UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

ECE/EB.AIR/WG.1/2009/9
8 July 2009

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON LONG-RANGE
TRANSBOUNDARY AIR POLLUTION

Working Group on Effects

Twenty-eighth session
Geneva, 23–25 September 2009
Item 5 of the provisional agenda

RECENT RESULTS AND UPDATING OF SCIENTIFIC AND TECHNICAL KNOWLEDGE

IMPACTS OF OZONE AND NITROGEN ON VEGETATION AND TRENDS IN NITROGEN AND HEAVY METAL CONCENTRATIONS IN MOSSES

Report by the Programme Centre of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

I. INTRODUCTION

1. Recent results on the effects of ozone (O_3) and nitrogen (N), and the results of the recent moss survey are presented here in accordance with item 3.5 of the 2009 workplan for the implementation of the Convention (ECE/EB.AIR/96/Add.2) adopted by the Executive Body at its twenty-sixth session in December 2008.

2. In 2007, the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) reported on the evidence of widespread O_3 damage to vegetation in Europe over the period 1990–2006 (ECE/EB.AIR.WG.1/2008/9; Hayes et al.

2007). This report describes further analysis of the data and their use within the Convention, in particular on the comparison of the risk of adverse effects of O_3 on vegetation with human health and on contributions to aspirational targets for the year 2050 (Harmens et al. 2009). Recently, the Programme Coordination Centre of the ICP Vegetation collated evidence of airborne N impacts on vegetation from the literature. This report also summarizes the outcome of that study, which was integrated in a more comprehensive overview of the impacts of airborne N on the environment and human health (ECE/EB.AIR.WG.1/2009/16). In 2008, ICP Vegetation finalized the data analysis of the European moss survey conducted in 2005/2006. This report also describes the spatial and temporal trends in heavy metal accumulation in mosses in Europe over the period 1990–2005 (Harmens et al. 2008a) and the spatial trends in N concentration in mosses in 2005/2006 (Harmens et al. 2008b).

II. FLUX-BASED RISK ASSESSMENT FOR OZONE

3. At its twenty-sixth session in December 2008 the Executive Body of the Convention took note of the evidence provided by ICP Vegetation on the widespread O_3 damage to vegetation. It decided that the latest scientific knowledge and data should be used, and in particular that O_3 effects on vegetation should be incorporated in integrated assessment modelling, especially in work for the revision of the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol). It also recommended that flux-based methods be used.

A. Policies aiming only at health effects will not protect vegetation in large areas of Europe

4. The Meteorological Synthesizing Centre-West (MSC-W) of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) provided the Programme Coordination Centre of ICP Vegetation with risk maps for O_3 for the year 2006. The maps were based on the generic flux-metric for crops ($AF_{st}3_{gen}$, a model of the cumulative O_3 flux into leaves of a generic crop, which takes into account the influence of temperature, light and humidity on the stomatal opening) and the metric used for O_3 health impact assessment (SOMO35, sum of maximum daily 8-hour mean over 35 ppb (parts per billion)). The EMEP grid squares in which ozone injury on vegetation was detected in 2006 were superimposed on both risk maps. The result showed that policies only aiming at protecting human health would not protect vegetation from adverse effects of O_3 in the northern third of the European area.

B. Contributions to aspirational targets for the year 2050

5. Political aspirations should be based on avoiding all detectable effects of O_3 on:

(a) The yield quantity and quality of agricultural and horticultural crops (including forage);

