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INTRODUCTION

# Key Studies on Air Pollution and Climate Change Impacts on Forests: An Introduction

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Global change can be viewed as the sum of all environmental pollution (Trevor, 2003). To sustain human activities, massive amounts of pollutants are discharged into the biosphere. The sum of all these activities results in warming the biosphere, weather extremes, loss of biodiversity and pollution of the water, air and soil components of the biosphere. Prior to 1940, when atmospheric concentrations of greenhouse gases (GHG) were low, solar radiation explains most of the northern hemisphere (NH) temperature changes. Since 1975, emission of GHGs and aerosols explains most of the observed temperature increases (National Assessment Synthesis Team, 2000). The largest change in climate may not be temperature but increased precipitation (a few tenths to 1% per decade in NH) and cloudiness (~2% per decade in NH). Precipitation seems to be coming in the form of heavier events rather than being spread out over time. The additional water runs off into streams are predicted to cause erosion and flooding but not substantial increase of long-term soil moisture (Keller, 2003). Carbon dioxide ($CO_2$), resulting mainly from burning of fossil fuels, is a main driver of climate change and in that regard is followed by methane ($CH_4$), halocarbons and nitrous oxide ($N_2O$) (IPCC, 2001). Aerosols and particulate matter can have either a positive or negative effect on climate depending on their composition. Tropospheric ozone ($O_3$), the secondary pollutant generated from non-methane volatile organic compounds (VOCs), carbon monoxide (CO) and nitrogen oxides ($NO_x$) in photochemical reactions, is particularly relevant for the linkages between climate change and air pollution. Climate change, especially high radiation and temperature, promotes increases in $O_3$ concentrations when precursors are present. The steadily growing background $O_3$ concentrations affect climate due to $O_3$ being a potent GHG itself and indirectly influencing concentrations of other GHGs such as $CH_4$ (Bytnerowicz et al., 2007). Ozone concentrations in NH have been increasing for more than 100 years. Highest peak concentrations were observed in 1950–1980 in the areas with high emissions of $O_3$ precursors and high solar radiation. Classical example of extremely high levels of $O_3$ is the Los Angeles Basin in southern California where in the 1960s and 1970s peak values occasionally were approaching 1 ppm. Even in the 1980s, the peak hourly $O_3$ values as measured in the mountains surrounding Los Angeles occasionally

