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Forest Decline and Reproduction: Regional and Global Consequences (Proceedings of a Workshop in Krakow, Poland, 23-27 March 1987)

Kairiukstis, L., Nilsson, S. and Straszak, A.

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FOREST DECLINE AND REPRODUCTION:
Regional and Global Consequences

L. Kairiukstis*
S. Nilsson**
A. Straszak***
Editors

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PROCEEDINGS OF THE WORKSHOP HELD IN KRAKOW, POLAND
23-27 March, 1987

**Environment Program, IIASA, A-2361 Laxenburg, Austria*
***Environment Program, IIASA, A-2361 Laxenburg, Austria*
and
College of Forestry, Swedish University of Agricultural Sciences, Garpenberg, Sweden
****Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland*

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

FOREWORD

Within the framework of the Dendrochronology, Biosphere and Acid Rain activities of IIASA's Environment Program, a Workshop on **FOREST DECLINE AND REPRODUCTION: Regional and Global Consequences** was held in Kraków, Poland from 23rd to 27th March, 1987. The Workshop was organized by IIASA in cooperation with the International Union of Forestry Research Organizations (IUFRO) and the Systems Research Institute of the Polish Academy of Sciences in Warsaw. The objectives of the Workshop were to seek a consensus about the status and knowledge of forest decline, especially in Europe, to identify the choices that international organizations, the forestry community, governments and industry must face, and to discuss ways to avoid further forest decline and facilitate the sustainability of the forest sector. A special field study trip was arranged to the Niepolomice Forest where special attention was given to the bio-indications of industrial damage and the disturbances of the main forest functions were discussed.

The Workshop was attended by some 90 senior scientists and agency representatives from East and West Europe, North America, Scandinavia and Japan. Great interest was shown by the ECE/FAO Team of Experts on Forest Decline whose representatives attended as observers. The Team of Experts held a special Committee Meeting in connection with the results achieved.

In addition to presentations of some 60 papers on forest decline, the Workshop organizers and a number of key speakers prepared a set of resolutions that were adopted by the Workshop participants. Briefly, the resolutions call for reductions of air pollutant emissions, improved monitoring of the extent and growth rate of forest decline, more research in specific areas, and increased international cooperation.

Robert E. Munn
Leader
Environment Program

August 1987

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all the participants of the Workshop who devoted their effort and time to making this meeting the success that it proved to be, for contributing to this volume and to continuing research in this field of science.

I would like to give special thanks to my colleagues at IIASA, Prof. Sten Nilsson and Dr. Peter Duinker and Ms. Olivia Völker for their efforts. Also I would like to thank Prof. R.E. Munn (Leader, Environment Program, IIASA), Prof. L. Lönnstedt (IUFRO, Sweden), Dr. Otmar Bein (IUFRO, Vienna) and our Polish colleagues Prof. A. Straszak and Dr. J. Owsiński (SRI, Warsaw) as well as our gracious hosts in Kraków, Acad. J. Litwiniszyn, Director Wacław, Director Wiltowski, Prof. Grodziński and Mr. M. Paszucha, for the kind hospitality extended to us during our visit in Kraków and for helping to make this meeting a very successful and fruitful experience.

Academician Leonardas Kairiukstis
Deputy Leader
Environment Program

August, 1987

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1. INTRODUCTION

1.1 FOREST DECLINE: BACKGROUND TO THE PROBLEM*

L. Kairiukstis
Deputy Leader, Environment Program
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, AUSTRIA

During the last ten years, forest decline has become a common phenomenon, particularly in highly industrialized countries. For example, forest damage in Western and Central Europe has progressed to an existential threat. Some estimations have shown that there are about 6 million hectars of damaged forest in Europe at this time. At least 1.2 billion cubic meters of standing volume in Central/Eastern and Western Europe are severely damaged. Also, in Nordic countries about 700 million cubic meters can be regarded as being affected in a declining state.

Recent reports (e.g., by Friedland et al., Sedjo, Linzon, Rennie, etc. published in this Proceedings) from the United States and Canada indicated that in the northeastern U.S. red spruce and balsam fir have shown a regionally consistent growth decline. A decline in radial increment and increased mortality among spruce and fir in the Appalachian mountains at elevations above 1000 meters have also been confirmed. A regional sugar maple decline has been the focus of attention in the Canadian provinces of Quebec and Ontario. Some small regional forests in South America, Southeast Asia and Japan are also reported to be damaged, although no quantitative estimates can be made about the damage in these regions. Currently therefore, forest decline can be considered as one of the most important economic and environmental problems facing humanity, at least in highly developed countries. The positive solution to these problems are of great interest not only to the forest sector but also for those concerned with the improvement of environmental conditions and the elimination of the negative processes in the biosphere as a whole.

Recent investigations on forest decline have shown that there are at least two main contributing factors acting simultaneously:

- anthropogenic pollution of the atmosphere (i.e., changes in atmospheric chemistry, as stated by air pollution experts as well as by physiological, biochemical and forestry research); and
- natural eco-climatic fluctuations, (i.e., changes in physical conditions as stated by dendrochronologists).

In addition to the factors mentioned above, insects and diseases have, in many regions, heavily aggravated the situation in the forests, particularly those already weakened (disturbed) by pollutants and climatic changes.

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Forest decline is not an entirely new phenomenon in human history, at least during the past several hundred years. Dendrochronologists may provide data about fluctuations in tree growth (an increase or decrease in annual increment of more than 70% compared with the average) over the last centuries. In some regions, these fluctuations appear regularly (cyclic) having different periods and amplitudes. When the different cycles coincide in the phase of decline, the increment of the forest in the long term can be considered as decline. In the Northern Hemisphere, forest decline took place during the eighteen-twenties, eighteen-eighties, nineteen-fourties and has now reached a minimum in the mid-eighties, coinciding with the increased amplitude of intra- and inter-annual ecological background fluctuations (temperature, precipitation, etc.). The latest minimum growth has been heavily aggravated by increased atmospheric pollutants which in some regions has led to forest dieback.

Alarming reports and signals from scientists about forest dieback have generated major concern among society in general, industry, governments and international organizations. Taking into consideration the current situation and the growing extent of forest damage, the Ninth World Forestry Congress held in Mexico in 1985, appealed to all humans, nations and governments, withing the framework of their own sovereignty, to recognize the importance of forest resources for the biosphere and the survival of humanity, and to devote themselves to safeguarding and promoting this resource which will provide humanity with food, raw materials, energy, rural well-being, ecological protection and improvement of the quality of life. Many countries have already adopted measures against forest decline that are even facilitating forest restoration. The International Conference on Acidification and its Policy Implications held in Amsterdam in 1986 also considered forest decline. The final report of this conference, as well as the Declaration of the XVIII IUFRO World Congress held in Jugoslavia in 1986, and the statement made at the Silva Conference on trees and forests held in France in 1986, stressed the importance of international, particularly East/West, cooperation in order to combat air pollution and to protect the environment and forest.

Following the above-mentioned meetings, new information and knowledge about forest decline has been generated by the scientific community. Within the framework of the Dendrochronology, Biosphere and Acid Rain Projects of IIASA's Environment Program, special studies have been launched dealing with the current development and further consequences of forest decline attributed to air pollution and climatic change.

At the same time, it has become evident that the forest sector itself currently needs more national and international support for information exchange in order to obtain a consistent picture of forest decline and to evaluate the long-term effects and identify the human responses required to gain sustainability of the forest, forest industry, as well as the regional ecosystems and the global biosphere.

As a result of these activities, an International Workshop on **Forest Decline and Reproduction: Regional and Global Consequences** took place in Kraków, Poland from 23 to 28 March, 1987. The Workshop was organized by IIASA in cooperation with the International Union of Forestry Research Organizations (IUFRO) and the Systems Research Institute of the Polish Academy of Sciences.

The purposes of the Workshop were:

- to glimpse at the current state of forest resources;
- to obtain a consistent picture of forest decline and its future trends;
- to discuss air pollutants and their possible causes and effects;
- to evaluate national experiences and research on forest decline:
  - methods of field data collection;
  - modeling forest decline;
- to look at possible ecological, industrial and economic consequences of forest decline;
- to discuss possible international protocols of forest-decline monitoring; and
- to identify choices that must be faced by: international organizations, governments and industry, and the forest community, in order to avoid further forest decline and facilitate sustainability of the forest sector.

