in mosses and measured bulk nitrogen deposition at the site level. Although these relationships needs to be analysed further using the 2010/2011 moss and modelled or measured deposition data, we do expect these relationships to be similar as in 2005/2006.

Persistent organic pollutants (POPs)

The PAH concentration in mosses was determined at selected sites in France, Norway, Poland, Slovenia, Spain (Navarra) and Switzerland. Norway also determined the concentration of other selected POPs. In Norway, the observed geographical distribution of the concentration of selected POPs in mosses indicated that the concentration in mosses reflect the atmospheric deposition patterns well. For most of the POPs the concentration in mosses decreased with northern latitude (similar to heavy metals), indicating that long-range atmospheric transport contributes to the higher concentrations observed in southern Norway. In Switzerland, high concentrations of PAHs were found in mosses sampled in the region of Basel (chemical industry), whilst low concentrations were observed in the western part of the central plateau where the population density is relatively low. There was a good correlation between the summed PAHs concentration in mosses and the concentration in PM_{10} and soil. The total PAHs concentrations in mosses was significantly lower in Navarra, a rural area in Spain, than in Île-de-France (metropolitan area of Paris) and in Switzerland. The total PAHs concentration in mosses was the lowest in Norway and Slovenia and the highest in Poland.

Supporting evidence for ozone impacts on vegetation

Since 2008, participants of the ICP Vegetation have been conducting biomonitoring campaigns using ozone-sensitive (S156) and ozone-resistant (R123) genotypes of *Phaseolus vulgaris* (Bush bean, French Dwarf bean). In 2012, experiments were conducted with ozone-sensitive and ozone-resistant bean at nine sites across Europe and one in the USA. The data from the 2008 – 2012 biomonitoring and ozone exposure experiments were combined into a database for dose-response analysis. Over 3000 leaf pore conductance measurements have been made and used to generate an ozone flux model for bean. However, so far no clear dose-response relationship has been found between ozone parameters and the yield biomass ratio between the ozone-sensitive and resistant variety. Overall, the bean biomonitoring system does seem to provide a good indication of the occurrence of ozone concentrations that are high enough to visibly damage plants. As such it is very valuable for use in countries just joining the ICP Vegetation programme as proof or otherwise that ozone levels are causing damage. However, we are concerned that differences between the sensitive and resistant varieties are not strong enough for continued application of bean as a biomonitor for yield effects.

Contributions to the WGE common workplan

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

- Further implementation of Guidelines on Reporting of Air Pollution Effects. The ICP Vegetation continued to monitor and model deposition to and impacts on vegetation for the air pollutants ozone, heavy metals, nitrogen and POPs.
- Ideas and actions to enhance the involvement of EECCA/SEE countries in the Eastern Europe, the Caucasus and Central Asia and on cooperation with activities outside the Air Convention. Whereas EECCA/SEE countries primarily participate in the European moss survey, countries outside the UNECE regions primarily participate in research on the impacts of ozone on vegetation. The ICP Vegetation is aiming to establish links with ozone experts in

more EECCA/SEE countries in the near future. In the coming year, the ICP Vegetation will report on the deposition of air pollutants to and the impacts on vegetation specifically in EECCA/SEE countries and South-East Asia. Outreach activities outside the UNECE region will be primarily focussed on ozone impact on vegetation, acknowledging the fact that ozone is a hemispheric pollutant.

- Ecosystem services and biodiversity report and booklet. The ICP Vegetation Programme Coordination Centre led the production of the WGE report on ‘Benefits of air pollution control for biodiversity and ecosystem services’ and the associated booklet.

Future activities of the ICP Vegetation

The medium-term workplan for 2014 – 2016 was adopted at the 26th Task Force Meeting of the ICP Vegetation (Halmstad, Sweden, 28 - 30 January 2013). Ongoing annual activities include reporting on i) the supporting evidence for ozone impacts on vegetation, and ii) preparations and progress with the moss survey 2015/2016.

New activities include:

2014:

- Report on air pollution deposition to, and impacts on vegetation, in EECCA/SEE countries and South-East Asia;
- Update of chapter 3 of the Modelling and Mapping Manual (inclusion of a new annex describing further technical developments).

2015:

- Report on the implications of rising background ozone for vegetation in Europe;
- Report on the interacting effects of co-occurring pollutants (ozone and nitrogen) and climatic stresses on vegetation.

Tentatively for 2016:

- Report on current and future ozone impacts in the Mediterranean basin, including implications for food security.

The ICP Vegetation will continue to contribute to the common workplan items of the WGE and the annual joint report(s) of the all bodies under the WGE, with clear policy-relevant messages and recommendations to WGE and the Executive Body.

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 and Hydrology (CEH) in Bangor. The ICP Vegetation is one of seven ICPs and Task Forces that report to the Working Group on Effects (WGE) of the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) on the effects of atmospheric pollutants on different components of the environment (e.g. forests, fresh waters, materials) and health in Europe and North-America. The Convention provides the essential framework for controlling and reducing damage to human health and the environment caused by transboundary air pollution. So far, eight international Protocols have been drafted by the Convention to deal with major long-range air pollution problems. 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. Consequences of ozone impacts on vegetation for ecosystem services and biodiversity were reviewed extensively in the last year.

The ICP Vegetation comprises an enthusiastic group of scientists from 42 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: not a Party to the LRTAP Convention.

Albania	France	Romania
Austria	FYR of Macedonia	Russian Federation
Belarus	Germany	Serbia
Belgium	Greece	Slovakia
Brazil	Iceland	Slovenia
Bulgaria	*India*	*South Africa*
China	Italy	Spain
Croatia	*Japan*	Sweden
Cuba	Latvia	Switzerland
Czech Republic	Lithuania	Turkey
Denmark	*Niger*	Ukraine
Egypt	Norway	United Kingdom
Estonia	*Pakistan*	USA
Finland	Poland	

[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 (e.g. Mills et al., 2011).

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 recently 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 Programme Coordination Centre 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, and the latest survey was conducted in 2010/11. Mosses were collected at thousands of sites across Europe and their heavy metal (since 1990; Harmens et al., 2010, 2013b), nitrogen (since 2005; Harmens et al., 2011, 2013b) and POPs concentration (pilot study in 2010; see Harmens et al., 2013a) were determined.

Ectohydric mosses do not have a vascular root system or a waxy cuticle layer and therefore obtain most trace elements (e.g. heavy metals), nutrients (e.g. nitrogen) and organic pollutants directly from atmospheric (wet and dry) deposition. The analysis of their concentrations in mosses provides a time-integrated measure of atmospheric deposition to terrestrial systems (Harmens et al., 2012a; Holy et al., 2010; Schröder et al., 2010a,b). It is easier and cheaper than conventional precipitation analysis as it avoids the need for deploying large numbers of deposition collectors with an associated long-term programme of routine sample collection and analysis. Hence, the moss survey provides a complementary method to assess spatial patterns and temporal trends of atmospheric deposition to vegetation (based on monitoring in the field) and to identify areas at risk from air pollution at a high spatial resolution.

1.3 ICP Vegetation workplan for 2013

The Executive Body of the LRTAP Convention agreed on a workplan for 2012 and 2013 at its 29th meeting in December 2011 (see ECE/EB.AIR/109/Add.2). For a detailed report on the items for 2012 we refer to Harmens et al. (2012b). Here we will report on the workplan items for the ICP Vegetation for 2013:

- Supporting evidence for ozone impacts on vegetation;
- Impacts of ozone on ecosystem services and biodiversity;
- Progress with European heavy metals and nitrogen in mosses survey 2010/11 (final report);
- Outcome of the pilot study of mosses as biomonitors of POPs.

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;
- Ideas and actions to enhance the involvement of EECCA/SEE countries in the Eastern Europe, the Caucasus and Central Asia and on cooperation with activities outside the Air Convention;
- Impacts of air pollution on biodiversity and ecosystem services.

In Chapter 3, the impacts of ozone on ecosystem services and biodiversity are described and Chapter 4 provides the results of the European mosses survey 2010/11 for heavy metals, nitrogen and the pilot study on POPs. Progress with the WGE common workplan items and other ICP Vegetation workplan items are discussed in Chapter 5. Finally, ongoing and new activities of the ICP Vegetation are described for 2014 – 2016.

2 Coordination activities

2.1 Annual Task Force meeting

The Programme Coordination Centre organised the 26th ICP Vegetation Task Force meeting, 28 – 30 January 2013 in Halmstad, Sweden, in collaboration with the local hosts IVL Swedish Environmental Research Institute and the Department of Biological Sciences, University of Gothenburg, with financial support from the Swedish Environmental Protection Agency. The meeting was attended by 63 experts from 21 countries, including 17 Parties to the LTRAP Convention and guests from Brazil, China, Japan and Pakistan. A book of abstracts, details of presentations and the minutes of the 26th Task Force meeting are available from the ICP Vegetation web site (http://icpvegetation.ceh.ac.uk).

The Task Force discussed the progress with the workplan items for 2013 (see Section 1.3) and updated the medium-term workplan for 2014 - 2016 (see Chapter 6) for the air pollutants ozone, heavy metals, nutrient nitrogen and POPs. The following decisions and recommendations were made by the Task Force:

- The Task Force approved the publication of the report on ozone impacts on ecosystem services and biodiversity by March 2013, as outlined by the Programme Coordination Centre.
- The Task Force decided to continue the ozone biomonitoring activities with snap bean and recommended to extend this activity in EECCA/SEE and other regions outside the UNECE area.
- The Task Force agreed on a method for developing ozone flux-response curves of the relative growth rate of trees from existing biomass flux-response relationships for applications in the future.
- The Task Force recommended to further stimulate activities in EECCA/SEE and promote outreach activities beyond the UNECE region (e.g. Asia, North Africa) as specified in the medium-term workplan (see Chapter 6).
- The Task Force approved the draft data and maps of the 2010/11 European moss survey, agreed on the outline of the report and decided to publish the final glossy report in March 2013 with minor amendments to the data and maps.
- The outcome of the pilot study on POPs for the 2010/11 European moss survey should be presented in the annual ICP Vegetation report for 2012/13.
- The Task Force recommended to continue the European moss survey on heavy metals, nitrogen and POPs, with the next one scheduled for 2015/16 (pending the outcome of the review of the ICPs). The Programme Coordination Centre should explore opportunities to enhance participation in EECCA/SEE and Asian countries and a more pronounced role of one of these countries in the coordination of future moss surveys.

