

**2002 STATE OF SCIENCE AND KNOWLEDGE GAPS WITH RESPECT TO AIR
POLLUTION IMPACTS ON FORESTS: REPORTS FROM IUFRO RG 7.04.00 MEETING**

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Introduction

The 20th meeting for specialists in air pollution effects on forest ecosystems (30th August - 2nd September, 2002, Zvolen, Slovakia) was devoted to 'Long Term Air Pollution Effect on Forest Ecosystems'. The contributions were grouped into three main categories, namely into 'problems in diagnosis, monitoring and evaluation' (section I, corresponding to the IUFRO Working Party 7.04.01), 'restoration and sustainable management' (II, WP 7.04.05) and 'climatic changes and effects on nutrient status and genetics' (III, grouping WPs 7.04.02, 7.04.03, and 7.04.04).

Since the focus of the meeting was on long-term monitoring of forest conditions and on restoration of affected areas, there were fewer participants from WP 7.04.02 and even less participants from 7.04.04. Their reports may therefore give only a partial view of the state of science and gaps in knowledge of their working parties.

The presentations given at the meeting focused on spatial and temporal characterization of ozone distribution, effects of ozone and atmospheric deposition on forests (including effects of elevated carbon dioxide and ozone), effects of point sources of air pollution on several indicators of forest health, distribution of heavy metals in various ecosystem compartments and development of indicators of forest health/air pollution effects. Both field studies and experimental works were presented, providing evidence documenting the air pollution impact on different ecosystems and/or forest trees in Europe and North America.

Because of increased interest on the effects of the elevated levels of atmospheric CO₂ and related climate change issues expressed by many participants at our last three meetings (Edinburgh, Houghton, Zvolen), discussion was held on the benefits of modifying the RG title into 'Impacts of air pollutants and

climate change on forest ecosystems'. The new title would better reflect changes that have occurred in the global pollution climate and the present research directions of our group.

Diagnosis, Monitoring and Evaluation (WP 7.04.01)

State of science

Monitoring has a key role to detect and evaluate the long-term effects of air pollution on forest ecosystems. In particular, proper monitoring is acknowledged as essential to document changes in the condition of forest resources in relation to air pollution and environmental stressors. These data are needed to provide scientific basis for action to be undertaken at the political level (e.g. air pollution abatement strategies). To accomplish these tasks, monitoring programmes should consider a variety of different aspects, among which the links with policy-relevant assessment questions, the needs of a proper design and the selection of suited indicators are essential. For example, the connections between monitoring and policy-relevant air pollution issues were examined by considering three major international and national activity, such as the UN/ECE ICP-Forests network in Europe, the EANET in East Asia and the management of air quality in wilderness area and national parks in the USA (Hausmann et al.). While the value of long-term, large-scale monitoring programmes is well recognized, the expected contribution of monitoring programmes to policy relevant questions implies that the data provided by the monitoring should be scientifically defensible: in particular, such programs should be reliable, unbiased and should concern indicators that have a clear link with the assessment question being examined (Table 1). The extent to which these data attributes are actually met has been examined by Fattorini and Ferretti for Europe and by Percy at a broader scale. There is evidence that the sampling design adopted for the forest condition survey in Europe cannot ensure an unbiased estimate of some parameters such as the defoliation at the site level. Therefore, reliable large-scale spatial and temporal comparisons are not possible. On the other hand, the value of defoliation as an indicator of air pollution effects has been questioned for some time, and can even be more questioned in relation to the changing pollution climate (from sulfur deposition and acidification, to nitrogen eutrophication and ozone) and geographical scale of concern (from local to global). In this perspective, Percy argues whether the current format of monitoring programmes can actually be the way to link forest health and air pollution.

The evidence of the changes that have occurred in the global pollution climate has been reflected by the presentations given in the session. In particular, much attention was given to ozone (alone or in combination with CO₂), and much less to heavy metals, acidification and point source emissions. As far as O₃ is concerned, the papers covered a variety of environmental situations (from South to Central and North Europe; field studies and experiments) and issues (from ozone uptake to visual and non-visual O₃ injury, to O₃ and CO₂ interactions on growth and biomass allocation) and suggest a number of topics (from diagnostic methods to the impact of O₃ on leaf senescence).