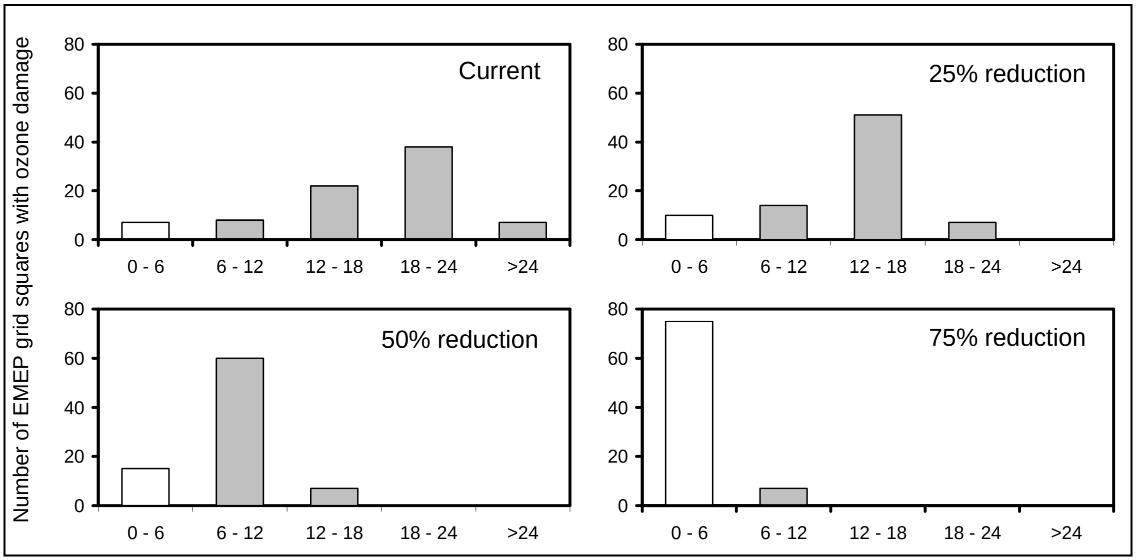
(b) The growth of individual species and biodiversity of (semi-)natural vegetation;

(c) The leaf appearance and growth of forest trees;

(d) The ecosystem services (including carbon sequestration) of vegetation.

6. At current climatic conditions, a reduction of 75 per cent of the generic O_3 flux ($AF_{st}3_{gen}$) to crop species would result in more than 90 per cent of EMEP grid squares, currently showing evidence of ozone damage to vegetation (Hayes et al. 2007), being within the "damage unlikely" category (figure 1). An advantage of the flux-based compared to the concentration-based (AOT40, accumulated concentration above a threshold of 40 parts per billion (ppb)) method is that the generic flux models can be applied to the predicted climate in 2050 (see table); climate change cannot be considered using the AOT40 approach. The "gap closure" principle as used before for critical loads and levels, or other cost-effective strategies that would prioritize areas with high O_3 fluxes, could be useful for defining interim targets.

Figure 1. Number of EMEP grid squares with O_3 damage at the current generic O_3 flux (mean of 1995–2004) and at 25, 50 and 75 per cent reductions in the current generic O_3 flux to crops.



Note: Up to a generic flux of 6 mmol m^{-2}, O_3 damage is unlikely to occur (white bars).

Table. Factors that can be taken into account in generic O_3 flux models regarding predicted climate change for 2050.

2050 climate	**Can be taken into account in generic flux models**
Changes in O_3 profile	Yes
Increases in temperature	Yes
Changes in vapour pressure deficit	Yes
Increase in atmospheric carbon dioxice concentration	By including a factor to simulate reduced stomatal conductance with enhanced carbon dioxide concentration
Changes in soil water availability	Irrigation assumed for crops where water supply is limited; would need to use full flux model for trees

III. IMPACTS OF NITROGEN ON VEGETATION AND CONCENTRATIONS IN MOSSES

7. The consequences of N enrichment (eutrophication) for ecosystems are a concern in many areas within the United Nations Economic Commission for Europe (UNECE) region due to continued high emission and deposition rates of reactive N. European areas at risk from eutrophication are predicted to decline only marginally from 49 per cent in 2000 to 47 per cent in 2020 based on emission scenarios assuming current legislation (Hettelingh et al. 2008). Current knowledge is summarized below on the impacts of N on vegetation and report on the N concentration in mosses as determined during the 2005/2006 European moss survey.

A. Nitrogen impacts on vegetation

8. Lichens and mosses contain species that are among the most sensitive to elevated atmospheric N deposition. Therefore, critical levels of ammonia have recently been set at a lower concentration (1 $\mu g\ m^{-3}$) for lichens and mosses (and ecosystems where lichens and mosses are a key part of ecosystem integrity) than for higher plants (3 $\mu g\ m^{-3}$; ECE/EB.AIR/WG.5/2007/3). Lichen communities in mixed conifer forests in a “Mediterranean” climate in North America were affected at N depositions above 3.1 kg N $ha^{-1}\ a^{-1}$, affecting food webs and other wildlife.