The participants, senior scientists and agency representatives from Eastern and Western Europe, North America, Scandinavia and Japan including an ECE/FAO Team of Experts, held productive discussions on the topics mentioned above. A special field study trip was arranged to the Niepolomice Forest where special attention was given to the bio-indications of industrial damage and the disturbances of the main forest functions were discussed.

The Polish Press showed interest in our Workshop and interviews were published in the Dziennik (Daily) Polski (on 27.3.87), in the weekly Zycie Gospodarcze (on 21.6.87) as well as in the Tribuna Ludu.

Consequently, this Workshop can be considered as a most fruitful initiative in combatting forest decline and it is hoped that further research efforts in this field will foster increased cooperation and bring positive results.

Providing these Proceedings to the broad community of foresters, forest industrialists, environmentalists, ecologists and dendrochronologists as well as to international organizations and decision-makers, I sincerely hope that more concensus about forest decline, particularly in Europe, will be achieved and ways to avoid further forest decline will be found.

1.2 WELCOMING ADDRESS*

R. Wacław
Department of Forestry and National Parks
Ministry of Agriculture, Forestry and Food Economy
Warsaw, Poland

Ladies and Gentlemen,

It is a great honor and pleasure for me, as a representative of the Ministry of Agriculture, Forestry and Food Economy of the Polish People's Republic, to welcome this distinguished assembly to Kraków, to Poland, and to the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, convened by the International Institute for Applied Systems Analysis in cooperation with the International Union of Forestry Research Organizations and the Systems Research Institute of the Polish Academy of Sciences.

This working conference is devoted to very important problems, essential for nations of East and West, for industrialized countries and developing countries, and to significant problems facing mankind and our globe. We are therefore most gratified that IIASA has given Poland the responsibility of acting as the host country for this Workshop. It is my hope that all the arrangements, a short field trip to Polish forests included in the program will enable an intense and fruitful exchange of thoughts and ideas and that the outcome of this Workshop will, in the long-run, benefit forestry and the forest environment in all our countries, and thus also contribute to the improvement of the state of the natural environment as well as to the economic and social development of our planet.

Several centuries ago, forests covered an overwhelming majority of the geographical area of Poland. In the course of time, the forest area has diminished owing to the demographic process and the development of agriculture and settlement areas. The process of deforestation was often accelerated by war damage. Just after World War II, the percentage of Poland's forested area was some 20%, and the real growing stock of forest stands was much below the normal one. We have therefore undertaken extensive and long-term efforts aimed at an increase in the country's forested area; nowadays, forests cover 28% of the Polish territory. Since 1945, we have afforested some 2.1 million hectars of land unsuited for agricultural or other

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purposes (uses). Considering the post-war afforestations, the majority of forest stands belong to younger age-classes, but nonetheless, the global increase and gross growing stock of Polish forests already show a continuously rising trend. At the same time, there has been the parallel development of wood-processing industries, whereas the non-wood functions of forests are tremendous and highly appreciated by the public and government authorities.

However, the natural environment, including the forest environment, has been changing. Poland's area is under the stress of anthropogenic factors which have an adverse impact on our forests. At the beginning of the 1980s, the main problem of our forestry was the infestation of the nun moth. We undertook a very difficult long-term fight against that insect. Now we may say that the campaign has been successful. Damage to forests attributed to industrial air pollution is the main problem facing Polish forestry at the present time. Forest damage in the upper mountainous regions, especially in the Sudeten Mountains, can be described as dramatic; very high concentrations of pollutants have caused the complete decline of forest stands which had been growing there for many decades. For a long time, forest damage has also been reported in the industrial regions of Upper Silesia, in the Kraków regions as well as in other industrial agglomerations. The area of affected forests has been showing a steadily rising trend. Apart from domestic sources of emissions, our forests are also being affected by long-range transboundary air pollution. According to our estimates, some 60% of sulphur dioxide in the air is being blown to Poland by western and southern winds.

Damage to forest resources and the pollution of the natural environment in general are the subject of growing attention and concern of the government, the forestry administration and the Polish people. As an example of this concern, let me mention the Complex Programme of the Improvement of Forestry Economy in Poland till the year 1990, adopted and implemented since 1984. The main goals of the Polish forestry economy within this Programme are the following:

- improvement of sanitation and state of health of forest stands and their biological resilience;
- better use of productive potential of forest sites and intensive reproduction of the growing stock;
- rational and optimal use of forest raw materials, adapted to possible supply and natural needs;
- multiple use of forested areas, matching the requirements of nature and environmental protection with those of the national economy and the people.

Recently, very expensive planning and balance studies were carried out in order to extend the time horizon of this Programme to the year 2050, i.e., for a period approximating the productive rotation of forest stands. Bearing in mind the complex and long-term capacity for forest management, the multiple functions played by extensive forest areas, and the sanitation and health condition of our forests and the state of the natural environment, we find that the prospects of forestry can be estimated rather in forecast categories rather than in precisely determined indices, e.g., allowable cut.

We realize, however, that a fundamental precondition of the conservation of forests and the further development of the forestry sector is the speedy improvement of the state of the natural environment, firstly with the radical reduction of agents which pollute the air, waters and soils. In the strategy of this country's development, aimed at the formation of lifestyle of our nation, the targets and criteria of ecological development will become increasingly important. Therefore, Poland, within the range of her possibilities, will actively participate in international activities for the protection of the environment, particularly in actions aimed at the limitation of airborne pollution and its transboundary translocations.

The legal system of environmental protection in Poland is coherent. The establishment of the Ministry of Environment Protection and Natural Resources in 1983 can be quoted as an expression of our concern in this regard. This Ministry, in its policy, programmes, plans and current projects, is taking into consideration the protection of forests on an equal footing with other components of the human environment. There are professional services of environmental protection at the level of local governmental authorities and in large industrial plants. We are in the process of establishing the monitoring of forest damage, covering the whole area of the country. In January 1987, the Polish Parliament voted in a special resolution on the state and protection of the environment which sets forth precise aims in restraining and then reducing airborne pollution.

We are interested in all forms of international cooperation in the field of air pollution as the principal means of protecting the natural environment, including forest environment. In 1979, Poland hosted the Seminar of the United Nations Economic Commission for Europe on the Impact of Airborne Pollution on Vegetation in Forestry and Agriculture. We take part in activities of working groups on the impact of air pollution on forests set up by the ECE Timber Committee and the FAO European Forestry Commission. We are happy that the consequences of forest damage attributed to air pollution have been extensively presented in the new study on the European Timber Trends and Prospects to the Year 2000 and Beyond, published under the auspices of the UN Economic Commission for Europe and the UN Food and Agriculture Organization in 1986. I wish to state that this present Workshop, convened in Kraków by IIASA is also a form of response to the resolutions of the "Silva" International Conference on Trees and Forests convened by the Government of France in February 1986 in which I had the honor to participate as a member of the Polish Delegation.

On behalf of the Polish Ministry of Agriculture, Forestry and Food Economy and the Administration of National Forests, I would like to stress with satisfaction that this Workshop has very ambitious and extensive aims relating to urgent economic and ecological problems, which have to be resolved by international communities and organizations, government authorities, those involved in economic management and science, and also by foresters.

The current state and the dynamics of forest resources under the impact of air pollution, the verification of methods used to monitor forest decline, the treatment and regeneration of forests damaged by emissions, the evaluation of forest damage from ecological and economical viewpoints, and, last but not least, the preparation of guidelines for the restoration of forest systems as well as the response of the forest economy to the current forest damage and threats – these are the central problems to be faced by this Workshop. I believe that the distinguished scientists and specialists participating in this Workshop will make an excellent contribution toward solutions to these problems.

We wish you every success in your endeavors and are looking forward to your very interesting deliberations.

1.3 A PERSPECTIVE ON FOREST DECLINE PROBLEMATIQUE: THE VIEW BASED UPON WORKSHOP PAPERS AND DISCUSSIONS*

Jan W. Owsiński
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
PL-01 447 Warsaw, Poland

The Workshop reported in this volume focused upon presentation and discussion of the present state and future development of the phenomenon referred to through the generic name of "forest decline". It was obvious from the start, however, that in order for such presentations and discussions to be meaningful they have to take into account the context of forest decline or declines, that is, causes and their mechanisms on the one hand, and consequences – direct and removed – of industrial and more broadly socio-economic nature, on the other. Simultaneously, one would have to look for potential remedies – again, direct ones, through forest management interventions, and indirect ones, oriented at pollution levels, together with a number of feasible accompanying activities (e.g., land use control and management, fertilization).