Besides O₃, the other presentations cover a variety of issues. Acidification/eutrophication studies were presented, with concern shifting from the chemical characteristics of the atmospheric deposition (studies of this type are still important for geographical areas where information is lacking) to the calculation of element budgets and to the effects of different N treatments (e.g., with or without S). A number of other studies (mostly field studies dealing with point source, heavy metals and indicators) provide a chance for a fruitful discussion about the value of the indicators (lichens, mosses, various tree compartments, animals) and the concept adopted for the monitoring (integrated vs. single media monitoring). For example, Kozlov presented a study on the air pollution effects on biodiversity in various ecosystems around the Nickel-Copper smelter of Monchegorsk. He suggested that complex interactions occur between the direct effects of air pollution (toxicity) and the subsequent changes in the microclimate of the concerned areas due to changes in forest health and coverage. Another example about the need of suited indicators is the one

suggested by the presentation of Lukác and Godbold based on an investigation carried out at POPFACE experiment in Italy: they found that belowground biomass responds to increase CO₂ levels by increasing C allocation and increased roots turnover. Their presentation reminded the audience that soil, and especially soil biota, are seldom considered in monitoring programmes.

Knowledge gaps

A number of topics were suggested as important directions for future research. Specific topics were suggested mostly in relation to O₃-oriented researches and include: the potential long-term adaptation to O₃, the need for a careful diagnostic approach during field studies, the importance of a better understanding of O₃-nutrient interactions, the relationships between O₃ exposure, O₃ flux and effects at the tree level, and the interactions between CO₂ and multiple level of O₃ exposure. Besides these research priorities, the scientists participating to Section I agreed upon that future works should be directed towards a better indicator development (with special emphasis on soil biota and mycorrhiza). In this respect, the unit felt that the term 'diagnosis' may overlap to 'indicator development' in WP 7.04.02, so that the term has been proposed to change to 'detection'. Future directions should also address integrated monitoring, adoption of suited sampling design, interactions between biotic and abiotic factors and cooperation/communication between scientists/organizations/monitoring and research networks. The latter issue has been raised over the last three meetings of the RG and is particular important when considering that impacts of air pollution on forests is likely to increase especially in parts of SE Asia, South-America and Africa, *i.e.* those parts of the world that were the least represented at the meeting and that will benefit from an improved networking of research.

Table 1 – Example of the connections between typical policy questions and the implicit data requirements (based on Fattorini and Ferretti, 2002).

Policy question	Assessment question	Assessment endpoint	In formulas (examples)	Data requirements
At what extent air pollution affects the forests ?	What is : • the proportion of forests affected by pollution? • the mean status of forests?	Estimate population parameters • population total (<i>T</i>) • population mean (<i>μ</i>)	$T = \sum_{i=1}^N y_i$ $m = \frac{1}{N} \sum_{i=1}^N y_i$	Allow unbiased estimates
What is the spatial and temporal trends of air pollution effects on forests ?	Is there any significant change in the mean status • between years? • between sites/groups of sites?	Statistical test (<i>t</i>) between: • measurement occasions • sites/groups of sites	$= \frac{ \bar{y}_1 - \bar{y}_2 \sqrt{N}}{S_{(\bar{y}_1, \bar{y}_2)}}$	Allow hypothesis testing
What cause-effect relationships are involved?	What is the relation between pollution level (stressor) and tree condition (response)?	Proportion of variance of response explained by the stressor (<i>R</i> ²)	$y = a_0 + a_1 x_1 + a_2 x_2 + \dots + a_n x_n$	Allow reliable values of dependent and predictive variables

Mechanisms of Action and Indicator Development (WP 7.04.02)

State of science

Free air release fumigation systems (including FACE) and tall single tree open top chambers (including 'normal' OTC) are now widely used tools in experiments with ozone and/or carbon dioxide in western European or North American countries. Emphasis is placed on older and mature trees as these are more relevant for the world situation and often show different reactions compared to saplings and young

plants. In the eastern European countries, field studies around smelters and regions with acid depositions and heavy metal pollution still dominate most investigations although in some cases it is more the decline in pollution – due to newly introduced filter technologies or the contemporary economic situations – that stirs interest. Noteworthy is that many of the results reported came out of collaborative studies from groups of western and eastern scientists, namely those of the research programs in the FACE experiments in the US, ozone fumigations in OTC in Finland and field investigations in the Czech Republic, Slovakia and Poland.