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

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

11. Plant species that are characteristic for low N conditions are particularly sensitive to airborne N pollution. Some of the most species-rich, infertile grasslands are often found at weakly buffered or neutral conditions, which make them sensitive to acidification and negative impacts of ammonium. For example, acid grasslands in the United Kingdom showed a large decline in species richness with increased N deposition above 10–15 kgN ha^{-1} a^{-1}. In grasslands, there is evidence that enhanced N deposition affects forbs negatively with reduced flowering occurring, whilst grasses increase in abundance. (Semi-)natural vegetation with low empirical critical loads <10 kgN ha^{-1} a^{-1} were predicted to be most at risk of elevated N inputs, such as in “Alpine and subalpine grasslands” and “Arctic, alpine and subalpine scrub” habitats of the European Nature Information System (EUNIS). Upland areas are also most prone to high N wet deposition due to cloud droplets and precipitation. Many of the rare species occur in early succession habitats such as coastal habitats. In sand dunes, rare species were highly susceptible to N-deposition driven soil and vegetation changes.

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

13. The impacts of N on Mediterranean vegetation have hardly been studied. In Mediterranean climates, dry deposition (gases and particulates) of N prevails. The first autumn rain washes and dissolves accumulated particulates, resulting in an N pulse that is not reflected in the annual deposition. Evidence from California in the United States showed that the major risk of N deposition on plant biodiversity in “Mediterranean” climates is an increase in invasive annual grasses in low biomass nutrient poor ecosystems, resulting in species loss at rather low N

loads (10–15 kgN ha^{-1} a^{-1}). However, lichen communities in mixed conifer forests in California were already affected at N loads of 3.1 kgN ha^{-1} a^{-1}.

B. Nitrogen concentrations in mosses in the 2005/2006 survey

14. For the first time in the European moss survey, Parties submitted data on the N concentration in mosses in 2005/2006. A pilot study in selected Scandinavian countries had shown that there was a good linear relationship between the total N concentration in mosses and atmospheric N deposition rates (Harmens et al. 2005). The aims of the 2005/2006 survey were to identify the main polluted areas and produce European maps of the N concentration in mosses and establish whether mosses can be used as biomonitors of atmospheric N deposition across Europe. Data were received from 16 countries encompassing almost 3,000 sites (Harmens et al. 2008b).

15. The lowest total N concentrations in mosses were observed in northern Finland and northern parts of the United Kingdom, and the highest concentrations were found in central and eastern Europe (figure 2). The spatial distribution of the N concentration in mosses was similar to that of the total N deposition modelled by EMEP for 2004, except that the modelled N deposition tended to be relatively lower in Eastern Europe. However, the relationship between total N concentration in mosses and modelled total N deposition, based on averaging all sampling site values within an EMEP grid square, showed considerable scatter (figure 3.a). The apparent asymptotic relationship shows saturation of the total N in mosses above a deposition rate of about 10 kgN ha^{-1} a^{-1}. Although the relationship showed less scatter when it was determined for grid squares where mosses were sampled at least five sites, the apparent asymptotic relationship hardly changed. In contrast, when the total N concentration in mosses was plotted against site-specific bulk N deposition values, for example in Switzerland, a strong positive linear relationship was observed (figure 3.b). This suggested that the relationship between N deposition and the N concentration in mosses was most robust when deposition rates were measured at the moss sampling sites.