If one remembers also that little is known about many of the processes involved in and related to forest decline, then it becomes clear that the whole system is very complex. However, for the sake of being able to solve real problems, one has to retain a holistic perspective. The present paper intends to show how against the background of such an overall perspective, the research and development activities reported in the proceedings can be located within an overall framework. Thus, the focuses of the workshop can be more easily revealed and some remarks on the entire proceedings forwarded.

STRUCTURE OF THE PROCESSES

Figure 1 (see also the paper by Owsinski et al. in this volume) outlines the sequence of processes related to forest decline in accordance with previous remarks. This simplified digram shall first be explained briefly and commented upon, and then shall be used to classify papers contained in this volume in the light of their correspondence to the various subsystems.

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The diagram (Figure 1) puts emphasis on air pollution as a cause, since this was the focus of most of the papers presented at the Workshop. It is recognized, of course, that "other stress factors" are also, and even sometimes may be more, important in causing declines. In fact, the subject of multiple causes is taken up explicitly in several cases.

The diagram omits the question of **temporal and spatial scales**. There exist, obviously, some correlations between the portions of the sequence shown and the scales of particular processes appearing in these portions (e.g. spatial scale and the levels of processes within the "Ecological Processes" domain). In general though, the processes indicated may take place on a variety of scales, ranging temporally from an hourly scale for pollutant transport and some chemical processes to decades when forest succession, acidification and the like are considered.

Thus, in **emissions** there is the question of the chemical composition, source intensity and location, with proper resolution in time and space. **Pollutant transport** has to take into account the type of emission, atmospheric features and weather conditions together with their dynamics, with particular emphasis on wind (its speeds and directions) and on precipitation. Thus, transport is closely related to **physico-chemical processes** taking place in the atmosphere under various conditions, with special attention to fogs and clouds.

It is from these processes that **concentrations** result. The dynamics of concentrations which act in superposition with **other stress factors** (e.g. winds, droughts, frosts, fungi, insects) is, in its actual influence, shaped by **biochemical processes** acting at various levels of **ecosystems** and **physiology**. Ultimately, one would have to consider all the relevant influences on the components of an ecosystem by examining their various physiological responses and their mechanisms, and thereafter study the propagation of impacts through the ecosystem. Similar procedures, though starting at a different end, should be applied in the case of restitution after damage or premeditated changes in ecosystems made in order to withstand potential damage. When considering the propagation of changes in the ecosystem, it should be remembered that its levels, e.g., those indicated in Figure 1 (**physiological processes, tree-level dynamics, stand-level dynamics, ecosystem dynamics** and **forest dynamics**) are to a large extent of a qualitative and not only a quantitative nature. At each level, different processes take place and transitions between the levels are by no means governed by linear relations. The kinds of interrelations that have to be taken into account include interconnection of partial processes in a non-additive way, (e.g., competition, inhibition). Moreover, impacts whose propagation is to be observed and studied act at each level through a different type of mechanism, which make the overall dynamics of change even more complex.

It is just because of this inherent complexity that – keeping in mind the overall structure – one should look for certain holistic behavioral regularities and identify and use them within the scopes of their validity. Thus, in concrete studies and applications, certain short-cuts and bypasses with regard to the whole structure are made for practical reasons. There are two such reasons: first, the interplay of time scales involved in research, in

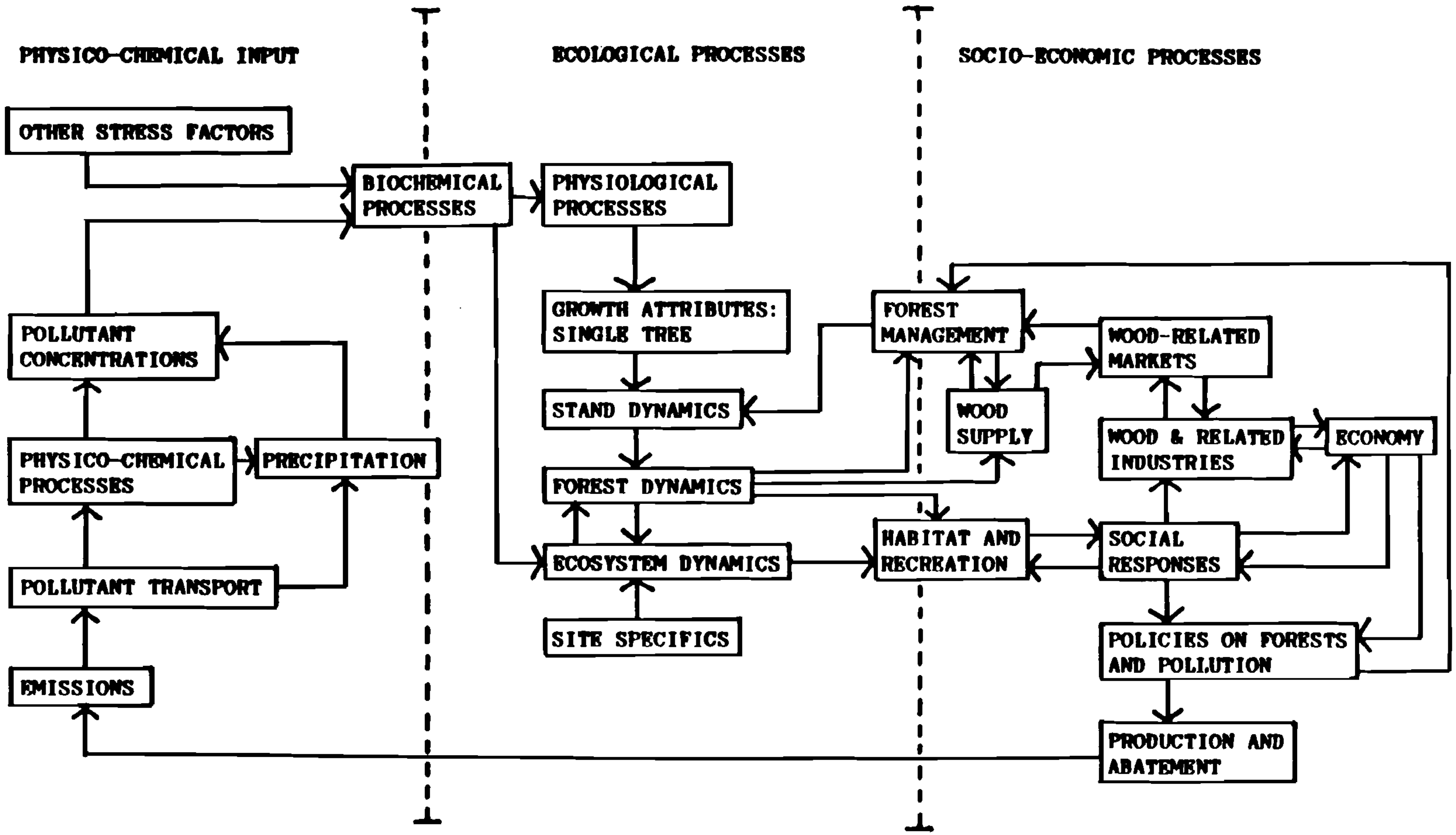

Figure 1. Domains of study pertaining to forest decline: a systematic setting.

dynamics of processes at hand and in preparation of a potential action, and second, even such simplified models may help in understanding the underlying processes.

The domain of "Socio-Economic Feedbacks" does not represent such a systematically structured subsystem as the other two. This domain, though, consists of some obviously distinct and clear-cut subdomains, like **forest management**, and **wood supply**, which are relatively less complex than some of the others. Nevertheless, just as is the case with **causes** – although for quite different reasons – a wide margin of uncertainty is brought into this domain with the necessity to consider general **economic relations** and **social responses**. The necessity arises from recognition that without closing the feedback loops of Figure 1, whether shorter or longer, going from consequences to causes and to the very processes, the design of appropriate policies will not be possible. That is where such studies as economic and social analyses, econometric projections and attitude research appear in the picture. There is, obviously, a wide discrepancy of complexity and state of knowledge between this feedback loop and the shortest one pertaining to forest management and its well-defined objectives.