The Task Force acknowledged and encouraged further fruitful collaborations with the bodies and centres under the Working Group on Effect and the Steering Body to EMEP, particularly EMEP/MSC-West, EMEP/MSC-East, the Task Force on Integrated Assessment Modelling and the Task Force on the Hemispheric Transport of Air Pollution, and bodies under the Working Group of Strategies and Review, in particular the Task Force on Reactive Nitrogen. For example, collaborations are currently taking place in the European Framework 7 project 'ECLAIRE (Effect of Climate Change on Air Pollution and Response Strategies for European Ecosystems, http://www.eclaire-fp7.eu), which includes contributions from several ICP Vegetation participants and other LRTAP Convention bodies. In addition, the Task Force encouraged further development of outreach activities to other regions in the world (see Section 5.1.2).

Over the years, participation in the ICP Vegetation and attendance of the Task Force meetings has been rising (**Figure 2.1**). Originally named as the ICP Crops, focussing on the impacts of ozone on crops, the programme started to incorporate impacts on (semi-)natural vegetation later on and therefore gained its current name in the mid-1990s. In 2000/1, the ICP Vegetation took over the coordination of the European moss survey on heavy metals from the Nordic Council of Ministers and therefore widened its scope and further enhanced particitation in its activities.

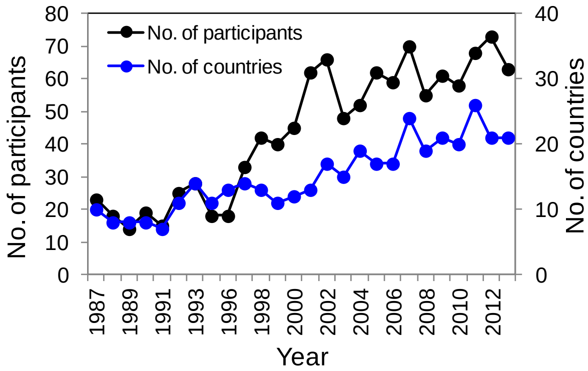

Figure 2.1 Participation in ICP Vegetation Task Force meetings since 1987.

The **27th Task Force meeting** will be held in France in or near Paris from 28 - 30 January 2014. The meeting will start with a one-day workshop to discuss further developments with critical levels of ozone for vegetation.

2.2 Reports to the LRTAP Convention

The ICP Vegetation Programme Coordination Centre has reported progress with the 2013 workplan items in the following documents for the 32nd session of the WGE, 12 - 13 September 2013, Geneva, Switzerland (http://www.unece.org/index.php?id=32278):

- ECE/EB.AIR/WG.1/2013/3: Joint report of the ICPs, Task Force on Health and Joint Expert Group on Dynamic Modelling;
- ECE/EB.AIR/WG.1/2013/8: Effects of air pollution on natural vegetation and crops;
- ECE/EB.AIR/WG.1/2013/13: Heavy metals and nitrogen in mosses: spatial patterns in 2010/11 and long-term temporal trends (1990-2010) in Europe (see Chapter 4);
- ECE/EB.AIR/WG.1/2013/14: Benefits of air pollution control for biodiversity and ecosystem services (see Chapter 3).

The ICP Vegetation also coordinated the publication of the full report on 'Benefits of air pollution control for biodiversity and ecosystems services' (informal document 1) and associated booklet (informal document 7), updated the leaflet of the European moss survey (informal document 3, also available in Russian), and contributed to the Guidance Document on health and environmental improvements using new knowledge, methods and data (informal document 4).

In addition, the Programme Coordination Centre for the ICP Vegetation has:

- published a glossy report on 'Ozone pollution: Impacts on ecosystem services and biodiveristy' (Mills et al., 2013), see Chapter 3;
- published a glossy report on 'Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe'; (Harmens et al., 2013b), see Chapter 4;
- published the current annual report on line.

2.3 Scientific papers

The following papers have been published or are in press:

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

Schröder, W., Pesch, R., Hertel, A., Schönrock, S., Harmens, H., Mills, G., Ilyin, I (2013). Landscape-specific correlation between atmospheric depositions of Cd, Hg and Pb and their concentrations in mosses across Europe. Atmospheric Pollution Research 4: 267-274.

Schröder, W., Pesch, R., Schönrock, S., Harmens, H., Mills, G., Fagerli, H. (2013). Mapping correlations between nitrogen concentrations in atmospheric deposition and mosses for natural landscapes in Europe. Ecological Indicators (in press).

3 Ozone pollution: impacts on ecosystem services and biodiversity

In this chapter we provide an extended executive summary of the full report, for further details and references we refer to the full report (Mills et al., 2013).

3.1 Ecosystem services – an introduction

Earth's ecosystems provide an array of services upon which humans depend for food, fresh water, disease management, climate regulation, aesthetic enjoyment and spiritual fulfilment (Millennium Ecosystem Assessment, 2005). Such 'Ecosystem Services' (more recently referred to as 'Natural Capital') are currently grouped according to the benefits they provide to humans, distinguishing between provisioning, regulating, supporting and cultural services (**Figure 3.1**). Although humans are an integral part of ecosystems, the increased global population along with increased standards of living and other socio-political, economic, technological and societal changes, mean that our interventions can have profound negative effects on the quality of the services provided by ecosystems. Because ecosystems are complex systems comprising animal, plant and microorganism communities together with the non-living environment (Millennium Ecosystem Assessment, 2005), these systems are inherently dynamic whilst maintaining some intrinsic resilience to natural disturbances. However, human-driven changes (principally over the last 50 years) have become increasingly worrying, and thus many of the World's ecosystems and the services they provide are now degraded, or vulnerable to degradation. In this report we provide an assessment of the state of current knowledge on the effects of ozone pollution on ecosystem services including consideration of effects on biodiversity.

Global toxification (including air pollution) is one of the "savage sextet" (Aguirre, 2009) of direct drivers of ecosystem degradation, with the others being over-exploitation of species, introduction of novel exotic species, land use changes (principally habitat destruction, fragmentation and degradation), pathogen pollution and global warming (Mantyka-Pringle et al., 2012). Indirect drivers of ecosystem change are associated with demographic, economic, socio-political and cultural or religious changes, and advancements in science and technology. Stressed or degraded ecosystems do not have the resilience or re-bound capacity of pristine/unstressed systems (Rapport and Maffi, 2009). Furthermore, there is often a substantial time-lag between a change in a driver and the time taken to realize the full consequences of that change in any given system. Even more worrying is that once a threshold is crossed, a system may alter to a distinctly changed and sometimes irreversible new state. Careful management of our ecosystems and the benefits and services we derive from them are therefore vital for future prosperity and general human well-being.

Human influence extends into even the remotest landscapes and more often than not has a pervasive influence on the ecosystems they support, frequently irreversibly changing biodiversity. Whilst extinction rates of species are now estimated to be 1,000 times greater than historical background levels (Millennium Ecosystem Assessment, 2005; Mantyka-Pringle et al., 2012), recent studies have identified linkages between changes in biodiversity and ecosystem functioning, highlighting the importance of adopting a multi-sectoral approach to policy and decision making (e.g. Maestre et al., 2012; Mace et al., 2012). Such an approach fully evaluates changes in ecosystem services and their impacts on humans and examines the supply and condition of each ecosystem service, as well as the interactions among them. Society needs to make difficult decisions regarding its use of biological resources and environmental valuation techniques provide useful evidence to support polices by quantifying both the monetary and non-monetary value associated with the protection of resources. To support this drive, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) was established in April 2012 by 90 governments and acts as a global mechanism for gathering, analyzing and synthesizing information to advise decision-making on biodiversity and ecosystem services (Redford et al., 2012).

As shown in **Figure 3.1**, ecosystem services can be classified into provisioning, regulating, supporting and cultural services. When considering impacts of one driver of change (in this case ozone pollution), it immediately becomes clear that impacts on one service are linked to several and sometimes all of the other services. For example, negative effects of ozone on root growth would impact on provisioning services (crop foods, wood production, water uptake), regulating services (climate and water regulation), supporting services (nutrient cycling, primary production, water cycling) and possibly cultural services by impacting on the aesthetics of a natural ecosystem. Because of such complexities and the growing desire to add an economic value to ecosystem services, the final ecosystem services that provide goods of value to humans can be considered to be linked by "stocks and flows" to the underpinning ecological processes (Mace et al., 2012). For example, ozone reduces primary productivity in forest trees (i.e. impacts on an ecological process), influencing the final ecosystem service of tree production which can be used for a variety of goods such as timber, fuel, carbon sequestration and recreational value. The final value of these goods is dependent on the inputs to the forest system such as management costs, fertilizer etc. all of which may be influenced by the negative effects of ozone on productivity.

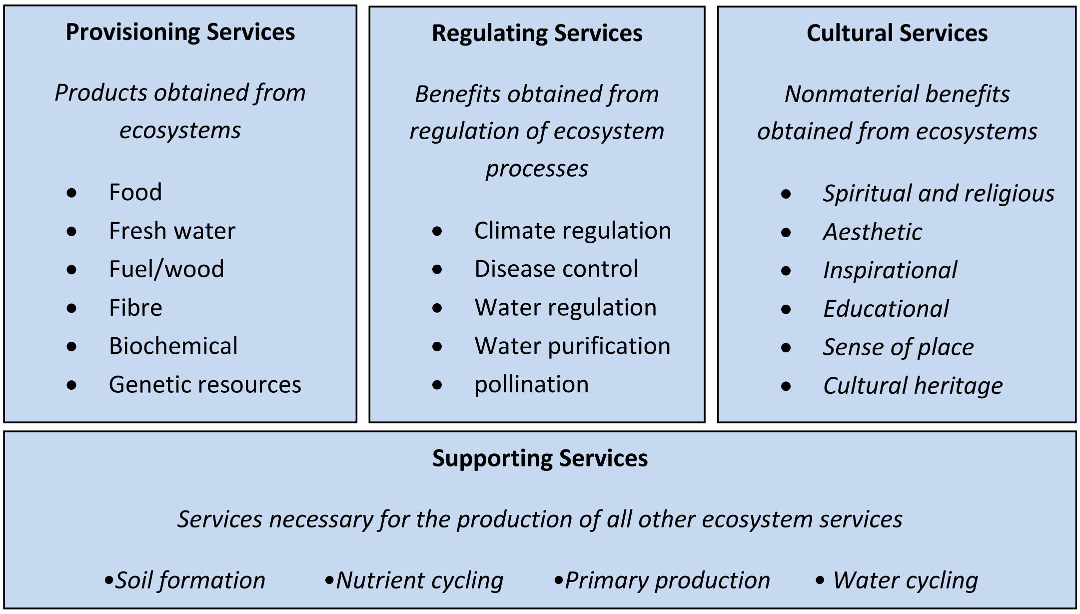

Figure 3.1 Ecosystems services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services (Millennium Ecosystem Assessment, 2005).