Figure 2. Median country-specific N concentration in mosses in 2005/2006

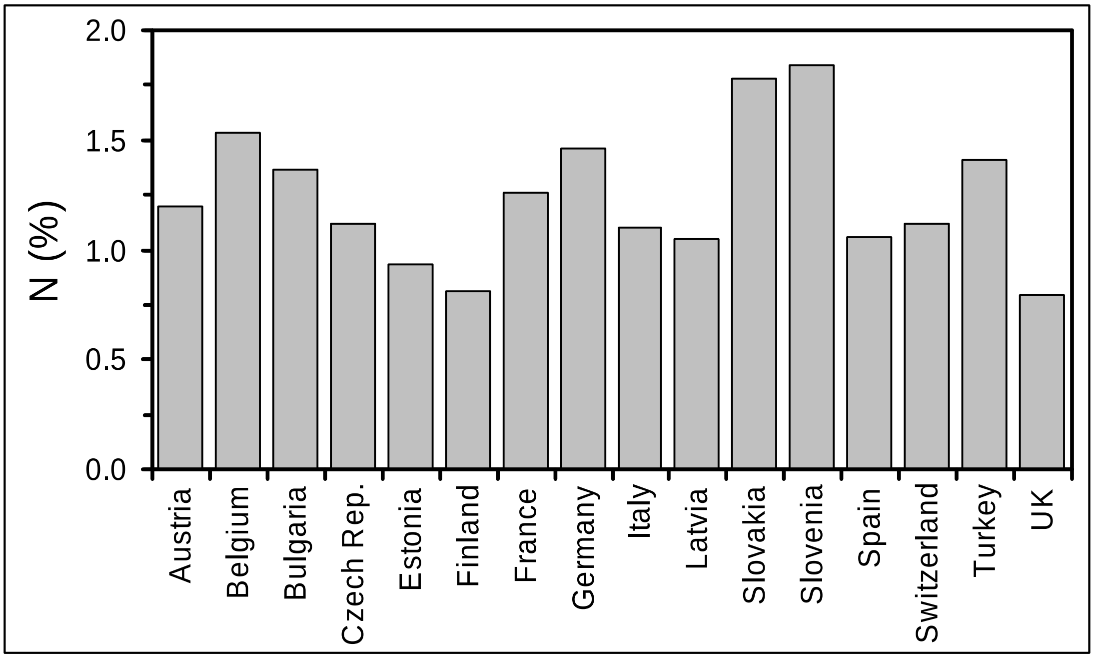
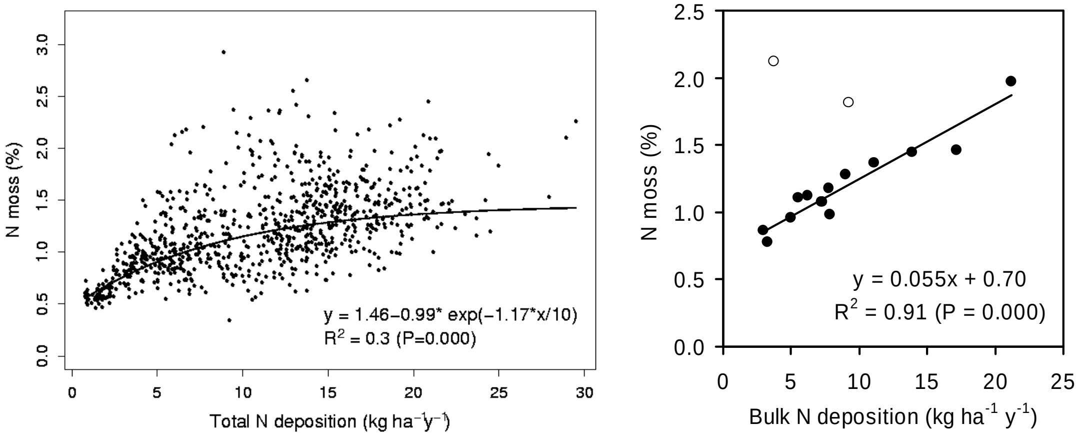


Figure 3. Total and bulk N deposition, showing the relationship (a) between EMEP modelled total N deposition (2004) and averaged N concentration in mosses (2005/2006) per EMEP grid square across Europe; and (b) between measured bulk N deposition rate and N concentration in mosses in Switzerland

(a) (b)



Note: The open symbols were excluded from the regression.

16. Bivariate analysis of the data showed the highest correlations between the total N concentration in mosses and modelled EMEP atmospheric deposition of various N forms: r ranged from 0.55 (dry deposition of reduced N) to 0.64/0.65 (total deposition, total wet deposition, wet deposition and dry deposition of oxidized N). Multivariate analysis identified dry deposition of oxidized N to be statistically the most significant factor, followed by total dry deposition and the livestock density in the participating countries.

17. The total N concentration in mosses can potentially be used as a surrogate for estimating total N deposition and identifying areas with high N deposition at a high spatial resolution. However, factors potentially influencing the relationship between N deposition and its concentration in mosses require further investigation in order to improve the application of mosses as biomonitors of atmospheric N deposition at the European scale. Parties to the Convention were requested to submit data on N concentrations in mosses in the next European moss survey, planned for 2010.

IV. SPATIAL AND TEMPORAL TRENDS OF HEAVY METALS IN ACCUMULATION IN MOSSES IN EUROPE (1990–2005)

18. In the 2005/2006 survey, 28 countries submitted data on the heavy metal concentration in mosses from about 6,000 sites (Harmens et al. 2008a). Data were submitted for the metals aluminium, arsenic, antimony, cadmium (Cd), chromium, copper, iron, lead (Pb), mercury (Hg), nickel, vanadium and zinc. The lowest concentrations of metals in mosses were generally found in Scandinavia, the Baltic States and northern parts of the United Kingdom, although higher concentrations were reported near local sources. Relatively low concentrations of iron, Hg, nickel and vanadium were also observed in Central Europe. Depending on metal, the highest concentrations were often found in Belgium and Eastern European countries, with localized lower concentrations being present. High concentrations of Hg were detected in mosses in Belgium, France, Latvia, Slovakia and Slovenia. Relatively high concentrations of aluminium, arsenic, chromium, iron, nickel and vanadium were found in eastern and southern France.