TOPICS OF PAPERS IN THE VOLUME

The correspondence of the domains shown in Figure 1 with papers contained in this volume is shown in Figure 2. Quite in accordance with the stated main subject of the Workshop, the largest group of papers center around descriptions of particular cases of forest damage and/or decline on national and subnational levels, and around more general assessments of the phenomenon, its causes and consequences. This group of papers is not quite homogeneous though. It includes, at the extremes, both very general statements and papers presenting detailed data from long-term studies. Their purpose, however, is not to elucidate cause-and-effect relations, but rather to give indications as to further research through proper illustration of real-life cases.

On the other hand, virtually all these papers do not show the truly dynamic picture of the process, as indicated by Figure 1 and the system's image behind it, but rather, at most, comparative statics, for relatively short time periods. Apparently paradoxically, the few papers which present some future perspectives do not deal with particular local or regional situations, but with larger areas. This is not uniquely related to the averaging effects of a larger number of forest stands, but also to the existence of planning efforts as well as areas with much less uncertainty.

Papers related to other subdomains are much less numerous. This applies especially to questions of pollutant-impact correlations, threshold analysis, forest management and ecosystem-oriented analysis. Still, representation of these other subdomains seems sufficient for an appraisal of the image of the present state-of-art, even if it does not convey a balanced view of research and development emphases.

Thus, as mentioned, some papers take up the subject of multiple causes. There is, however, not yet a sufficient empirical basis for making definite

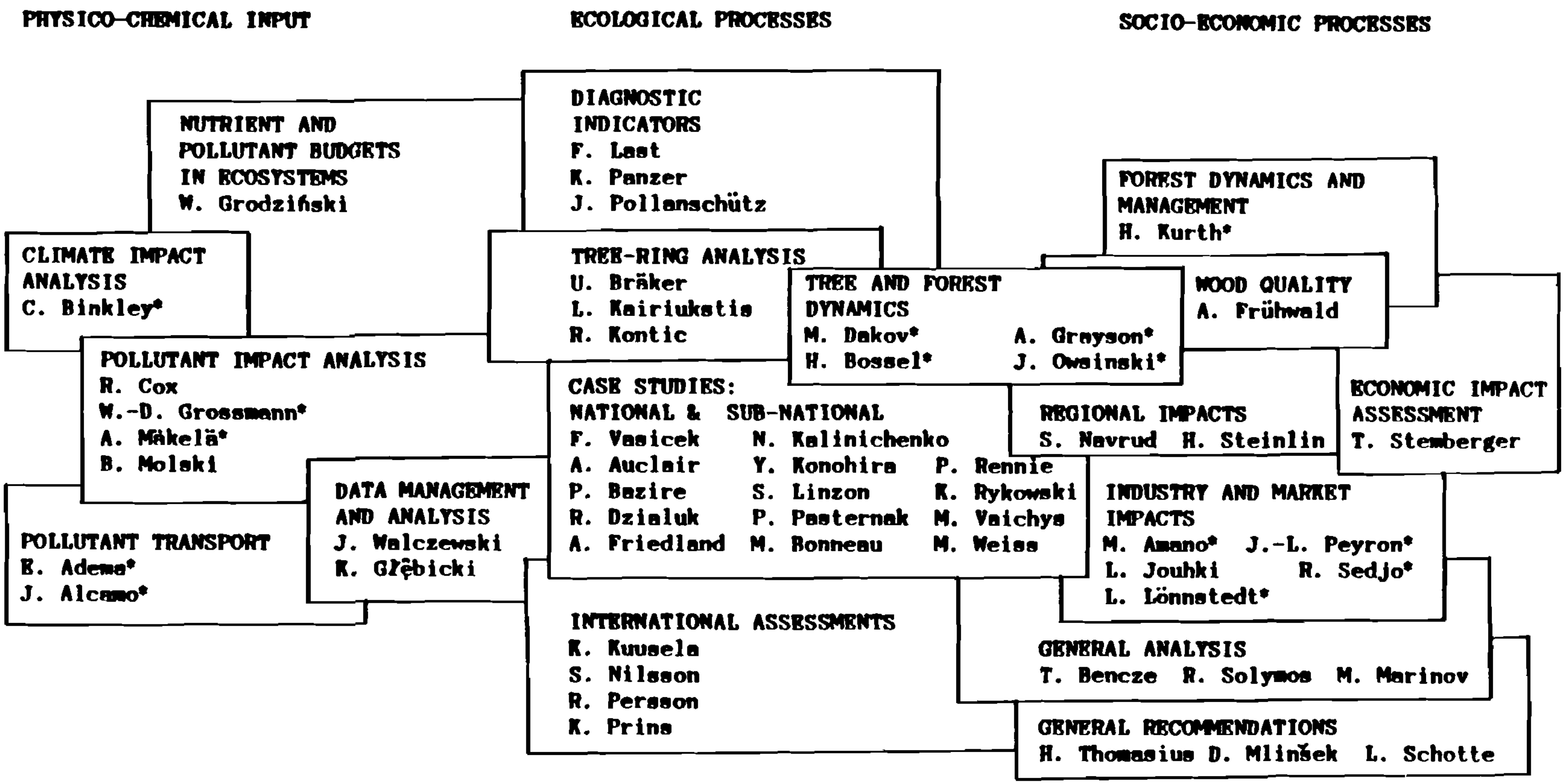

Figure 2. Classification of papers presented at the Workshop (names given are first authors of papers in the proceedings). Asterisks denote presentations explicitly referring to modelling methods.

conclusions, even on the correlation level. One is therefore still at the hypothesis formation stage. In particular, there is not enough employment of multivariate analysis capacities. This is reflected in the fact that all the papers which do not refer to modeling focus on just one time scale, while one of the most important features of the processes involved consists in the transition between time scales. Therefore, a proper resolution level in shorter time series is required. This also applies to spatial scale, where improper choice may lead to entirely erroneous results (e.g. displacement of pollution sources). Facing the complexity, one should recur to bypasses or introductory correlational or other incidence-oriented studies carefully following, however, both the tracks offered and doubts raised. This applies in particular to cause- and diagnosis-oriented studies.

While it is obviously wasteful to await comprehensive results in ecosystem analysis soon (virtual absence of papers at this Workshop and at other such meetings), such domains as forest management are well prepared for advanced practical tools based upon modeling approaches, to be used also in decline situations. The low number of papers herein on that subject reflects, in fact, a broader phenomenon based presumably on the skepticism of forest sector people towards quantitative models.

Another domain where obviously important lacunae exist is explicit policy analysis involving design of long-term silvicultural measures, land-use and pollution control as well as energy consumption policies. It is because of these lacunae, which make the detailed analysis too difficult and inhibit development of sound, all-embracing models, that scenario building has to be employed and pursued, possibly into a formal model-like exercise (see the paper by Prins in this volume).

It is possible that some of the questions raised cannot be readily answered in the near future. Some papers take up, therefore, the subject of fundamental or even ethical principles to govern the activities related to forest growth and use, principles that would, with a wide margin, guarantee forest-wise sustainability of these activities over a long or even infinite time horizon. However, before more detailed studies give definite results, even that fact cannot be certain.

2. POLLUTANT INPUTS TO FORESTS

2.1 QUANTIFICATION OF AIR POLLUTANTS IN EUROPE AND ITS IMPORTANCE TO VEGETATION*

E.H. Adema
Department of Air Pollution
Agricultural University
Wageningen, THE NETHERLANDS

SUMMARY

In this paper, a survey is given of the emission in Europe of SO_2, NO_x, NH_3, heavy metals and particulated matter which are the main pollutant compounds. The atmospheric concentrations of several compounds are given especially that of ozone. Some information about wet and dry deposition shows the dispersion of air pollution in Europe, while aeroplane measurements are given as illustration of the long range transport. Some of the information is based upon model calculation confirmed by measurements. Not every country has relevant data available, which is necessary for a proper description of the quality of the atmosphere above Europe. As required, estimates have been made to complete the information.

1. INTRODUCTION

It is obvious that air pollution is a matter of international concern. The huge amounts of SO_2, NO_x, NH_3, heavy metals, hydrocarbons and similar products cause tremendous effects on the whole ecosystem.