3.2 Biodiversity as an ecosystem service

The role of biodiversity in ecosystem services is often rather unclearly stated – biodiversity is sometimes considered as a separate service and yet is implicit in most ecosystem services. Mace et al. (2012) addressed this issue and showed how biodiversity is involved throughout the ecosystem hierarchy: "as a regulator of underpinning ecosystem processes, as a final ecosystem service and as a good that is subject to valuation." They described biodiversity contributions as being from both an "ecosystem services perspective", measured in simplest terms by ecosystem service flows, and from a "conservation perspective", where higher value is given to conserving charismatic species. There are many drivers of loss in biodiversity, with the increase in human population, especially in the last century, having a profound influence by, for example, increasing the need for biomass for fuel and construction, changes in land-use towards food and fodder production, industrial and residential developments, introduction of invasive species, pollution and climate change. Species losses are currently outpacing background rates calculated from fossil records (Millennium Ecosystem

Assessment, 2005) and it is widely recognised that the earth is facing its sixth mass extinction (Barnosky et al., 2011). Some ecosystems are more resilient to change than others, with for example, primary forests being more resistant to change than modified natural forests or plantations (Thompson et al., 2009).

Meta-analyses of published data on effects of species loss on the key ecosystem processes of productivity and decomposition have shown how important species loss is in ecosystem service delivery (Hooper et al., 2012). For example, species losses of 21 – 40% reduced plant productivity by 5 – 10%, an equivalent amount of reduction as that estimated for effects of UV light and global warming. The study also indicated that species losses of 41 – 60%, as projected for global extinctions by the end of this century, is predicted to result in a 13% biomass loss, a similar amount to that predicted for ozone effects alone. In a similar study, Mantyka-Pringle et al. (2012), investigated the synergies between climate change and habitat loss for explaining biodiversity loss. They showed that habitat loss and fragmentation were highest in areas where the maximum temperature of the warmest month has increased the most. Although not included in their meta-analysis, globally, ozone concentrations tend to be relatively high in many high temperature areas (e.g. southern USA, the Mediterranean, South East Asia), and it is possible that ozone may also be a contributory driver in habitat loss and fragmentation.

3.3 Impacts of ozone on ecological processes and supporting services

Until recently, much of the research on ozone impacts has focussed on quantifying effects on ecological processes rather than considering the implications for ecosystem services. This report, for the first time, places current process-based knowledge within the context of ecosystem services and thus reports on the potential for impacts of ozone on ecosystem services and biodiversity. Ozone pollution impacts directly or indirectly on many of the fundamentally important ecological processes and supporting services that underpin almost all ecosystem services, these include:

Primary productivity and carbon cycling Ozone reduces whole plant photosynthesis by directly impacting on the photosynthetic machinery (Rubisco and chlorophyll content), reducing leaf area by promoting early senescence and leaf abscission, diverting carbon (C) use into detoxification and/or repair metabolism, changing stomatal conductance (both increases and decreases have been noted, see below) and altering C allocation in favour of the above ground parts rather than below ground parts. Carbon flux to and from the soil is also altered by changes in leaf litter quality, altered rhizodeposition of C, changes in soil microbial community composition, and altered soil processes.

Nutrient cycling Tropospheric ozone has the capacity to impact on nutrient cycling by both direct and indirect mechanisms: by altering the chemical composition of plant tissue and the quantity (and quality) of litter fall, impacting on below-ground plant biomass and root exudates, indirectly altering microbial community composition(s) and functioning, and soil processes and the chemical properties. All of these have the capacity either, independently or in concert, to ultimately reduce the long-term sustainability of ecosystems (Lindroth et al., 2001).

Stomatal functioning and water cycling Tropospheric ozone is known to alter stomatal responses to environmental stimuli and in the short term (at higher concentrations) can cause stomata (leaf pores) to close, however, under prolonged chronic exposure (at lower concentrations) many reports document ozone-induced stomatal opening or loss of stomatal sensitivity to closing stimuli, such as drought, light and humidity. In a review of 49 papers covering 68 species conducted for the full report, 22% of species showed no change in stomatal conductance, 10% showed a slowed (sluggish) stomatal response to elevated ozone, 23.5% showed an increased stomatal opening under elevated ozone and 44% displayed stomatal closure in response to ozone (Mills et al., 2013). No clear patterns emerged for the ozone concentration range for the different responses, except perhaps a tendency for stomatal opening to occur at lower concentrations than stomatal closure. For consequence in water cycling, see Section 3.5.

3.4 Impacts of ozone on provisioning services

Examples of impacts of ozone on provisioning services include impacts on:

Crop production Effects of ozone on primary productivity are especially relevant for crop plants. With the world population predicted to increase to 9 billion by 2050, security of food supplies is one of the most important challenges for this century. Ozone damages crop plants by, for example, reducing photosynthesis, causing a yellowing of leaves and premature leaf loss, decreased seed production and reduced root growth, in turn resulting in reduced yield quantity and/or quality and reduced resilience to other stress such as drought. As a consequence, the key components of the food system that ozone interferes with are the productivity of crops, the nutritional value and the stability of food supplies as ozone concentrations and therefore impacts vary from year to year. Some of the world's most important staple food crops are sensitive (wheat, soybean and other pulses) or moderately sensitive (maize, rice, potato) to ozone and effects on the yield of these crops are of global significance. A recent state of knowledge report by the ICP Vegetation (Mills and Harmens, 2011), for the first time, quantified ozone impacts on wheat yield in Europe using the stomatal flux-based methodology and predicted that losses would remain at 9% in 2020 amounting to €2 billion in EU27 (+ Norway and Switzerland). Current ambient ozone levels in South Asia are also considered to be reducing crop yield and quality for a range of important crops in the region, commonly within the range of 10 to 20% (See Emberson et al., in Mills and Harmens, 2011).

Timber production A recent meta-analysis has suggested that the increase in ozone since the industrial revolution has been responsible for a reduction in photosynthesis of approximately 11% in trees (Wittig et al., 2007), which may have reduced tree productivity by approximately 7% (Wittig et al, 2009). In general, deciduous trees tend to be more sensitive to ozone than coniferous trees, with ozone sensitive species present across most of Europe (Wittig et al., 2009). Using National forest age class statistics, ozone response relationships for different species and ages, a model of stem increment growth and national mean AOT40[2] values, it was estimated that losses in C stocks averaged 10% across 10 northern European countries, with the highest losses predicted for the Czech Republic, Germany and Poland (see Karlsson, in Harmens and Mills, 2012; see also Section 3.5).

3.5 Impacts of ozone on regulating services

By impacting on carbon sequestration, nutrient cycling, land-atmosphere exchanges and biodiversity, ozone impacts on many beneficial regulatory functions of ecosystems, including:

C sequestration and global warming If ozone concentrations are high enough to reduce photosynthesis (i.e. CO_2 fixation) and/or above-ground plant growth, then less CO_2 and ozone will be absorbed by the leaves of vegetation, leading to a positive feedback to atmospheric CO_2 and ozone concentrations and therefore more global warming (Sitch et al., 2007). The ICP Vegetation recently conducted the first flux-based assessment of effects of ozone on C sequestration in the living biomass of trees in Europe focussing on 2000 and 2040 effects (Harmens and Mills, 2012). This study showed that applying the flux-based methodology using a climate-region specific parameterisation for 2000 revealed C reductions of 14% in the living biomass of trees. Predictions for 2040 indicated that the reduction of C storage is expected to decrease considerably compared to the reduction in 2000, mainly as a result of a predicted reduction in atmospheric ozone concentrations across Europe.

Air quality Globally, it has been estimated that ozone deposition to vegetation (by reaction with plant surfaces and uptake through the stomata) reduces tropospheric ozone concentrations by as much 20% (Royal Society, 2008). This is an especially significant function of vegetation given that ozone is the third most important greenhouse gas causing global warming (IPCC, 2007). Under drought

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

conditions, however, plants close stomata to conserve water and stomatal uptake of ozone is substantially reduced, with one study indicating that the European summer heatwave in August, 2013 led to 20 – 30 ppb increase in ozone concentration (Vienno et al., 2010). This has important implications for exposure of humans to ozone and the impacts on human health (WHO, 2008). A further level of complexity involves ozone-induced emission of biogenic volatile organic compound (BVOCs) from plants - these can either react with ozone to reduce concentrations or lead to ozone formation.

Methane emissions There is evidence that ozone may influence emissions of the greenhouse gas, methane, from wetlands although the results are less conclusive than for CO_2 effects. Global estimates of carbon sequestration in peatlands are in the region of 20-30 gC m^{-2} yr^{-1} (Wieder et al., 2001), and thus any effects of increasing ozone are of global significance for climate regulation. Results from experiments are rather mixed, with some studies indicating methane increases (Williamson, 2009; Niemi et al., 2002) whilst others show a decrease (Toet et al., 2011). The inconsistencies in these effects are most probably due to differences in species present and concentration and duration of ozone exposure.

Water cycling As described above, there are two main stomatal responses to ozone, each potentially having an opposite effect on the water cycle: ozone-induced stomatal closure will preserve water within soils whilst ozone-induced stomatal opening will increase water loss from vegetation and soils. Global climate modellers have until recently assumed the former mechanism is dominant, but very recently the implications of increased water loss as a result of chronic ozone exposure are beginning to be considered within such models. Extensive measurements of a Southern Appalachian forest in the USA have indicated an almost linear increase in average daily sap flows and enhancement of the amplitude of daily water–loss from native trees with increasing ambient ozone exposure, suggesting an ozone-induced disruption to the whole-tree water balance, not only as a result of increased day-time transpiration but also due to increased night-time stomatal conductance (McLaughlin et al., 2007a,b; Sun et al., 2012). Sun et al. (2012) suggest that loss of stomatal sensitivity will not only increase drought frequency and severity in the region, thus affecting ecosystem hydrology and productivity, but it will also have negative implications for flow-dependent aquatic biota.