Concerning the pollutant target levels within the ecosystem, the whole trees and leaves as well as the roots were mostly studied and only to a lesser extent the level of the cell. The investigations focussed on system parameters such as growth, allocation and biodiversity. A few studies also dealt with competition and nutrient cycling in the ecosystem. Generally it was more the development of the indicators that was analysed and not so much the mechanisms of action. The studies were also more descriptive than explanatory. Only some of the reported investigations were based on modern molecular-biological technologies although these methods are known among the members of our working party.

Knowledge gaps

Our knowledge of the effects of air pollution on the mechanisms of action on a plant level and the competition and succession impact on the ecosystem is still small. Methods in functional genomics and proteomics, as well as entire research programs that link controlled experiments with defined pollutant regimes and model ecosystems to case studies in the field verifying hypotheses, may help to develop models predicting the effects of long-term pollution. In this regard, the gaps in knowledge that were identified at the meetings two and four years ago still exist.

Atmospheric Deposition, Soils and Nutrient Cycles (WP 7.04.03)

State of Science

As a result of international collaboration between the Czech and Italian scientists, progress has been made in understanding responses of forests in the Krkonose Mountains, the Czech Republic, to industrial air pollution. In general, heavy metal distribution in soil profiles did not indicate appreciable contribution of atmospheric contamination. The opposite was typical of lead that showed highest concentrations in the topsoil organic layer. No relationship between heavy metals accumulation in soils and forest decline was determined – the highest levels of metals were found in the least damaged sites. While the geostatistical analysis indicated significant spatial dependence for distribution of Pb and Cu, no significant relationship between topsoil concentrations of these metals and forest decline was found. These results are somewhat surprising considering that reports on forest decline in the “Black Triangle” from the 1970s and 1980s were pointing towards long-term toxic effects of heavy metals on tree roots triggered by high acidity related to S and N industrial deposition. Different results have been reported from the Swiss mountain forests: increasing soil acidification in these forest ecosystems caused by long-term N deposition resulted in a decrease of the ratio of base cations/aluminum in soil extracts, increased Mn and reduced P concentrations in beech foliage. Another consequence of increasing soil acidity was decreased root distribution within soil profile that might reduce resistance of trees to windthrow. That study confirmed some field observations from Romania and Slovakia where in recent years large areas of beech forests were affected by windthrow in the regions characterized by high N deposition.

For the Slovak forests, critical loads for N, S, and heavy metals were calculated based on the steady-state mass balance method while the AOT40 values for ozone were calculated based on real-time concentrations of the pollutant. These datasets were developed within the ICP-Forests network and will be included in the European-wide evaluation of forest health in relation to atmospheric deposition. Chemical analysis of moss samples was used for evaluation of Norway spruce forests stands in Slovakia.

Comparison of samples collected in 1991 and 2000 indicated that concentrations of Cd, Cu and Pb were reduced by about 50%, and Zn concentrations even by 70%. During the same period, concentrations of Ni and V increased by about 50%, and Hg and Fe concentrations did not change. These changes indicate decreasing production of steel and non-ferrous metals, phasing out of leaded gasoline, and gradual increase of heavy oil combustion. This study is part of the pan-European moss survey 2000 and the results will be incorporated into the Atlas of Heavy Metals Atmospheric Deposition in Europe.

Multivariate statistics was used to evaluate relationship between atmospheric deposition and forest condition in German forests for the 1989 – 1995 data. Results of that analysis indicated increasing importance of N deposition and declining importance of S deposition. In case of Scots pine and Norway spruce, S and Ca inputs were related to high foliar levels of these elements. N deposition to Scots pine stands negatively affected Mg content of foliage.

In Slovenia, long-term effects of decreasing levels of SO₂ had minimal effects on soil chemistry and foliar tree nutrient status of beech and Norway spruce stands. Similarly, no significant tree-ring width decline during the periods of high S atmospheric emissions were found, with only occasional increase during years of reduced pollution.

In Sierra Nevada, California, ponderosa pine responded positively both to elevated CO₂ and N - both CO₂ and N additions increased growth of trees. Elevated CO₂ caused reduction of N foliar concentrations, but the increase in biomass more than offset this resulting in an increase in N uptake from the soil. The authors of the study concluded that trees growing at elevated CO₂ concentrations might be trying to reach for available N into deeper layers of soil.