The most alarming aspect of damage to materials is the rapid deterioration of historical monuments. The direct effects of air pollution on human beings are particularly apparent in the urban vicinity of heavy industries, where in general, the quality of the atmosphere is very bad. Important questions to be solved concerning the abatement of air pollution are related to the extension of the area in which the pollutants have their impact and in which forms the pollutants are active, in what concentrations or during which times. It is therefore very important to know their atmospheric chemistry, the velocities of the dry and wet deposition, the mean residence time in the atmosphere and knowledge about the meteorology and toxicological and chemical properties of the pollutants.

The impact of air pollution is dependent on numerous factors such as the nature of the pollutant, the exposure time and -concentration, the nature of the substrate, death or living material, the sensitivity of the organism, seasonal influences, natural stress factors and so on. This is the reason why it is impossible to characterize and to judge the quality of the environmental compartment, the atmosphere, with one or a few simple parameters. Therefore, the quality of the atmosphere has been indicated

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with some examples with respect to wet and dry deposition, immission concentrations and emission data. The meaning of this data with respect to damage to vegetation should be regarded in connection with the presented no-adverse levels for the several species.

2. SULFUR DIOXIDE AND NITROGEN DIOXIDE

The main pollutant compounds directly responsible for the acidification of the environment are SO_2 and NO_x. The development of the emissions in a number of countries during the period 1960 - 1980 is given in the figures 1 and 2 (Asman, 1986B).

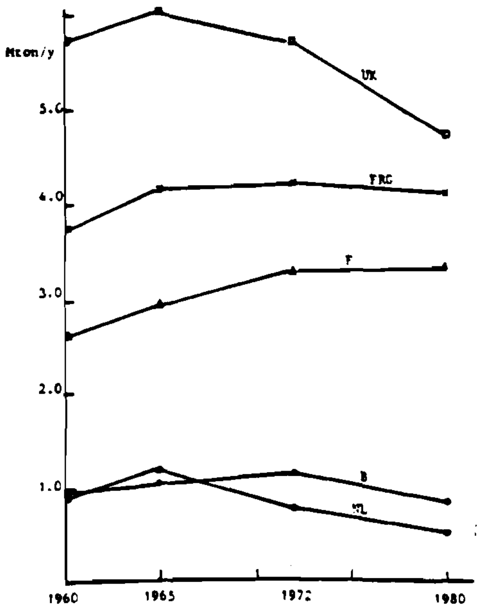

FIGURE 1. SO_2-emission in Mton/year in a number of European countries.

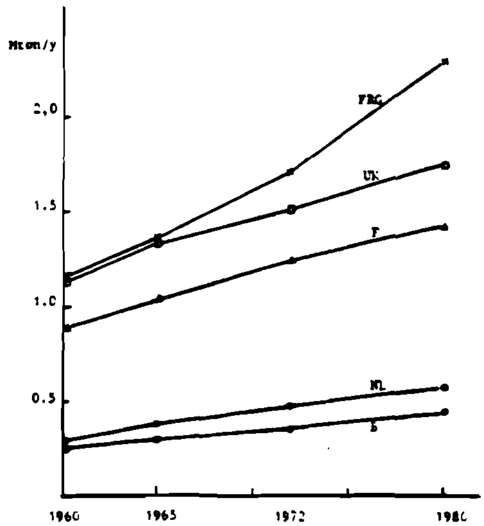

FIGURE 2. NO_x-emission in Mton/year NO_2 in a number of European countries.

In accordance to more intensive traffic, the NO_x curves show an increasing trend. The SO_2 emissions are somewhat reduced since 1965-1970 for several reasons. Besides a backward tendency in industrial activities, attention has been paid to diminish the sulfur content in the fuel and exhaust gases. The same trends have been found in the composition of the rainwater sampled in the Netherlands (Delft, Guicherit and Van den Hout, 1982). Figure 3 shows the increasing nitrate and the decreasing sulfate concentration with time. The emission data for the European countries in the year 1980 are summarized in table 1 (Asman, 1986B).

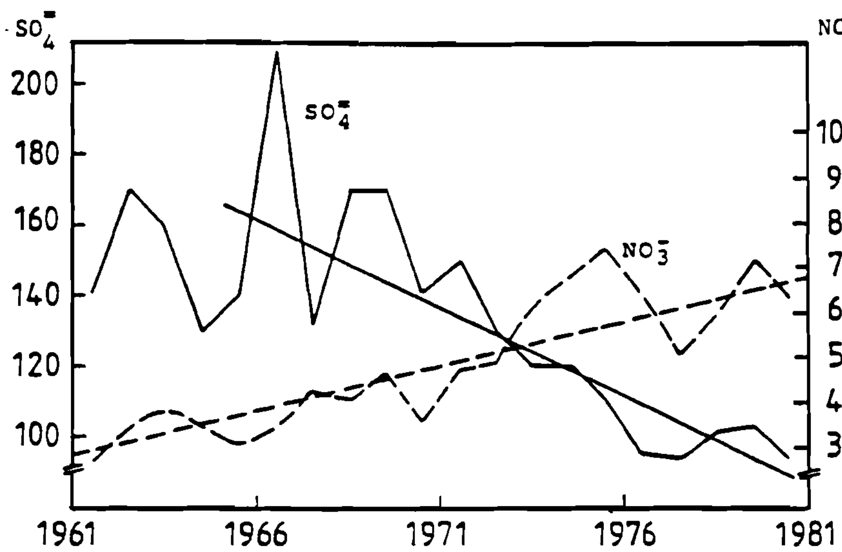

FIGURE 3. Change of nitrate and sulfate concentration (μmole.l^{-1}) in precipitation in the period 1961-1981 in the Netherlands according to Guicherit (1982).

The dry and wet deposition are in the first instance, the main routes for the removal of substances from the atmosphere. However, the intensities with which the removal takes place are strongly dependent on the physical and chemical properties of the substances and the surface upon which deposition takes place. Therefore, some compounds like NO and NO_2 will almost only be removed after being transformed into other species as nitrate and nitric acid. For model calculations the rate of transformation of these compounds a value of 4.3% per hour is often used (NAS-report, 1983). In the atmosphere, it is assumed that SO_2 will be oxidized into sulfuric acid or sulfates with a rate of 1.4% per hour. It is extremely difficult to determine the transformation velocities as well as the dry and wet deposition. The uncertainties in the data used are therefore very high. In fact the values are not constant due to the continuing variation of the circumstances (concentration, relative humidity, temperature, light intensity, etc.) and composition of the polluted atmosphere where numerous reaction paths are possible.

From windtunnel experiments, it can be concluded that the boundary layer resistance for the deposition of NO_2 on a water layer (at pH > 5) is 30 times higher than for SO_2 (Adema, 1986). It is therefore very probable that the dry deposition velocity of NO_2 will be at least 10 times smaller than that for SO_2. So the principal route for NO_x from the atmosphere to the earth's surface is in the form of the nitrate. In this respect, the wet deposition is more important than the dry deposition.

The principal route for the removal of SO_2 is mainly by dry and to a lesser extent by wet deposition. The removal of sulfate is mainly by wet deposition. As an average for whole Europe, it can be calculated that ratio's of the dry (d) and wet (w) deposition of sulfur, emitted in the Netherlands are SO_2(d) : SO_4(d) : SO_2(w) : SO_4(w) = 23 : 1 : 10 : 7. The calculations are performed by Asman et al (1986A) using a model based on that of Eliassen and Saltbones (1983).

The mutual influence of NH_3 and SO_2 with respect to dry and wet deposition, is very important. In areas with high concentrations of both compounds higher concentrations of NH_4^+ and SO_4^{--} are found in rainwater and relatively larger amounts of $(NH_4)_2SO_4$ are deposited on vegetation and materials as would be expected (Van Breemen, 1982).