Flowering, pollination and insect signalling Reported ozone-induced changes in the number and timing of flowering will play an important role in the reproductive success of plants, particularly for species in which flowering is closely synchronized with pollinating species (Black et al., 2000; Hayes et al., 2012). However, the impact of ozone on the timing of flowering varies markedly between species (Rämö et al., 2007; Hayes et al., 2012). A recent meta-analysis of ozone effects on plant reproductive growth and development indicated that current ambient ozone concentrations significantly reduced seed number, fruit number and fruit weight, while there was a trend towards increasing flower number and flower weight at elevated ozone (Leisner & Ainsworth, 2012). Floral scent trails, important in pollinator attraction and plant defenses against herbivorous insects, have also been shown to be destroyed or transformed by ozone (McFrederick et al., 2008). These ozone-induced changes in flowering timing and signaling could have large ecological impacts, affecting plant pollination, the food supply of nectar feeding insects or defense against herbivorous insects.

3.6 Impacts of ozone on cultural services

The potential for impacts of ozone on cultural services has attracted very little attention so far even though ozone can have both subtle and profound influences over some, if not all, aspects of cultural services by impacting on the visual appearance and quality of the natural environment, including potentially impacting on the tourist industry. Ozone impacts on leaf colour may be the most visually noticeable effect, as ozone induces early senescence in leaves and visible injury such as stippling and bronzing on sensitive species. Approximately 80 species of (semi-)natural vegetation have been recorded with symptoms attributed to ozone in Europe over the period 1990 – 2006, with records of injury being widespread across Europe and found in 16 countries (Hayes et al., 2007; Mills et al., 2011). Furthermore changes in the species balance of natural ecosystems (see Section 3.8) might make some natural areas less visually attractive.

3.7 Valuing ozone impacts on ecosystem services

There is an explosion of interest globally in placing an economic value on ecosystem services. This is seen as a useful way to communicate the benefits provided by the natural environment to policy makers, and to capture in a systematic way many of the unintended consequences of policy actions or management decisions. It also facilitates comparisons of effects of different drivers of change. Examples of approaches are discussed in the full report (Mills et al., 2013), including: estimating the impact of ozone on a product or service compared with assumed zero impact under no or low ozone; scenario analysis, estimating marginal cost of a change in a level of ozone and cost-benefit analysis.

3.8 Impacts of ozone on (plant) biodiversity and species balance

Typical effects of ozone on sensitive species include: accelerated aging (early scenescence) and changes in biomass, resource allocation and/or seed production. Each of these can impact on the vitality of component species of plant communities, potentially altering plant biodiversity as well as that of the animals, fungi, bacteria and insects that live in close association with plants or in nearby soils. In so doing, ozone-induced changes in species diversity or shifts in species balance will impact on many ecological processes, thereby impacting on ecosystem services, flows, goods and values. Effects on species balance have been widely reported from controlled exposure experiments, but a less clear picture emerges from field-based studies with long established communities and from field surveys. Although more studies are needed, it is clear that impacts of ozone are of particular concern for global biodiversity hotspots such as the Mediterranean basin. Current knowledge on direct ozone effects on biodiversity in Mediterranean European countries is still too limited for quantification and to draw firm conclusions (see González-Fernández et al., in Mills et al., 2013). Importantly, field validation of effects observed under experimental conditions is still lacking for many species and plant communities. Also indirect effects remain mostly unknown, despite the fact that they are probably of great importance in terms of assessing ozone effects on ecosystem biodiversity.

3.9 Research recommendations

Whereas there is a wealth of information on ozone impacts on natural- and agri-ecosystems, almost all studies were not originally conducted in the context of ecosystem services, and a comprehensive quantitative assessment of ozone effects on ecosystem services, including an economic valuation, is not currently possible for most services. We therefore recommend that the following further research is conducted:

- A systematic review and data mining exercise for each ecosystem service to derive generic response functions for calculation of effects.

- Use this review to identify those services for which there is insufficient experimental information available for derivation of response functions and make recommendations for further experimental work. Examples of experimental research would include:

    - Further quantification of below-ground impacts of ozone on carbon sequestration in roots and soils;
    - Further studies of the effects of ozone on stomatal conductance and the potential uncoupling from photosynthesis;
    - Experimental studies on the responses of vegetation to ozone in representative future climates and CO_2 concentrations
    - Large-scale field ozone exposure experiments on intact ecosystems;

  - Epidemiological analysis of field measurements to detect spatial and temporal trends in ecosystem processes and functions;
  - In association with proof of concept ozone exposure experiments, surveys to show the extent of occurrence of visible injury, early senescence and changes in expression of autumn colour.

- Identification of appropriate spatial data, including land-use, ozone, species distribution, ecosystem functions and products (for example, carbon stocks and yield), to facilitate a spatial analysis of impacts on ecosystem services.

- Further research on economic valuation methods, especially for those ecosystem services provided by natural ecosystems that are difficult to value without large uncertainty.

- Using the above, conduct a comprehensive quantitative assessment of past, current and predicted future effects of ozone on ecosystem services, and where possible a cost-benefit analysis for future scenarios.

4 European moss survey 2010/2011 on heavy metals, nitrogen and persistent organic pollutants

In this chapter we provide an extended executive summary of the full report on heavy metals and nitrogen, for further details and references we refer to the full report (Harmens et al., 2013b).

4.1 Introduction

The heavy metals in mosses biomonitoring network was originally established in 1980 as a Swedish initiative and has since then been repeated at five-yearly intervals (Harmens et al., 2010). The first moss survey at the European scale was conducted in 1990. Twenty five European countries and over 4,500 sites were involved in the 2010/11 survey (Harmens et al., 2013b). In 2005, nitrogen was included for the first time (Harmens et al., 2011), and 15 countries reported on nitrogen concentrations in mosses, collected at ca. 2,400 sites in 2010/11 (**Table 4.1**). In addition, six countries determined the concentration of selected persistent organic pollutants (POPs), particularly polycyclic aromatic hydrocarbons (PAHs), at a selected number of sites. A recent review has shown that mosses can also be applied as biomonitors of selected POPs (Harmens et al., 2013a). During 2000/1, responsibility for the coordination of the survey was handed over to the ICP Vegetation Programme Coordination Centre.

Table 4.1 Countries[1] that submitted data[2] for the 2010/11 European moss survey. For some countries mosses were only sampled in specific regions (see footnote 3 – 7).

Albania	**Estonia**	Romania
Austria	**Finland**	Russian Federation[5]
Belarus	**France**[POPs]	**Slovakia**
Belgium	Iceland	**Slovenia**[POPs]
Bulgaria	**Italy**[4]	**Spain**[POPs, 6]
Croatia	**Macedonia**	Sweden
Czech Republic	Norway[POPs]	**Switzerland**[POPs]
Denmark[3]	**Poland**[POPs]	Ukraine[7]

[1] Although not a Party to the Convention on Long-range Transboundary Air Pollution, Kosovo (United Nations administered region, Security Council resolution 1244 (1999)) also submitted heavy metal data.

[2] Countries in bold submitted data on heavy metals and nitrogen, the other countries submitted only data on metals. Countries that also submitted data on POPs are indicated.

[3] Faroe Islands; [4] Bolzano region; [5] Ivanova, Kostromskaya and Tikhvin-Leningradskaya regions;
[6] Galicia and Rioja (heavy metals), Navarra (heavy metals, nitrogen and POPs) regions;
[7] Donestsk region.

From the start, the European moss survey has provided data on concentrations of ten heavy metals (arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, vanadium and zinc) in naturally-growing mosses. Since 2005, the concentration of aluminium (a good indicator of wind-blown dust as it is present in high concentrations in the earth's crust), antimony (a good indicator of anthropogenic pollution as it is present in very low concentrations in the earth's crust) and nitrogen were also determined. The moss data provide a complementary measure of elemental deposition from the atmosphere to terrestrial systems, it is easier and cheaper than conventional precipitation analysis, and therefore enables a high sampling density to be achieved. The aim of the survey is to identify the main polluted areas, produce European maps and further develop the understanding of long-range transboundary air pollution of heavy metals and nitrogen. Apart from spatial patterns, the repeated surveys also provide an indication of temporal trends of heavy metal and nitrogen deposition (Harmens et al., 2010, 2011).

4.2 Methodology

As in previous surveys, moss samples were collected according to a standardised protocol (ICP Vegetation, 2010) and the elemental concentrations were determined in the last two to three years' growth segments using a range of analytical techniques (Harmens et al., 2013b). *Pleurozium schreberi* was the most frequently sampled species (ca. 42%), followed by *Hylocomium splendens* (23.5% and 15.3% for heavy metals and nitrogen respectively) or *Hypnum cupressiforme* (19.6% and 26.9% respectively), *Pseudoscleropodium purum* (ca. 8%) and other species (ca. 7 - 9%). For quality assurance purposes moss reference material was included in the analyses (Steinnes et al., 1997; Harmens et al., 2010) and where necessary, correction factors were applied to outliers and in some cases, severe outliers were excluded from further data processing. The reported data were checked for anomalies and the format standardised before European maps were produced for 2010/11, including maps showing the relative changes since the 2005 survey. The maps display the mean element concentration per 50 x 50 km^2 EMEP[3] grid cell.

4.3 Temporal trends (1990 – 2010) and spatial patterns in 2010/11

4.3.1 Heavy metals

The decline in emission and subsequent deposition of heavy metals across Europe in recent decades has resulted in a decrease in the heavy metal concentration in mosses since 1990, with the decline continuing since the previous moss survey in 2005 (**Table 4.2; Figure 4.1, 4.2**). In general, the decline in metal concentrations in mosses was higher between 1990 and 1995 (or 2000) than in later years. The metal concentration in mosses has declined the most for lead, due to the abolishment of leaded petrol, and the least for copper. For cadmium, lead and mercury, the temporal trends in concentrations in mosses are in good agreement with trends reported for atmospheric deposition modelled by EMEP (**Figure 4.1**; Ilia Ilyin, pers. comm.; Travnikov et al., 2012). Between 1990 and 2010, the average cadmium and lead concentration in mosses has declined by 51% and 77% respectively, whereas the average modelled cadmium and lead deposition in the EMEP domain has declined by 51% and 74% respectively. Between 1995 and 2010, the average mercury concentration in mosses has declined by 23%, whereas the average modelled mercury deposition in the EMEP domain has declined by 27%.