Knowledge gaps

In many reported studies, information of the effects of air pollution on forests is still not supported by comprehensive information regarding long-term changes in physical environment. Changes in spatial and temporal pollution distribution, changes in pollution ratios, or information on climatic conditions recorded over long periods of time are essential for understanding forest health changes. There is a need for studies on forest health changes on the well-characterized air pollution gradients in natural settings. Examples of such studies are the San Bernardino Mountains in California with well-defined ozone and N deposition gradients, or Tatra and Retezat ranges in the Carpathian Mountains. There is an urgent need for more work in development of critical loads approach for evaluation of N, S and heavy metals deposition on forests. There is a great progress in development of methodologies and models for that task. Better international exchange of information and collaboration between scientists, managers and decision makers are needed in this regard. The IUFRO RG 7.04.00 could greatly help in this task.

In regards to the potential response to elevated CO₂, we lack knowledge about how nutrient-deficient forest will respond. Specifically: 1) Will their growth continue to be constrained by nutrients or will lower concentrations facilitate greater nutrient use efficiency? 2) Will elevated CO₂ allow greater carbon allocation to roots and greater soil nutrient uptake? 3) Will elevated CO₂ facilitate greater non-symbiotic, rhizosphere N fixation? Some of these questions have been addressed at the seedling/sapling stage, but information is needed on responses in mature forests, including feedbacks via nutrient cycles. Free-Air CO₂ (FACE) studies are underway now which will contribute greatly to our understanding of these processes.

Influence of Air Pollution and Climate Change on Genetics, Adaptation and Succession (WP 7.04.04)

State of science

During the 20th Meeting, forest genetic topics were under-represented as compared to former conferences such as Edinburgh 1998. Unfortunately, the preceding IUFRO Symposium of Population and Evolutionary Genetics of Forest Trees (Stará Lesná, Slovakia, Aug. 25-29) did not result in a coordinating effect between the two RGs. Nevertheless, the two genetic contributions highlighted the state of science with respect to the use of biochemical genetic and molecular genetic markers in the monitoring of the

genetic response of tree populations to stress. In case of the studies on oak decline (Hertel & Zaspel), the genetic characterisation of three vitality groups resulted in higher genetic variation in the intermediate group as compared to the tolerant and the sensitive groups. Furthermore, results indicate responses in terms of selection processes. In case of the study on genetic differentiation of populations of Norway spruce in response to air and soil pollution (Schubert et al.), chloroplast microsatellite markers revealed genetic differentiation between tolerant and sensitive subsets. Extranuclear markers seem to play a more important role in the monitoring of stress response than expected so far. This may also concern its future use in marker-assisted selection.

In order to practise a better integration of forest genetic groups into the work of RG 7.04.00, it was suggested to put a stronger emphasis on the co-operation with RG 2.04.00 in particular with respect to links between genetics and physiology. The invitation of key-note speakers may help to compensate for the current deficiencies.

Knowledge gaps

In spite of the fact that exciting tools were developed in order to study gene expression in response to stress and corresponding links between functional genomics and proteomics, there are still substantial gaps in the utilisation of these tools. In particular, studies on the genetic response to biotic stress are scarce. Furthermore, it is evident that there is hardly any information about the genetics of the host-parasite-systems. It appears that gaps between the efficient work of both, geneticists on the one side and of physiologists on the other, could be bridged more efficiently than done in the past. Evidently, one of the barriers is related to different views at populations and correspondingly strongly diverging sample sizes: physiologists tend to focus the individual level by studying very small sample sizes while geneticists usually address the population level with inclusion of at least many tens of individuals per population. Compromises with respect to sample sizes will also help to increase the representativeness of physiological studies because most forest tree species reveal outstandingly large genetic variation within populations.

Within the fields of forest genetics, substantial efforts on genome analysis and marker development are required which offer highly valuable information and opens up many fields of co-operation. For instance, the verification of correlations between genetic markers and various phenotypic traits such as growth, tolerance or susceptibility against a-biotic and/or biotic stress components supplies valuable diagnostic tools as well as links to research in the fields of physiology, botany, zoology, soil sciences, ecology, forest management and tree breeding.

Restoration and Sustainable Management (WP 7.04.05)

State of science

Presentations focused on two main topics: forest injuries due to acidification and alkalization of forest environment. It was noticed that deposition of N compounds demonstrate a double effect on forest: fertilization – nutrient enrichment and depression – and acidification. According to the data of the Lithuanian foresters, intensity of these processes depends on concentration level of pollutants. The ratio between tree height and radial increment, which could reach about 1.6-1.8, and the ratio between branch length increment from upper and lower parts of the crown, which could reach about 2 and more could be used as tree parameters characterising stability of premature and mature forest stands.