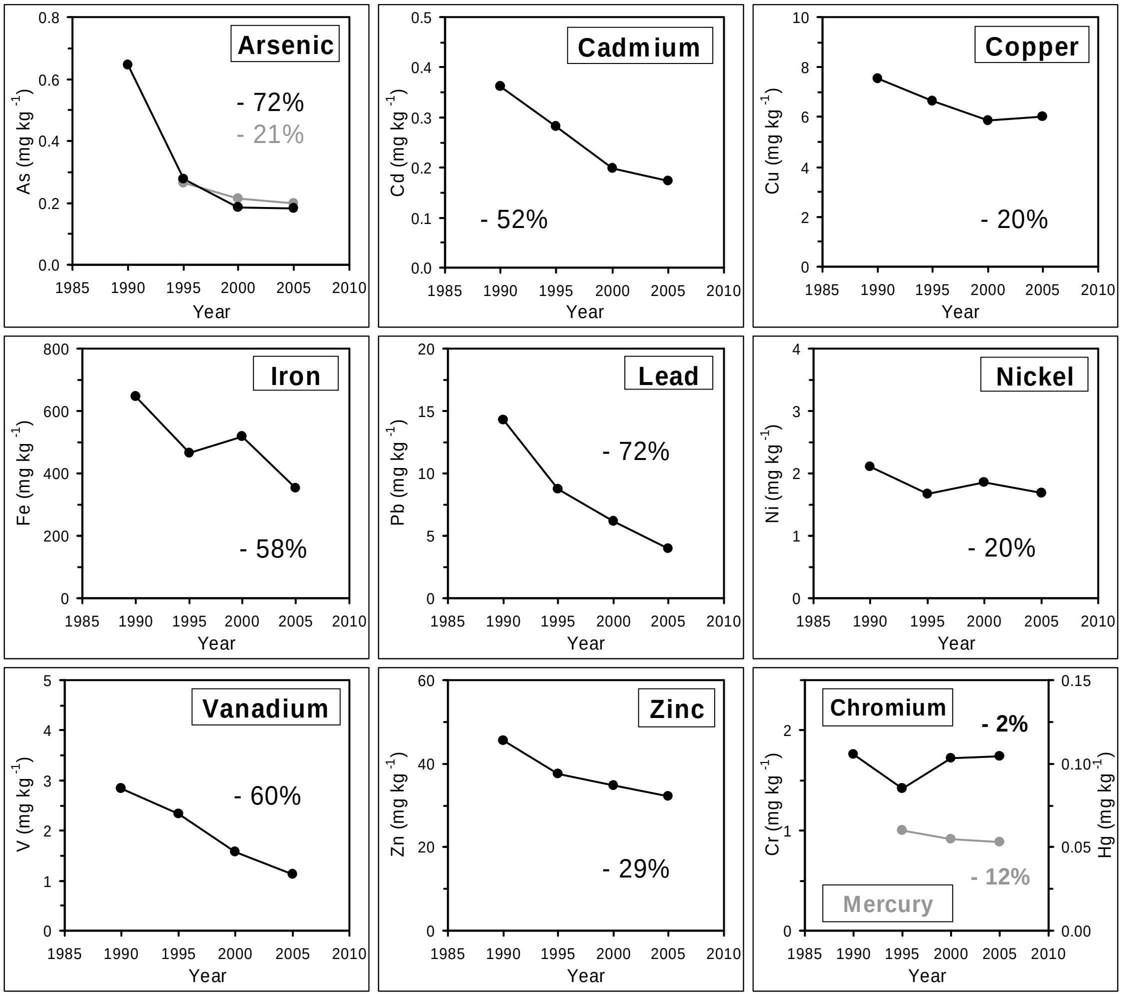
19. Bivariate analysis of the data showed the highest correlations between the Cd and Pb concentration in mosses and (a) modelled EMEP depositions (r = 0.63 for Cd, r = 0.73 for Pb); (b) EMEP total emissions (r = 0.49 for Cd, r = 0.65 for Pb); and (c) the ratio of urban land use in a 100 km radius (r = 0.42 for Cd, r = 0.43 for Pb). Correlations between the Hg concentration in mosses and modelled EMEP depositions (r = 0.20) or anthropogenic emissions were low (r = 0.14).