Table 4.2 Decline in the average median heavy metal and nitrogen concentrations in mosses since the start of the European moss survey in 1990 and since the previous survey in 2005.

Element	Decline since 1990* (%)	Decline since 2005 (%)	Element	Decline since 1990* (%)	Decline since 2005 (%)
Aluminium	n.a.	28	Lead	77	36
Antimony	n.a.	23	Mercury	23*	20
Arsenic	26*	25	Nickel	33	12
Cadmium	51	7	Vanadium	57	27
Chromium	43	23	Zinc	34	7
Copper	11	6			
Iron	52	15	Nitrogen	n.a.	5

* Decline since 1995 for arsenic and mercury as only a few countries have reported concentrations in mosses for these metals in 1990; n.a. = not available.

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

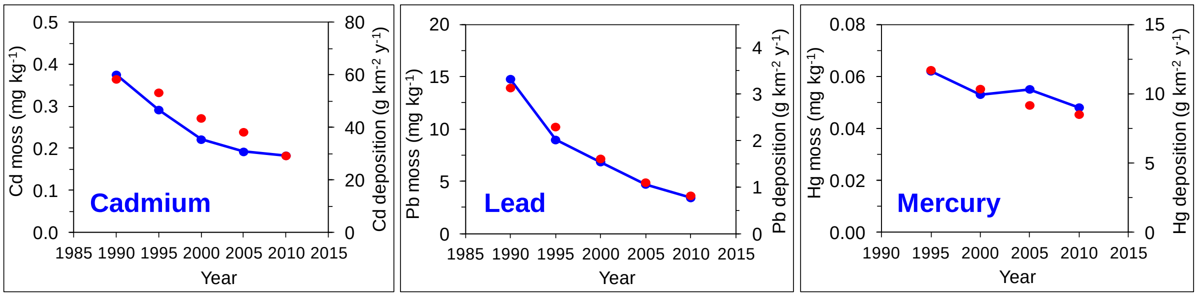

Figure 4.1 Temporal trend of cadmium (Cd), lead (Pb) and mercury (Hg) concentration in mosses compared to the trend of EMEP-modelled deposition for these heavy metal (red dots).

For other metals, the decline in concentrations in mosses also follows the decline in reported emissions since 1990, with the lowest decline being reported for copper for both variables (**Table 4.2; Figure 4.2**). However, on a national or regional scale within countries deviations from the general European trend were found sometimes, i.e. temporal trends were country or region-specific, with no changes or even increases being observed between survey years. Therefore, even in times of generally decreasing metal deposition across Europe, temporal trends can be different for different geographical scales (Harmens et al., 2013b).

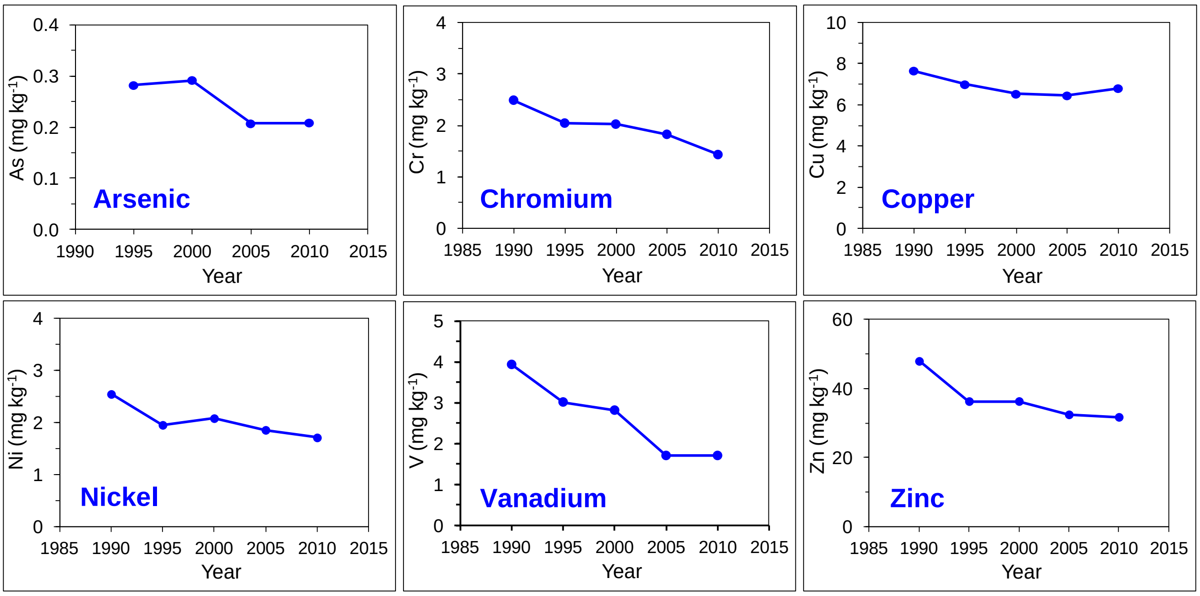

Figure 4.2 Average median metal concentration in mosses for countries that reported data for the respective metals for at least four out of the five survey years since 1990.

As in previous surveys, the lowest concentrations of heavy metals in mosses were generally found in northern Europe, although higher concentrations were reported near local sources. Low to intermediate heavy metal concentrations in mosses were generally observed in western and central Europe. The highest concentrations were often found in (south-)eastern Europe, with localised lower concentrations being observed. Here we report in a bit more detail the spatial patterns in 2010/11 for the metals cadmium, lead and mercury. Spatial patterns in 2010/11 for the other metals are described in more detail in Harmens et al. (2013b).

Cadmium

Cadmium concentrations in mosses were generally low in Northern Europe (**Figure 4.3**). The cadmium levels were lowest in north-west Scandinavia, Iceland and the western parts of France. However, in France the median value has increased since 2005. Relatively low median values were also observed in Albania, Kosovo and the Russian Federation. Very high levels of cadmium were observed in Romania, followed by Slovakia, Croatia, Ukraine and Belgium. However, in Belgium the median value has declined by 38% since 2005. Whereas a decline has also been found in other countries, several countries reported an increase of the median value since 2005. The average median cadmium concentration in mosses has declined by only 7% - from 0.21 mg kg^{-1} in 2005 to 0.20 mg kg^{-1} in 2010.

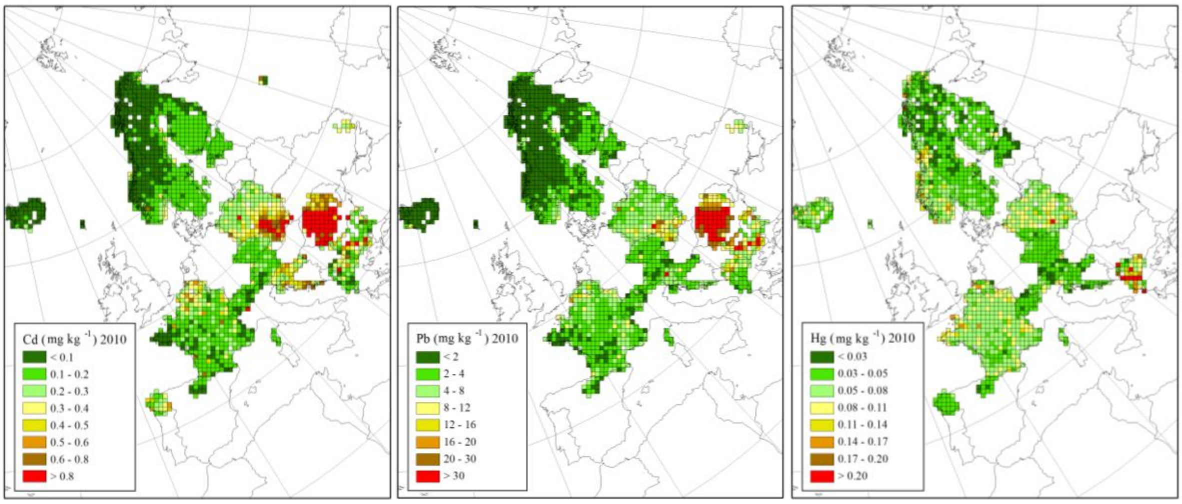

Figure 4.3 Mean cadmium (Cd), lead (Pb) and mercury (Hg) concentration in mosses per EMEP 50 km x 50 km grid cell in 2010/11.

Lead

Very high lead concentrations in mosses were still reported in Romania (**Figure 4.3**), where the use of leaded petrol has been banned completely only since January 2012. In addition, the presence of large industrial areas (including metallurgical works or melting plants) located in Baia Mare, Magoaja, Letca, Cergau, Zagra and Copsa Mica, contribute to the high concentration of lead in mosses. Relatively high lead concentrations were also found in Bulgaria, Kosovo, Slovakia, Slovenia and Ukraine, although the median lead concentration in mosses has declined between 31 and 50% in Bulgaria, Slovakia and Slovenia since 2005. Relatively high lead concentrations were also found in parts of southern Poland. In Belgium the median lead concentration in mosses has declined by 74% since 2005. A slight increase in the median lead concentration in mosses since 2005 was only reported for Croatia, which might be due to the relatively low median value reported for 2005 (compared to neighbouring countries). The average median lead concentration in mosses had decreased by 36%, from 5.62 mg kg^{-1} in 2005 to 3.57 mg kg^{-1} in 2010.