Ground vegetation is often more sensitive to acidification effects than forest trees. In stands in Germany and in the Czech Republic that were severely damaged, the observed invasion of nitrophilous plants and grain herbs were attributed not only to the eutrophication of the environment caused by increased N deposition, but also to a reduction in competition due to thinning of the crowns (defoliation)

and tree density in the stand. Floristic changes most frequently occur due to abundance of plant species that are not typical of a forest environment.

Some main differences arise when forests are damaged by alkalizing pollutants. Under deposition loads solid substances become more alkaline up to pH 7-10. This results in the damage of coniferous stands at a distance of a few km from the industrial plants. Damages are heavier in older stands. Soil undergoes more distinct changes. With increasing soil alkalinity the abundance of acidophyllous (*Vaccinium myrtillus* L., *V. vitis – idaea* L.) species decreases. They are substituted by more tolerant to alkaline environment species, i.e. calcephyllous (*Rubus caesius* L., *Campylium stellatum* Hedw. Etc.) and eutrophic species. Mosses respond to the alkalization of environment more than grasses and woody vegetation.

The presented data indicated that under acidic pollution the distance from the industrial plant over which chemical changes in forest soil were observed is 3-8 times less than the distance over which emission compounds damaged coniferous stands. Contrary results were obtained in the areas under alcalic pollution. Changes in forest soil are much more evident than worsening of tree condition.

The main result of long term pollution effect on forest ecosystem is the increasingly wide spread clear-cut areas. The trees planted in these sites do not have the cover of older stands and are under strong environmental stress. Some forestry treatments are suggested in afforestation of these areas. In the Czech Republic dolomitic limestone powder is applied directly in to the area of planting pits. In Lithuania such areas due to infestation by grasses are already treeless. Application of herbicide is suggested in some cases of afforestation. In Slovakia application of the tablet fertilizer SILVAMIX®MG on survival and growth of Norway spruce planting stock, in one-year or older cultures is suggested. It should be emphasized that each application should be carried out individually on the basis of a thorough analysis of the local condition.

The negative impact of bulldozers on forest condition was noticed in the Czech Republic. Bulldozing represents profound degradation of forest soils, consisting of removal of humus layer with nutrients into windows, nutrient cycle disturbance and decline of plantation growth. Therefore in the sites degraded by bulldozing, the Czech forest researchers suggested to select preparatory species with maximum favorable restoration effects, consisting of the maximum biomass production and quality, and use appropriate liming and fertilization which should accelerate site restoration.

Problem of yellowing of the Norway spruce needles is solved by dolomite liming in order to supply Mg. As a result of liming, the reaction of soil pH raised, as well as the base content and base saturation. Content of available Mg and Ca increased, in contrast to the K and N contents. On the other hand unfavorable effects of liming on the N dynamics were observed.

While stand thinning improved health and productivity of stands in polluted areas, thinner stands are more damaged by air pollutants than denser stands. Reseachers from Germany and Lithuania note the following stand stability parameters: dense stand, mixed stand and suppressed tree cutting during thinning of stand. It is suggested not to use thinning cutting, especially in older stands in the highly polluted areas.

Species composition is important in afforestation of clear-cut areas in polluted areas. Larch is rated as the species with the best growth dynamics. On the other hand beech is the worst species for afforestation under these conditions according to the experience of the Czech forest researches. One of the causes of a poor performance of that species is that it often could be damaged by frost.

Knowledge gaps

The data in the 23 talks presented at the meeting showed that levels of anthropogenic stresses range from lower level of damage to total technogenic destruction caused by acid or alcalic deposition and by improper forest practice. Remedial silvicultural measures depend on the level of injuries. In slightly and moderately stressed forest stands, the classical silvicultural treatments offer acceptable potential of their stabilization. In the heavily damaged stands or in the clear-cut areas with destroyed soil compartment, a

total restoration of such stands is suggested. But presented data have indicated a lack of the ecosystem-oriented view on the investigated problems resulting in growing knowledge gaps especially in cases when the common effects of natural, anthropogenic and improper forest treatments are considered. In polluted areas the main problem remains to maintain the long-term sustainability of forest ecosystems by all available means. Therefore it should be noticed that each application of forestry treatments have to be carried out individually on the basis of a thorough analysis of the local condition and state of science.