TABLE 1. Emissions in European countries of SO_2, NO_x and NH_3 for the year 1980 expressed in 10^8 mole. y^{-1} (NO_x = NO + NO_2).

area km²		NH_3	SO_2	NO_x
29 x 10^3	Albania	12	16	2
85	Austria	42	67	60
29	Belgium	48	127	94
111	Bulgaria	74	156	52
127	Czechoslovakia	100	469	130
43	Denmark	65	66	54
340	Finland	26	84	44
543	France	417	510	316
105	GDR	122	625	148
248	GFR	218	641	500
131	Greece	56	110	109
92	Hungary	76	234	48
101	Iceland	3	2	2
70	Ireland	69	27	20
307	Italy	212	688	337
3	Luxemburg	3	8	11
35	Netherlands	88	77	122
322	Norway	21	23	24
312	Poland	238	672	217
93	Portugal	28	26	24
238	Romania	177	313	100
490	Spain	136	313	185
442	Sweden	31	86	57
41	Switserland	32	18	35
493	Turkey	402	151	130
242	United Kingdom	238	730	376
3460	USSR	739	2531	1087
260	Yugoslavia	116	481	46
2	North Africa	180	80	11
3613	Sea Areas	0	1	1
12405	Total	3989	9310	4339

In southern Scandinavia, the ratio NO_3^-/SO_4^{--} in precipitation has changed in the period 1950-1970 from 0.27 to 0.47. The latter value equals the ratio of the total European emission of NO_x and SO_2 in the year 1980. This must be no more than incidental.For the ratio of the local dry and wet deposition of the N- and S-compounds differ strongly for every part of

Europe. As an example of an emission pattern, the emission figures of the FRG are summarized in table 2 (Umweltbundesamt, 1984). Ambient air concentrations as measured in that country for several types of land use are given in table 3.

TABLE 2. Emission data of the FRG for the year 1982, subdivided into the main categories of activities in percentages.

	SO_2	Particulated matter	NO_x	Hydro carbons	CO
Transportation	3	9	55	39	47
Domestic use small industries	10	9	4	32	16
Power Plants	62	22	27	1	18
Industry	25	60	14	28	19
	100	100	100	100	100
Emission in 10^6 ton	3.0	0,7	3,1	1,6	8,2

TABLE 3. Immission concentrations in several types of regions in Central Europe (µg/m³) (annual averages (a) and maximum values).

	SO_2		NO		NO_2		O_3	
	a	max	a	max	a	max	a	max
background	0.5	-	0,2	-	1	100	<10	-
area without sources	5	100	1	-	5	30	80	200
rural area	20	300	2	-	10	80	-	-
urban/industrial area	70	1000	40	800	40	400	30	300
centre of big cities inner town	140	1500	50	1200	80	800	30	400

3. AMMONIA

In Europe there are only a very few stations where NH_3 in air has been measured. The reason for this limited interest is that only in the last five years the importance of this compound with respect to its effects on vegetation and soil acidification has become clear. The temporary neutralization of sulfuric acid and nitric acid, formed in the atmosphere, by NH_3 will often be canceled by the nitrification of NH_4^+ in the soil. Due to this microbiological process an additional equivalent nitric acid can be found. More information of measurements of NH_4^+ in air is available. This ion occurs mainly in the form of the stable compound $(NH_4)_2SO_4$. A minor amount is present in the form of the unstable NH_4NO_3. In many sites in Europe NH_4^+ in precipitation has been measured. Buijsman and Erisman (1986A) examined and corrected the 1980-data for 210 stations. The result is shown in figure 4.

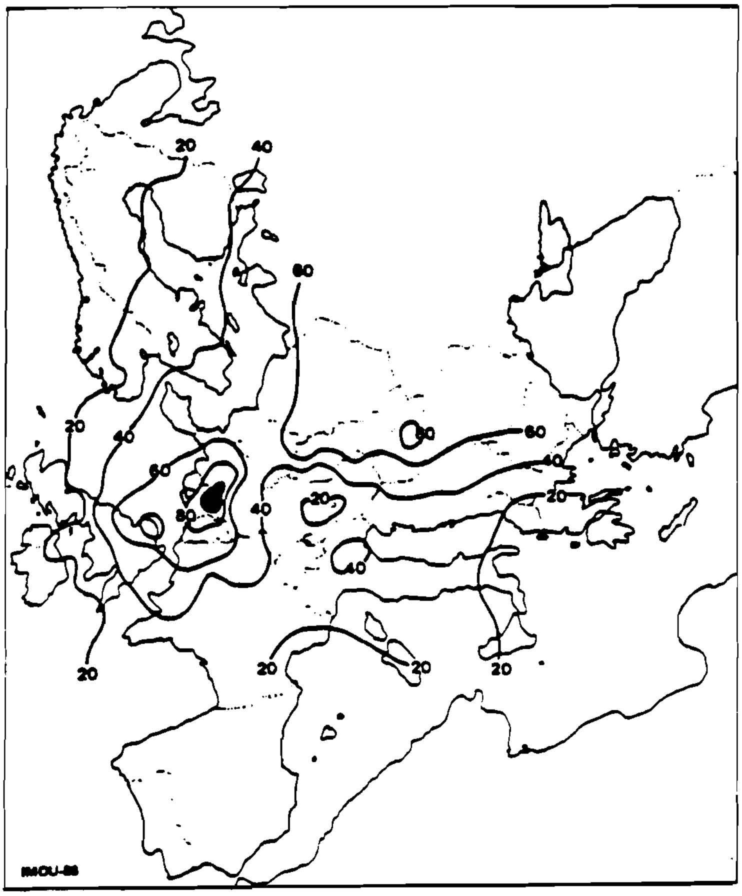

FIGURE 4. Measured NH_4^+ concentration in precipitation (µmole/l). (Buijsman et al, 1986A)

Based on the EMEP-type model (Eliassen, 1978) Asman and Janssen (1986) developed a lagrangian long-range transport model for NH_3 and NH_4^+ for Europe. Based on the NH_3-emission data for Europe they could calculate the NH_3 (figure 5) and NH_4^+ concentrations in air, NH_4^+ in precipitation and the total NH_x deposition (figure 6). The NH_3-emissions used in the model were derived from a study of Buijsman et al (1986B)on the emissions caused by animals, the use of fertilizers and some industrial processes. The NH_3 emissions expressed in 10^8 mole/y for the several countries of Europe are compiled in table 1.

Due to the strong variations in time of the NH_3-emissions, the NH_3 concentrations in air are also strongly variable in time. Daily concentrations up to 250 µg/m³ NH_3 can be found if manure spreading occurs in the near surroundings. The median concentration in the Netherlands is about 5 µg/m³ NH_3. The background concentration in marine areas amounts to approximately 0.1 µg/m³ (Georgii and Gravenhorst, 1977). The spatial variation in the average concentration of NH_4^+ is much less than for NH_3.

FIGURE 5. Computed NH_3 concentration in air ($\mu g/m^3$) (Buijsman et al,1986A)

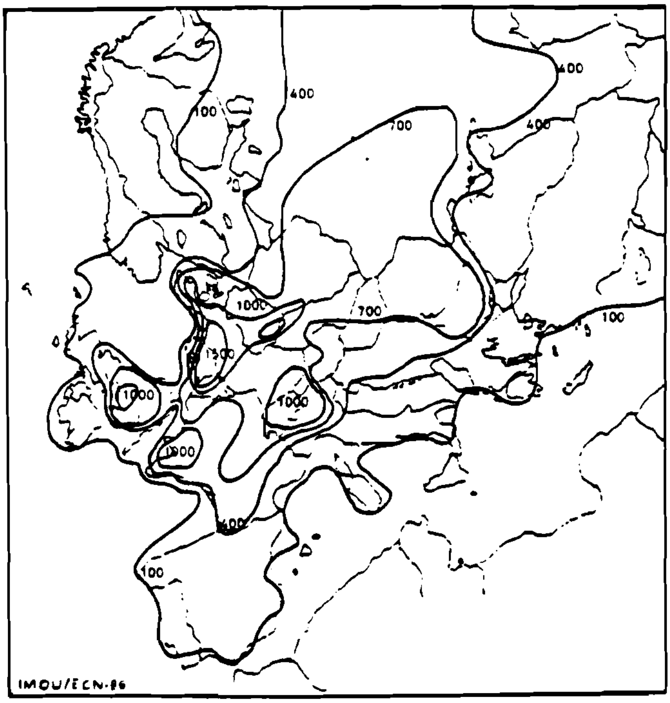

FIGURE 6. Computed total NH_x deposition ($mole.ha^{-1}.y^{-1}$) (Asman, 1986 A)

Georgii and Gravenhorst reported maritime background concentrations between 0.2 - 1 μg/m³ NH_4^+. In precipitation on the Atlantic Ocean Buijsman et al (1985) found an average NH_4^+ concentration of about 5 μmole/l. From this figure the calculated the NH_4^+ concentration in air to be about 0.1 - 0.2 μg/m³.