Mercury

In contrast to other metals, mercury is a global pollutant and can be transported in the atmosphere around the globe. Therefore, emission sources located on other continents have a significant impact on mercury pollution in Europe. Due to the long residence time of gaseous mercury in the atmosphere, most of it will be transported outside Europe. The global nature of mercury pollution appears to result in a more homogenous spatial pattern of mercury concentration in mosses in Europe compared to many other metals (apart from zinc). The highest levels of mercury in mosses were found in Albania and the former Yugoslav Republic of Macedonia, followed by Italy, Poland and France (**Figure 4.3**). In France, particularly areas with relatively high mercury concentrations in 2005 showed a considerable decline in the concentrations in mosses in 2010. Relatively high levels of mercury were also reported for Norway, and the levels have increased since 2005 in many parts of Norway. Arctic mercury depletion events (episodes in polar areas where gaseous elemental mercury is transformed to oxidized species) might be contributing to the elevated mercury concentrations in mosses in northern Norway (Berg et al., 2008). Whereas in many areas in southern Finland the mercury concentration in mosses has increased since 2005, the opposite was true for many areas in northern Finland. As with many other metals, since 2005 a considerable decline in mercury concentrations in mosses was reported for Belgium (decrease of the median value by 59%). The average median mercury concentration in mosses has declined by 20% - from 0.066 mg kg^{-1} in 2005 to 0.053 mg kg^{-1} in 2010.

4.3.2 Nitrogen

The spatial pattern of the nitrogen concentration in mosses in 2010/11 was similar to the spatial pattern in 2005/6, with lower values being observed for Finland than the rest of Europe (**Figure 4.4**). Generally, high concentrations of nitrogen were found in western and central Europe. The small decline (5%) in the average median nitrogen concentration in mosses (**Table 4.1**) is in agreement with the 7% decline reported by EMEP for modelled total nitrogen deposition in the EU27 since 2005. Previous analysis of the relationship between nitrogen concentration in mosses and EMEP-modelled total nitrogen deposition showed considerable scatter with saturation occurring at a total nitrogen deposition rate of ca. 15 kg N ha^{-1} y^{-1} (Harmens et al., 2011). However, in some countries a linear relationship has been observed between the total nitrogen concentration in mosses and measured bulk nitrogen deposition at the site level. Although these relationships needs to be analysed further using the 2010/11 moss and modelled or measured deposition data, we do expect these relationships to be similar as in 2005, as was reported for Switzerland (Harmens et al., 2013b).

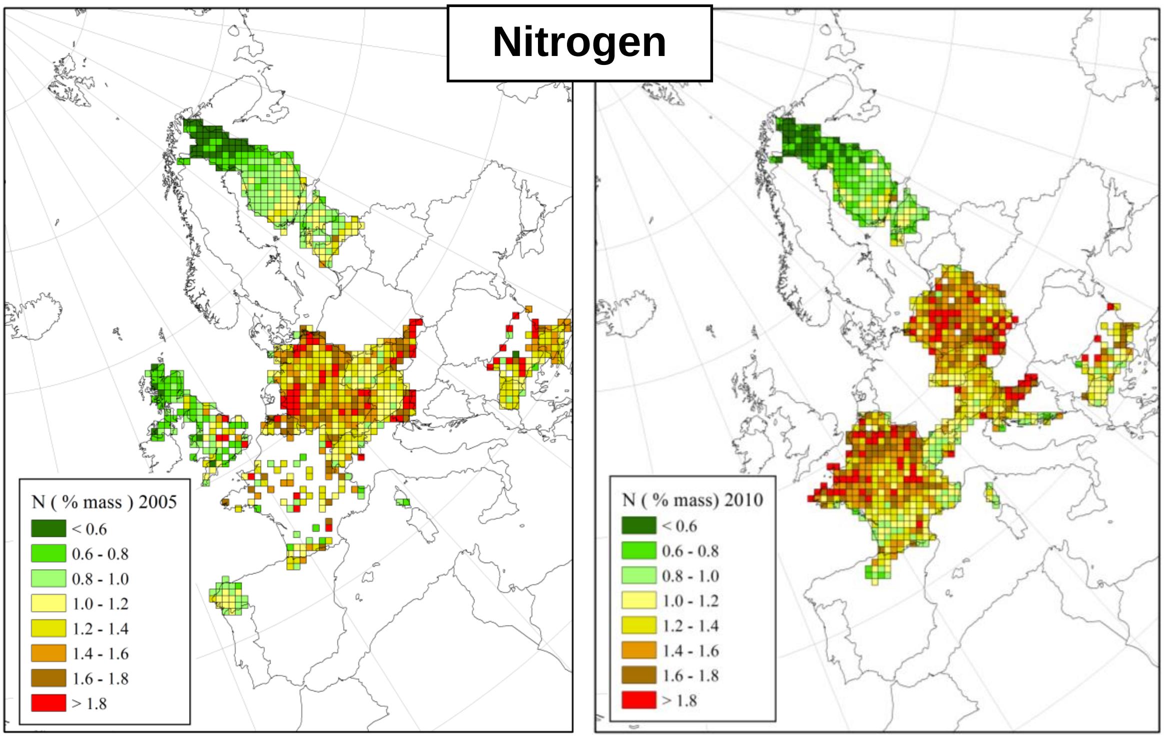

Figure 4.4 Mean total nitrogen concentration in mosses per EMEP 50 km x 50 km grid cell in 2005 (left) and 2010 (right).

A summary of the full report on heavy metals and mosses (Harmens et al., 2013b) was made available as an official document for the 32nd session of the WGE (ECE/EB.AIR/WG.1/2012/13; http://www.unece.org/fileadmin/DAM/env/documents/2013/air/wge/ECE_EB.AIR_WG.1_2013_13_ENG_01.pdf), with translations being available also in French and Russian.

4.3.3 Persistent organic pollutants (POPs)

A recent review study (Harmens et al., 2013a) by the ICP Vegetation has shown that mosses are suitable organisms to monitor spatial patterns and temporal trends of atmospheric concentrations or deposition of POPs, including polycyclic aromatic hydrocarbons (PAHs), polychlorobiphenyls (PCBs), dioxins and furans (PCDD/Fs), and polybrominated diphenyl ethers (PBDEs; flame retardants). Six countries conducted a pilot study in 2010/11 on the application of mosses to monitor atmospheric deposition of POPs: France, Norway, Poland, Slovenia, Spain and Switzerland, with only Norway analysing other compounds in addition to PAHs.

In Norway, the observed geographical distribution of the concentration of selected POPs (PCB, DDT (dichlorodiphenyltrichloroethane), HCH (hexachlorohexane) PAHs, PBDEs and PFAS (perflorinated compounds)) in mosses indicated that the concentration in mosses reflect the atmospheric deposition patterns well (Steinnes and Schlabach, 2012). For most of the POPs the concentration in mosses decreased with northern latitude (similar to heavy metals), indicating that long-range atmospheric transport contributes to the higher concentrations observed in southern Norway.

In Switzerland, high concentrations of PAHs were found in mosses sampled in the region of Basel (chemical industry), whilst low concentrations were observed in the western part of the central plateau where the population density is relatively low. There was a good correlation between the summed PAHs concentration in mosses and the concentration in PM_{10} and soil (**Figure 4.5**).

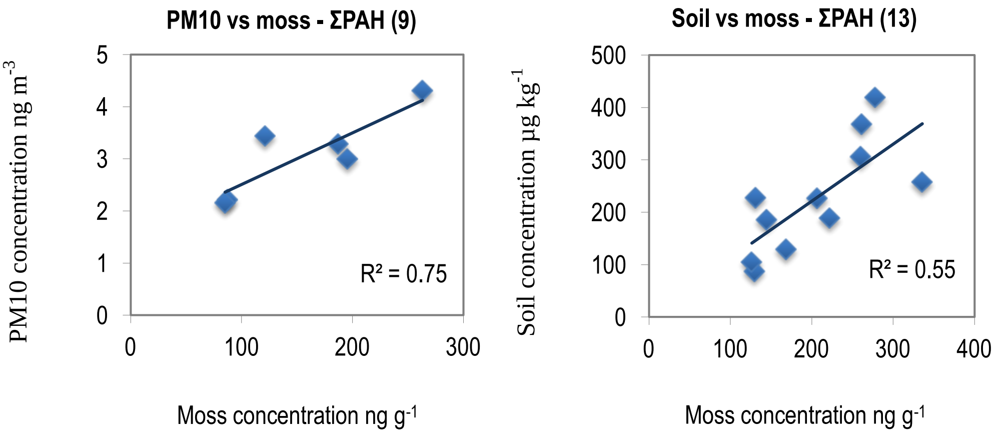

Figure 4.5 Relationship between the sum (Σ) of PAHs concentration in mosses and (left) PM_{10} (left) and soil (right) in Switzerland.

The total PAHs concentrations in mosses was significantly lower in Navarra, a rural area in Spain, than in Île-de-France (metropolitan area of Paris) and in Switzerland (Foan et al., submitted). The concentration of heavy PAHs in mosses varied partly with the level of urbanisation in a 10 km radius. This was not the case for lighter PAHs as they are mainly emitted by road traffic. Hence, mosses sampled in Navarra were characterised by a low percentage of heavy PAHs due to the low degree of urbanisation in Navarra. Specific correlations with heavy metal concentrations in mosses confirmed that the main PAH emission sources in Switzerland and Navarra were industrial activity and road traffic respectively. The total PAHs concentration in mosses was the lowest in Norway and Slovenia and the highest in Poland (**Table 4.3**).

Table 4.3. Values for the sum of 13 polycyclic aromatic hydrocarbons (PAHs) of the 16 PAHs prioritised by USA EPA (not included: naphthalene, acenaphthylene, indeno(-cd)pyrene)).

Country	Mean (mg kg^{-1})	Min (mg kg^{-1})	Max (mg kg^{-1})	No. of sites
Norway	79	16	203	20
France	264	149	360	18
Spain (Navarra)	197	100	536	23
Switzerland	242	98	698	20
Slovenia	75	42	108	15

4.4 Conclusions and recommendations

Conclusions:

- Moss biomonitoring provides a cheap, complementary method to deposition analysis for the identification of areas at risk from high atmospheric deposition fluxes of heavy metals, nitrogen and selected POPs and for monitoring changes with time.
- For the priority metals cadmium, lead and mercury and for nitrogen the decline in average median concentrations in mosses across Europe is in agreement with that reported for modelled atmospheric deposition.
- Despite the general European decline in concentrations in mosses between 2005 and 2010 (and also since 1990), country and region-specific temporal trends were observed.
- Despite the apparent success of the implementation of air pollution abatement techniques in large areas of Europe, further measures are required in (south)-eastern Europe to reduce the relative high emissions of heavy metals. For nitrogen, more stringent air pollution abatement strategies are required across large parts of Europe to reduce the area at risk from adverse effects of high atmospheric nitrogen deposition.