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exceeded 400 ppb (A. Bytnerowicz, unpublished). With reformulation of gasoline that was aimed at reducing $O_3$ production, peak $O_3$ concentrations gradually decreased first in southern California and later also in other parts of the US and Europe. At present, in North America, Europe and Asia there is a general trend of reducing peaks and rising background levels of $O_3$ even in remote areas due to increasing emissions of $NO_x$ and VOCs worldwide and their long-range transport (Midgley et al., 2002). This includes effects of the trans-Pacific transport of polluted air masses from Asia to North America, trans-Atlantic transport of the North American air pollution plume to Europe, and transcontinental movement of polluted air masses from Europe to Asia (Derwent, Stevenson, Collins, & Johnson, 2004). Ozone has the highest potential for phytotoxic effects at its ambient levels — it is predicted that by 2100 half of the World's forest will be exposed to phytotoxic levels of this pollutant (Fowler et al., 1999). In addition to $O_3$, other air pollutants produced by fossil fuel burning, industrial, agricultural and urban emissions may have pronounced effects on forests. Sulfur dioxide is probably the best known example — at elevated concentrations it can cause extensive direct damage to vegetation and can also contribute to acidification of ecosystems (Legge, Jager, & Krupa, 1999). Sulfur dioxide continues to be a persistent problem, especially in developing countries in Asia where in the future more coal is projected to be used for energy production. On the contrary, in North America and Europe, effective air pollution control measures have resulted in a significant reduction of the present and predicted $SO_2$ emissions. Nitrogen oxides and ammonia ($NH_3$) as well as the secondary N pollutant, nitric acid ($HNO_3$) vapor, may have direct phytotoxic effects but only at high ambient concentrations (Bytnerowicz et al., 1999). Gaseous N pollutants and the in water dissolved N compounds contribute to N deposition that can have various effects on forests and other ecosystems (Fenn et al., 1998). At present, even at the highest $NO_2$ and $HNO_3$ ambient concentrations, phytotoxic effects are very unlikely in forests of Europe and North America (Bytnerowicz et al., 1999). However, considering the rapidly increasing air pollution in areas such as China and other parts of Asia an increase of such negative effects may be expected in the near future. Dry deposition of $NO_x$, $NH_3$ and to a smaller degree also of particulate $NO_3^-$ and $NH_4^+$ provide significant amounts of nutritional N to forest and other ecosystems. In the near future, eutrophication caused by N deposition will remain a substantial threat to large areas throughout Europe, North America and Asia. Nitrogenous air pollutants as the key components of acidic precipitation and therefore contributing to the acidification of entire ecosystems are also predicted to remain of high importance. Within the European Union (EU), between 1990 and 2000, emissions of acidifying pollutants decreased by 40% (EEA, 2003). Acidification is nevertheless still a major environmental problem in Europe, especially in its central part (EEA, 2003). In the US, a decrease of acidic deposition has been taking place since the 1980s. Between 1994 and 2004, an increase of the precipitation pH has been observed, with the most visible improvement in the eastern states. This improvement was caused by the decrease of both $SO_4^{2-}$ and $NO_3^-$ concentrations resulting from increasing effectiveness of pollution control strategies.

To understand the integrated effects of air pollution and climate change on forest ecosystems, a multi-pollutant and multi-effect approach is required. In response to the increasing awareness about the links between air pollutants and climate change, and its impact on forests, special sessions were organized at the XXII IUFRO World Congress, August 2005, Brisbane, Australia, on behalf of the IUFRO Research Group 'Impacts of Air Pollution and Climate Change on Forest Ecosystems' (RG 7.01.00). The mission of the IUFRO RG 7.01.00 is to promote international cooperation, to encourage an interactive process between scientists, policy makers and representatives of local to regional governments and institutions, in order to share scientific knowledge and harmonize effective strategies aimed to reduce the risk for forests related to air pollution and climate change.

A part of the poster presentations during these sessions has been included in this special issue of Environmental Monitoring and Assessment, and summarizes key studies on potential and actual impacts of air pollution and climate change on forests. As guest editors, we wish to thank the 24 reviewers who contributed their assessments of the papers submitted for this special issue. The themes are centred around the following topics of global importance: monitoring the exposure to air pollutants (Waldner et al., this issue; Paoletti, De Marco and

Racalbuto, this issue), evaluation of response indicators (Kraigher et al., this issue; Grebenc and Kraigher, this issue; Drobyshev et al., this issue; Tausz et al., this issue), and investigation on the mechanisms of action of single (Cano et al., this issue; Paoletti, Nali and Lorenzini, this issue) or interacting factors (Shimizu and Feng, this issue; Van Miegroet and Jandl, this issue). Monitoring is essential to document environmental changes. For a reliable quantification of risk, efforts to translate exposure (potential risk assessment) into impacts on forests (actual risk assessment or impact assessment) face the still open questions related to the value of the response indicator used in multivariate analysis and to the importance of the monitoring design (Paoletti et al., 2003). Most of the attention in this issue focuses on ozone. Despite of the topicality of the ozone problem, future work should address the synergistic effects of air pollution and climate change to a greater extent. Quantifying the risks to forests posed by air pollutants and climate change still requires a complete characterization of the risk and of the thresholds when hazard is significant. A simultaneous addressing of the air pollution and climate change effects on forests may result in more effective research, management and monitoring as well as better integration of local, national and global environmental policies (Bytnerowicz et al., 2007).

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