In many areas of Central Europe,the wet and dry deposition of ammonium and nitrate have reached values of 30 to 40 $kg.ha^{-1}.y^{-1}$ N. In some cases throughfall data exceed depositions of 60 $kg.ha^{-1}.y^{-1}$ N. Also high depositions are observed on slopes at forest edges and nearby areas with animal farms and manure spreading (Grennfelt and Hultberg, 1986).

4. HEAVY METALS

Heavy metals may accumulate in the environment and constitute therefore a potential hazard. This is one of the conclusions of the EMEP workshop on heavy metals held in Norway, 1984 (EMEP, 1984). Heavy metals are mostly highly toxic if they become available for living organisms. In the non-acid environment, heavy metals have often been bound in water insoluble complexes. However, due to the acidification of the environment the ion concentrations of heavy metals in groundwater and surface water reach values far above normal and no-adverse effect levels. Heavy metals are transported through the air mostly in the form of small particles. Substances present in the accumulation mode (particle diameter 0.1-2 μm) have the longest atmospheric residence time (2-4 days) (Müller, 1985). Accordingly these particles shall cover the longest distances. Especially heavy metals which after transport of more than 1000 km may still give rise to some harmfull effect, cause a great deal of concern. A survey of the emission of heavy metals in Europe is given in table 4 (Pacyna, 1985).

TABLE 4. Emission of heavy metals in Europe in 1979 (Pacyna, 1985).

Element	t/year	Main sources
As	6500	Cu/Ni production
Be	50	Combustion (Utilities - Industrial)
Cd	2700	Zn production
Co	2000	Combustion (Utilities - Industrial)
Cr	18900	Iron/Steel production
Cu	15500	Combustion, Cu/Ni-, Iron/Steel-production Wood combustion
Mn	17600	Iron/Steel production, combustion
Mo	850	Combustion (Utilities - Industrial)
Ni	16000	Combustion (Utilities - Industrial, Mining)
Pb	123000	Gasoline combustion, Lead-Iron/Steel-production
Sb	380	Combustion (Utilities - Industrial), refuse incinerator
Se	420	Combustion (Utilities - Industrial)
V	34500	Combustion (Utilities - Industrial)
Zn	80000	Zinc-Iron/Steel-production, refuse incinerator wood combustion

5. OZONE

Acid rain and ozone are the two types of pollutants most frequently mentioned as the cause of the forest die back. Ozone as a secondary pollutant is formed in the atmosphere from hydrocarbons and NO_2 under photochemical conditions. It has been shown that the concentration of tropospheric ozone has increased since the last century. Measurements from the 'Observatoire de Monsouris' in Paris 1876/1877 give an average value of about 14 ppb. This is about three times lower than is found nowadays (Volz, 1986).

A matter of much concern is the influence of atmospheric impurities on the ozone layer. The deterioration of this layer on the one hand and the build up of the ozone near the earth's surface on the other hand is depicted in figure 7. The graph has been composed based on a model and measurements (Crutzen, 1986).

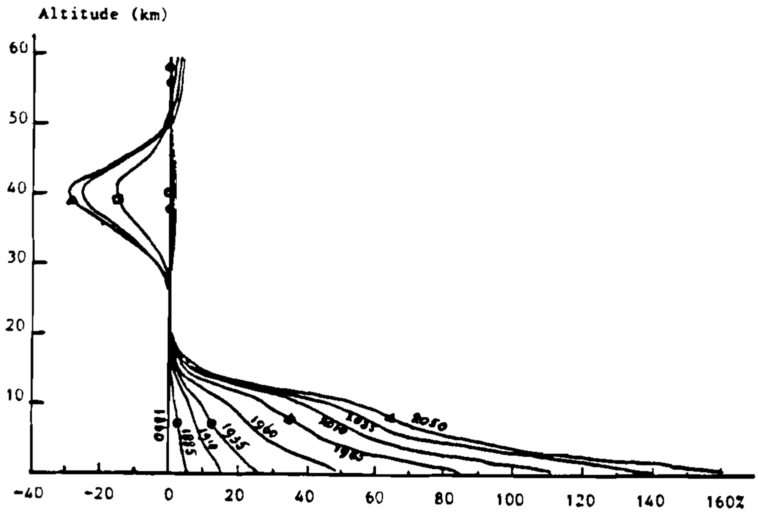

FIGURE 7. Changes in tropospheric and stratospheric ozone concentrations in the period 1860 - 2050.

Relatively high concentrations of ozone have been observed during the ozone episodes. In July 1980 values up to 180 ppb (360 µg/m³) were found in GFR and The Netherlands while in June 1982 values of 130-160 ppb were obtained (OECD-workshop, PHOXA-project, 23-25 October 1985, Schauinsland GFR). Examples of horizontal profiles are given in figure 8. They are obtained from aeroplane measurements performed by GEOSENS along the border of GFR and GDR. From the ozone profile a total flow of about 3400 t/h O_3 from east to west could be calculated. In this calculation, it was assumed that the height of the mixing layer is 1700 m and that only in this layer dispersion and transport take place. From the horizontal SO_2-profile obtained by the integrated COSPEC-method, a total flow of 1300 t/h SO_2 was calculated (figure 9). A heavy plume from the direction ESE is clearly shown. On the base of one year the SO_2 flow should mean about 11 Mton. This figure equals the estimated sum of the total emission of GDR, Poland and Czechoslovacia. From the SO_2 concentration in situ over the whole track a flow of about 6 Mton/y was derived also based on a mixing layer of 1700 m.

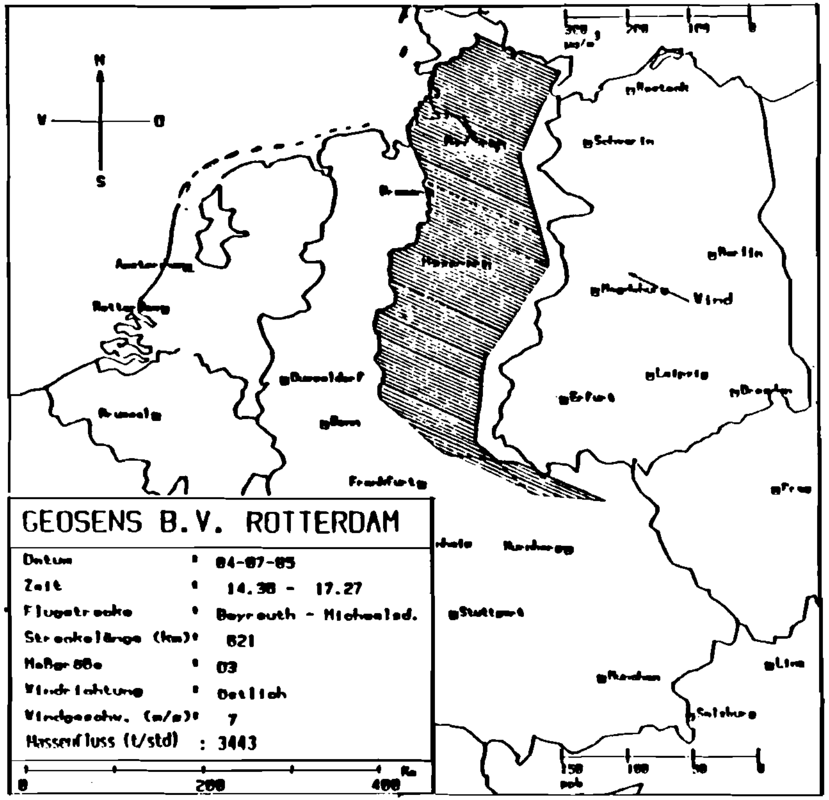

FIGURE 8. Horizontal O_3-profile along the border of GFR and GDR. Concentration measurements (μg/m³).