Recommendations:

The moss survey should be continued to monitor any future trends in heavy metal and nitrogen deposition in Europe, with the next survey anticipated for 2015/16. Further stimulation of the participation in (south)-eastern European countries for both heavy metals and nitrogen is especially encouraged. In addition, more countries are encouraged to report on the nitrogen concentration in mosses in the future. An extension of the moss survey into Asia would also be welcome. The pilot study on POPs has shown to provide a good indication of areas at risk from high deposition of POPs and in some areas provides an indication of the contribution of long-range atmospheric transport. Therefore, countries participating in future European moss surveys are encouraged to also include determination of POPs (particularly PAHs) concentrations in mosses. It is recommended to use the newly available data for 2010/11 to further assess the performance of the EMEP models, particularly the model that estimates the atmospheric deposition of the priority heavy metals cadmium, lead and mercury. For nitrogen we recommend to investigate in further detail the relationship between measured total nitrogen deposition and the total nitrogen concentration in mosses at the site level.

5 Common WGE and other ICP Vegetation activities in 2012/2013

In this chapter, progress made with the common WGE and other ICP Vegetation workplan items for 2013 is summarised.

5.1 Contributions to WGE common workplan items

5.1.1 Further implementation of the Guidelines on Reporting of Air Pollution Effects

Table 5.1 provides an overview of the monitoring and modelling effects reported by the ICP Vegetation according to the Guidelines (ECE/EB.AIR/2008/11).

Table 5.1 Monitoring and modelling effects reported by the ICP Vegetation.

Parameter	Ozone	Heavy metals	Nitrogen	POPs
Growth and yield reduction	X			
Leaf and foliar damage	X			
Exceedance critical levels	X			
Climatic factors	X			
Concentrations in mosses		X	X	X

5.1.2 Ideas and actions to enhance the involvement of EECCA/SEE countries in the Eastern Europe, the Caucasus and Central Asia and on cooperation with activities outside the Air Convention

Table 5.2 provides an overview of the participation of EECCA/SEE countries and countries outside the UNECE regions in the activities of the ICP Vegetation. Whereas EECCA/SEE countries primarily participate in the European moss survey, countries outside the UNECE regions primarily participate in research on the impacts of ozone on vegetation.

Table 5.2. Participation of EECCA/SEE countries[4] and countries outside the UNECE region in recent activities (last five years) of the ICP Vegetation, including attendance of the Task Force meeting. M = moss survey; O_3 = ozone impacts on vegetation.

EECCA	SEE	Outside UNECE
Belarus (M)	Albania (M)	Brasil (O_3)
Russian Federation (M)	Bulgaria (M)	China (O_3)
Ukraine (M, O_3)	Croatia (M, O_3)	Cuba (O_3)
	Greece (O_3)	Egypt (O_3)
	Macedonia (M)	India (M, O_3)
	Romania (M)	Japan (O_3)
	Serbia (M)	Niger (O_3)
	Slovenia (M, O_3)	Pakistan (O_3)
	Turkey (M)	South Africa (O_3)

[1] Although not a Party to the Convention on Long-range Transboundary Air Pollution, Kosovo (United Nations administered region, Security Council resolution 1244 (1999)) also submitted heavy metal data for the moss survey.

There is a clear need to enhance participation of EECCA/SEE countries in research on the impacts of ozone on vegetation. Hence, the ICP Vegetation is aiming to establish links with ozone experts in

4

more EECCA/SEE countries in the near future. In the coming year, the ICP Vegetation will report on the deposition of air pollutants to and the impacts on vegetation specifically in EECCA/SEE countries and South-East Asia (see Chapter 6). Outreach activities outside the UNECE region will be primarily focussed on ozone impact on vegetation, acknowledging the fact that ozone is a hemispheric pollutant.

Regarding the European moss survey, the ICP Vegetation Programme Coordination Centre is currently discussing with the Russian Federation how its role can be increased in the coordination of the moss survey in the future. The expert in the Russian Federation has been very active in the past in enhancing the participation of EECCA/SEE countries in the moss survey. The next European moss survey is provisionally scheduled for 2015/16 (see Chapter 6). In 2013, a short leaflet was produced on the results of the 2010/11 European moss survey, which was translated into Russian for distribution in EECCA countries and can be downloaded from the ICP Vegetation web site.

5.1.3 Ecosystem services and biodiversity report and booklet

The ICP Vegetation Programme Coordination Centre led the production of the WGE report on 'Benefits of air pollution control for biodiversity and ecosystem services' (see http://www.unece.org/fileadmin/DAM/env/documents/2013/air/wge/No.1__Benefits_of_air_pollution_control_for_biodiversity_and_ecosystem_services.pdf) and a booklet on the same theme (see http://www.unece.org/fileadmin/DAM/env/documents/2013/air/wge/No.7__Benefits_of_air_pollution_control_for_biodiversity_and_ecosystem_services_-_Brochure.pdf). A summary of the full report was made available as an official document for the 32nd session of the WGE (ECE/EB.AIR/WG.1/2012/14; http://www.unece.org/fileadmin/DAM/env/documents/2013/air/wge/ECE_EB.AIR_WG.1_2013_14_ENG_01.pdf), with translation being available also in French and Russian. The booklet was available as informal document at the 51st Session of the Working Group on Strategies and Review of the LRTAP Convention, presented at the 'Clean Air for Nature' workshop at Environment DG of the EC (20th March 2013) and at the 5th Stakeholder Expert Group meeting for the review of European air pollution policy (3rd April 2013). A review from the ICP Vegetation on the impacts of ozone pollution on ecosystem services and biodiversity (Mills et al., 2013) was incorporated in both documents. Further details of the contribution from the ICP Vegetation are provided in Chapter 3.

5.2 Supporting evidence for ozone impacts on vegetation

Since 2008, participants of the ICP Vegetation have been conducting biomonitoring campaigns using ozone-sensitive (S156) and ozone-resistant (R123) genotypes of *Phaseolus vulgaris* (Bush bean, French Dwarf bean) that had been selected at the USDA-ARS Plant Science Unit field site near Raleigh, North Carolina, USA. The bean lines were developed from a genetic cross reported by Dick Reinert (described in Reinert and Eason (2000)). Individual sensitive (S) and tolerant (R) lines were identified, the S156 and R123 lines were selected, and then tested in a bioindicator experiment reported in Burkey et al. (2005). A trial of this system occurred in central and southern parts of Europe during the summer of 2008. This was extended in 2009 and included again in the ozone biomonitoring programme since then.

In 2012, the biomonitoring of ozone effects using bean was scaled down compared to the previous years, reflecting less interest from the participants. Nevertheless, experiments were conducted with ozone-sensitive and ozone-resistant bean (*Phaseolus vulgaris*) at nine sites across Europe and one in the USA. As in previous years, bean seeds of the strains S156 and R123 were kindly provided by Kent Burkey (USA). Seeds of both varieties and an updated experimental protocol (ICP Vegetation, 2012) were sent out to participants who recorded the occurrence of visible injury to leaves and quantified the reduction in pod yield of the sensitive compared to the resistant variety for plants exposed to ambient ozone. Some participants carried out stomatal conductance measurements to contribute to the development of a flux-effect model.

The data from the 2008 – 2012 biomonitoring and ozone exposure experiments with bean were combined into a database for dose-response analysis. Over 3000 leaf pore conductance measurements have been made and used to generate an ozone flux model for bean. Over the course of the 2-3 month experiment, hourly accumulated ozone flux (POD_0) ranged from 4.4 (Bangor, UK) to 18.9 (Seibersdorf, Austria) mmol m^{-2}. Visible ozone injury (bronze stippling) regularly occurred across the network. Using the data for sites where ozone injury had occurred within the first four weeks on the ozone–sensitive variety and less than 15% of leaves were injured on the resistant variety of bean, there was an indication of a threshold for the proportion of injured leaves of a 12h mean of ca. 35 ppb and a POD_0 of ca. 4 mmol m^{-2} (**Figure 5.1**).

Our analysis conducted so far has not found a clear dose-response relationship between ozone parameters such as the 12h mean or POD_0 and the yield biomass ratio between the ozone-sensitive and resistant variety. Overall, the bean biomonitoring system does seem to provide a good indication of the occurrence of ozone concentrations that are high enough to visibly damage plants. As such it is very valuable for use in countries just joining the ICP Vegetation programme as proof or otherwise that ozone levels are causing damage. However, we are concerned that differences between the sensitive and resistant varieties are not strong enough for continued application as a biomonitor for yield effects.

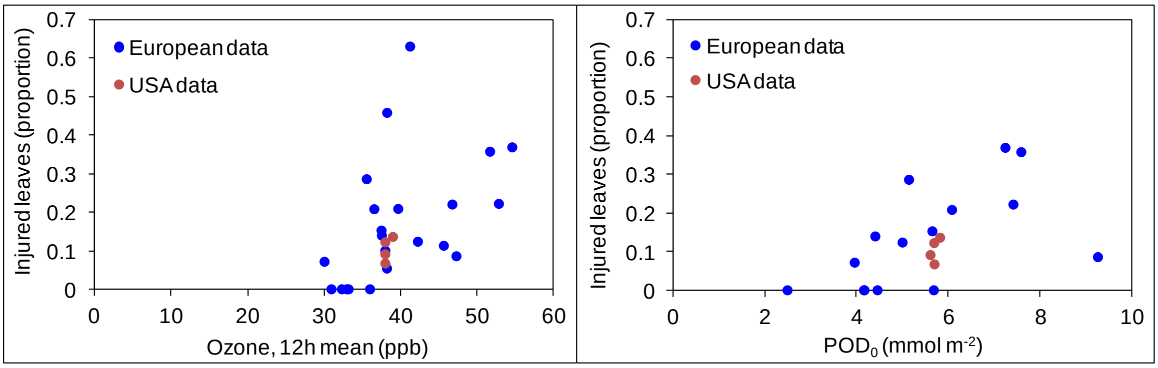

Figure 5.1. Relationships between proportion of leaves injured on the ozone-sensitive variety of bean after 4 weeks exposure to ambient air and (left) 12h mean ozone concentration and (right) stomatal flux (POD_0) at the sites.