20. The decline in emission and subsequent deposition of heavy metals across Europe has resulted in a decrease in the heavy metal concentration in mosses since 1990 for the majority of metals (figure 4). Between 1990 and 2005 the metal concentration in mosses has declined the most for Pb (72 per cent), arsenic (72 per cent, based on five countries), vanadium (60 per cent), Cd (52 per cent) and iron (45 per cent). An intermediate decrease was found for zinc (29 per cent), copper (20 per cent) and nickel (20 per cent) and there was no significant reduction for

chromium (2 per cent). Few countries reported data for arsenic and Hg in 1990, but since 1995 the arsenic concentration in mosses has declined by 21 per cent (based on 14 countries), whereas Hg showed no significant decline (12 per cent). On a national or regional scale large deviations from the general European trend were found, i.e. temporal trends were country or region-specific, with no changes or even increases being observed since 1990. Therefore, even in times of generally decreasing metal deposition across Europe, temporal trends were different for different geographical scales.

21. In collaboration with the Meteorological Synthesizing Centre-East (MSC-E) of EMEP, concentrations of Cd, Pb and Hg in mosses were compared with atmospheric deposition fluxes of these metals simulated by the EMEP atmospheric transport model. Preliminary data analysis showed that for Europe as a whole the spatial pattern of Cd and Pb concentrations in mosses and modelled deposition fluxes was similar. In general, regions with higher deposition had higher concentrations in mosses and vice versa. For Hg the spatial pattern was less similar. Initial data analysis indicated that the temporal trends in metal concentration in mosses agreed reasonably well with the trends in metal deposition. Taking the area of sampling into account, the metal concentration in mosses had declined by 73, 46 and 20 per cent across Europe between 1990 (1995 for Hg) and 2005, whereas the modelled deposition had declined by 70, 41 and 30 per cent for Pb, Cd and Hg respectively. Further data analysis will be conducted in the future.

Figure 4. Trends in median heavy metal concentration in mosses, based on data from countries that reported data for all survey years for the respective metals



Note: The negative numbers in each graph indicate the percentage decline in metal concentrations in mosses between 1990 (or 1995) and 2005.

V. PRIORITIES FOR THE FUTURE

22. There is a clear need to incorporate the O_3 flux-based method for vegetation into integrated assessment modelling and to define effects-based targets for the future for policy purposes. To support this process, development of a generic flux-based method for (semi-) natural vegetation is urgently required. Needs to further our knowledge of the damaging impacts of ozone on vegetation were reported in ECE/EB.AIR.WG.1/2008/9. Additional priorities for the future include a review on the impacts of ozone on food security, carbon sequestration and linkages between O_3 and climate change.

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

24. The relationship between heavy metal concentration in mosses and atmospheric deposition modelled by EMEP, including the identification of factors affecting the relationship, requires further investigation at various geographical scales. In addition, detailed comparison of temporal trends will provide further evidence regarding the performance of the EMEP atmospheric transport model. To enhance the application of the heavy metals in mosses data, further integration with other European data sets needs to be explored.

VI. REFERENCES[1]

Harmens H, Mills G, Hayes F et al. (2009) Air pollution and vegetation. ICP Vegetation annual report 2008/2009.

Harmens H, Mills G, Hayes F, Williams P, De Temmerman L (2005) and the participants of ICP Vegetation. Air pollution and vegetation. ICP Vegetation annual report 2004/2005.

Harmens H, Norris D and the participants of the moss survey (2008a) Spatial and temporal trends in heavy metal accumulation in mosses in Europe (1990–2005). ICP Vegetation Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, United Kingdom.

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

Hayes F, Mills G, Harmens H, Norris D (2007) Evidence of widespread ozone damage to vegetation in Europe (1990–2006). ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, Bangor, United Kingdom.

Hettelingh J-P, Posch M, Slootweg J (editors) (2008) Critical load, dynamic modelling and impact assessment in Europe: CCE Status Report 2008. Coordination Centre for Effects, Netherlands Environmental Assessment Agency.

---

[1] The references have been reproduced as received by the secretariat.