6 Medium-term workplan (2014-2016)

The medium-term workplan for 2014 – 2016 was adopted at the 26th Task Force Meeting of the ICP Vegetation (Halmstad, Sweden, 28 - 30 January 2013). Workplan items for 2014 and 2015 were submitted to the 32nd session of the WGE and will be forwarded for approval to the 32nd session of the Executive Body of the LRTAP Convention in December 2013. Compared to the medium-term workplan adopted at the 26th Task Force meeting of the ICP Vegetation, two workplan items for 2014 and 2015 were swapped around to make delivery better feasible within the time frame considered:

Ongoing annual activities:

- Report on supporting evidence for ozone impacts on vegetation;
- Report on preparations and progress with the moss survey 2015/2016.

New activities:

2014:

- Report on air pollution deposition to, and impacts on vegetation, in EECCA/SEE countries and South-East Asia;
- Update of chapter 3 of the Modelling and Mapping Manual (inclusion of a new annex describing further technical developments).

2015:

- Report on the implications of rising background ozone for vegetation in Europe;
- Report on the interacting effects of co-occurring pollutants (ozone and nitrogen) and climatic stresses on vegetation.

Tentatively for 2016:

- Report on current and future ozone impacts in the Mediterranean basin, including implications for food security.

The ICP Vegetation will continue to contribute to the common workplan items of the WGE and the annual joint report(s) of the all bodies under the WGE, with clear policy-relevant messages and recommendations to WGE and the Executive Body.

7 References

Aguirre, A. A. (2009). Biodiversity and human health EcoHealth 6: 153-156.

Barnosky, A. D., Matzke, N. et al. (2011). Has the Earth's sixth mass extinction already arrived? Nature 471(7336): 51-57.

Berg, T., Aspmo, K., Steinnes, E. (2008). Transport of Hg from atmospheric mercury depletion events to the mainland of Norway and its possible influence on Hg deposition. Geophysical Research Letters 35, L09802.

Black, V. J., Stewart, C. A. et al. (2000). Direct effects of ozone on reproductive development in *Plantago major* L. populations differing in sensitivity. Environmental and Experimental Botany 69: 121-128.

Burkey, K.O., Miller, J.E., Fiscus, E.L. (2005). Assessment of ambient ozone effects on vegetation using snap bean as a bioindicator species. Journal of Environmental Quality 34:1081-1086.

Foan, L., Leblond, S., Thöni, L., Raynaud, C., Santamaria, J.M, Sebilo, M., Simon, V. (submitted). Spatial distribution of PAH concentrations and stable isotopic ratios (δ13C, δ15N) in mosses from three European areas - Characterization by multivariate analysis. Environmental Pollution.

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., Ilyin, I., Mills, G., et al. (2012a). Country-specific correlations across Europe between modelled atmospheric cadmium and lead deposition and concentrations in mosses. Environmental Pollution 166: 1-9.

Harmens, H., Mills, G. (2012). Ozone pollution: Impacts on carbon sequestration in Europe. Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-1-906698-31-7.

Harmens, H., Mills, G., Hayes, F., Norris, D. and the participants of ICP Vegetation. (2012b). Air pollution and vegetation. ICP Vegetation annual report 2011/20112. ISBN: 978-1-906698-35-5.

Harmens, H., Norris, D. A., Cooper, D.M., Mills, G., et al. (2011). Nitrogen concentrations in mosses indicate the spatial distribution of atmospheric nitrogen deposition in Europe. Environmental Pollution 159: 2852-2860.

Harmens, H., Norris, D., Mills, G., and the participants of the moss survey (2013b). Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. ISBN: 978-1-906698-38-6.

Harmens, H., Norris, D.A., et al. (2010). Mosses as biomonitors of atmospheric heavy metal deposition: spatial and temporal trends in Europe. Environmental Pollution 158: 3144-3156.

Hayes, F., Mills, G., Harmens, H., Norris, D. (2007). Evidence of widespread ozone damage to vegetation in Europe (1990 – 2006). Programme Coordination Centre of the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-0-95576-721-0.

Hayes, F., Williamson, J. et al. (2012). Ozone pollution affects flower numbers and timing in a simulated BAP priority calcareous grassland community. Environmental Pollution 163: 40-47.

Holy, M., Pesch, R., Schröder, W., Harmens, H., Ilyin, I., et al. (2010). First thorough identification of factors associated with Cd, Hg and Pb concentrations in mosses sampled in the European Surveys 1990, 1995, 2000 and 2005. Journal of Atmospheric Chemistry 63: 109-124.

Hooper, D. U., Adair, E. C. et al. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486(7401): 105-U129.

ICP Vegetation (2010). Heavy metals in European mosses: 2010 survey. Monitoring manual. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. http://icpvegetation.ceh.ac.uk

ICP Vegetation. (2012). Yield response and ozone injury on *Phaseolus vulgaris:* Experimental Protocol. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. http://icpvegetation.ceh.ac.uk

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon et al., eds). Cambridge University Press, UK and USA.

Leisner, C. P., Ainsworth, E. A. (2012). Quantifying the effects of ozone on plant reproductive growth and development. Global Change Biology 18: 606-616.

Lindroth, R. L., Kopper, B. J. et al. (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.

Mace, G. M., Norris, K.et al. (2012). Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology & Evolution 27: 19-26.

Maestre, F. T.,. Quero, J. L et al. (2012). Plant Species Richness and Ecosystem Multifunctionality in Global Drylands. Science 335(6065): 214-218.

Mantyka-Pringle, C. S., Martin, T. G. et al. (2012). Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. Global Change Biology 18: 1239-1252.

McFrederick, Q. S., Kathilankal, J. C. et al. (2008). Air pollution modifies floral scent trails. Atmospheric Environment 42: 2336-2348.

McLaughlin, S. B., Nosal, M. et al. (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. et al. (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.

Millenium Ecosystem Assessment (2005). Ecosystems and human well-being: synthesis. Island Press, Washington. DC.

Mills, G., Harmens, H. (eds). (2011). Ozone pollution: A hidden threat to food security. Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK. ISBN 978-1-906698-27-0.

Mills, G., Hayes, F., Simpson, D., Emberson, L., Norris, D., Harmens, H., Büker, P. (2011). 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., Wagg, S., Harmens, H. (Eds) (2013). Ozone pollution: Impacts on ecosystem services and biodiversity. ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. ISBN: 978-1-906698-39-3.

Niemi, R., Martikainen, P. J. et al. (2002). Ozone effects on Sphagnum mosses, carbon dioxide exchange and methane emission in boreal peatland microcosms. Science of the Total Environment 289: 1-12.

Rämö, K., Kanerva, T. et al. (2007). Growth onset, senescence, and reproductive development of meadow species in mesocosms exposed to elevated O_3 and CO_2. Environmental Pollution 145: 850-860.

Rapport, D. J., Maffi, L. (2009). Eco-cultural health, global health, and sustainability. Ecological Research 26: 1039-1049.

Redford, K. H., Groves, C.et al. (2012). Conservation stories, conservation science, and the role of the Intergovernmental Platform on Biodiversity and Ecosystem Services. Conservation Biology 26: 757-759.

Reinert, A., Eason, G. (2000). Genetic control of O_3 sensitivity in a cross between two cultivars of snap bean. Journal of the American Society of Horticultural Science 125: 222-227.

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.

Sitch, S., Cox, P.M., Collins, W.J., Huntingford, C. (2007) Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. Nature 448: 791-794.

Steinnes, E., Rühling, Å., Lippo, H., Mäkinen, A. (1997). Reference material for large-scale metal deposition surveys. Accreditation and Quality Assurance 2: 243-249.

Steinnes, E., Schlabach, M. (2012). Moseundersøkelse i Norge 2010: Nivåer av organiske miljøgifter på 20 lokaliteter. Statlig program for forurensningsovervåking (SPFO) Report 1120/2012. ISBN 978-82-425-2515-4 (electronic version).

Sun, G., McLaughlin, S. B. et al. (2012). Interactive influences of ozone and climate on streamflow of forested watersheds. Global Change Biology 18: 3395-3409.

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.

Thompson, I., Mackey, B. et al. (2009). Forest resilience, biodiversity, and climate change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series.

Toet, S., Ineson, P. et al. (2011). Elevated ozone reduces methane emissions from peatland mesocosms. Global Change Biology 17: 288-296.

Travnikov, O., Ilyin, I., Rozovskaya, O., Varygina, M., Aas, W., Uggerud, H.T., Mareckova, K., Wankmueller, R. (2012). Long-term changes of heavy metal transboundary pollution of the environment (1990-2010). EMEP Status Report 2/2012.

Vieno, M., Dore, A. et al. (2010). Modelling surface ozone during the 2003 heat-wave in the UK. Atmospheric Chemistry and Physics 10: 7963-7978.

WHO (2008). Health risks of ozone from long-range transboundary air pollution. World Health Organisation.

Wieder, R. K. (2001). Past, present, and future peatland carbon balance: An empirical model based on Pb-210-dated cores. Ecological Applications 11: 327-342.

Williamson, J (2009). The impacts of elevated ozone on plant vitality and carbon cycling in wetlands. Ph.D. thesis, Bangor University. UK.

Wittig, V. E., Ainsworth, E. A. et al. (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. et al. (2009). Quantifying the impact of current and future tropospheric ozone on tree biomass, growth, physiology and biochemistry: a quantitative meta-analysis. Global Change Biology 15: 396-424.

8 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		✓	
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Estonia					
Siiri Liiv	Tallinn Botanic Garden Kloostrimetsa tee 52 11913 Tallinn	siiri@tba.ee		✓	✓

Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
Finland					
Eero Kubin Juha Piispanen Jarmo Poikolainen Jouni Karhu	Finnish Forest Research Institute Oulu, PO Box 413, 90014 University of Oulu	Eero.Kubin@metla.fi Juha.Piispanen@metla.fi Jarmo.Poikolainen@metla.fi Jouni.Karhu@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					
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Name/Country	Institute	Email	Ozone	Heavy metals	Nitrogen
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Air Pollution and Vegetation
ICP Vegetation
Annual Report 2012/2013

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 more than 40 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:

- Impact of ozone on ecosystem services and biodiversity.
- Ozone biomonitoring programme.
- European heavy metals and nitrogen in mosses survey 2010/2011.
- A pilot study on mosses as biomonitors of POPs.

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