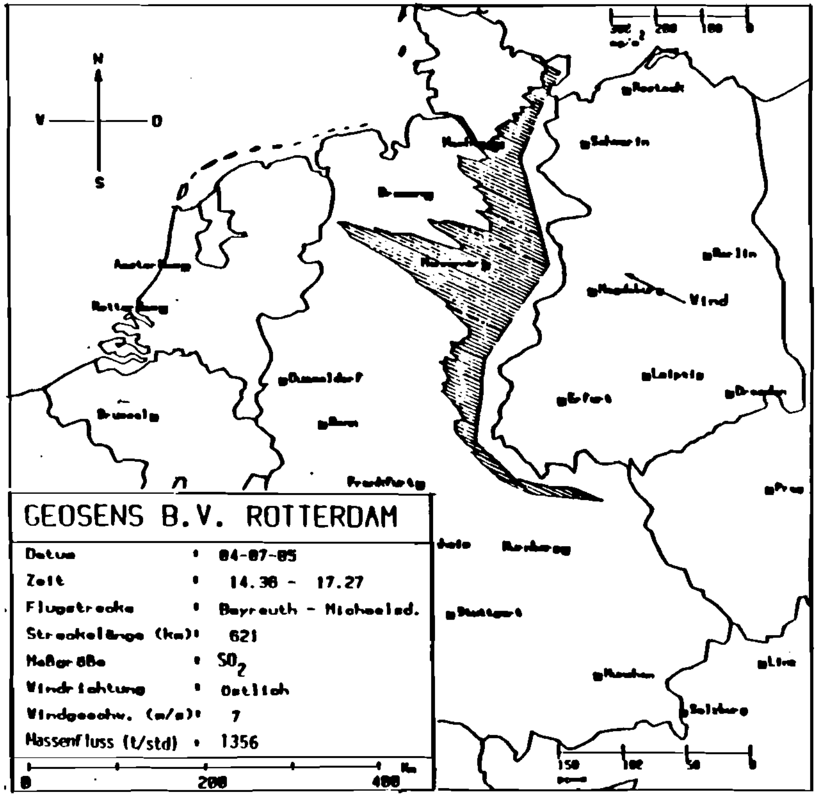

FIGURE 9. Horizontal SO_2-profile along the border of GFR and GDR. Vertical integrated COSPEC-measurements (mg/m² or ppm.m resp.).

An example of a vertical profile is given in figure 10. It can be seen that the height of the mixing layer on that place and time was about 1700 m. In the inversion layer, a sudden decrease in SO_2 and O_3 concentration was observed. In continental models, the average height of the mixing layer used is 1000 m.

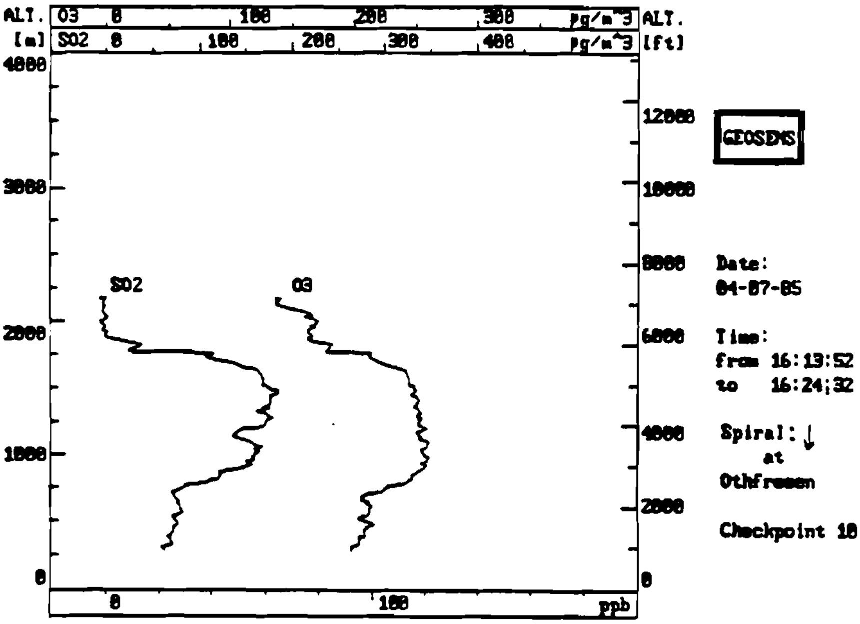

FIGURE 10. Vertical profile of O_3 and SO_2 by flight (GEOSENS B.V., Rotterdam) (UBA, 1986).

There are seasonal and daily variations especially the diurnal variations can be very large. At night, the mixing layer may often diminish to about 50 m. Sometimes however, under certain meteorological conditions, the inversion layer reaches the earth's surface. In similar cases, no dispersion of pollution takes place resulting in high concentrations of air pollution.

6. IMPACT OF AIR POLLUTION ON VEGETATION

As mentioned in the introduction it is impossible to characterize the air quality with a few sample parameters. It is still very important to judge the air quality in connection with the adverse influence on the whole ecosystem. The meaning of certain levels of air pollution with respect to vegetation could best be derived from the information about the no-adverse levels of the several species in relation to the direct effects. The indirect effects on vegetation through changes in soil and water quality caused by air pollution are not included in this consideration In a number of publications, observations has been reported concerning damage to vegetation (leaf injury, growth reduction and reduction of production and quality) only in relation to concentration and exposure time. Other affecting parameters as growth season, climate, soil specification, plant species, etc. did not have taken into account. The data obtained in this way can be represented in concentration-exposure time plots, in which the observed damage has been indicated (envelop model). With more or less hyperbolic functions no-adverse effect levels can be drawn. Effect of combinations of several air polllutants are very important. However, the synergistic or antagonistic effects have been left out of consideration. The no-adverse levels for a number of air pollutant compounds are summarized in table 5 (Posthumus, 1983).

TABLE 5. No-adverse effect levels for a number of air pollutant compounds (concentrations in µg/m³, exposure time in hour).

Hour	NH_3	NO_2	SO_2	O_3	PAN	HF	HCl
1	>2500	4000	130	200	310	100	1700
8	1000				80		
24	500	600	53	65		3	150
240	150	>400	49	60		0,5	40
2400	70						

Calculations of the relationship between production volume of crops and air pollution levels are illustrated in figure 11. The annual mean concentrations for the year 1983 are given as 100%. The total reduction in the yield due to air pollution above the indicated background is estimated as 5% (Van der Eerden, 1986). In conclusion air pollution causes relatively little damage to Dutch farmers since air pollution induced crop loss is compensated by higher prices.

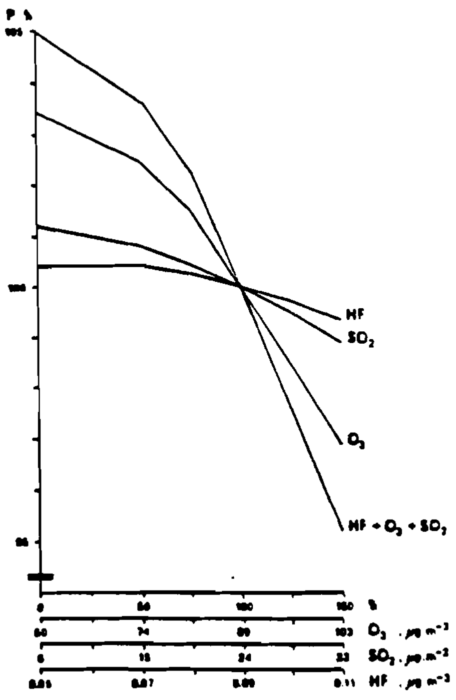

FIGURE 11. Production volume at several air pollution levels in the Netherlands. (Van der Eerden, 1986).

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2.2 FUTURE SULFUR DEPOSITION SCENARIOS IN FORESTED AREAS OF EUROPE*

J.M. Alcamo
Acid Rain Project
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, AUSTRIA

Abstract

Sulfur inputs to forests have been related to tree damage via direct foliar impacts of SO_2 and the soil acidifying effects of wet and dry sulfur deposition. In a brief report, some scenarios of sulfur inputs to forested areas of Europe are presented. These scenarios cover the years 1900 to 2040. Calculations from 1960 to 2000 are taken from a IIASA model of acidification in Europe (RAINS); estimates from 1900–1960 and 2000–2040 are derived from simple assumptions.

The effects of three different emission scenarios were investigated: a *reference scenario* which assumes a 30% reduction of emissions (relative to 1980 levels), an *optimistic scenario* which assumes major emission controls for each country, and a *pessimistic scenario* in which no emission controls are assumed. Results are presented for six different forested areas. It was found that there are large differences in the levels of deposition received by different forested areas; these levels may differ by a factor of 10 or 20. Deposition was found to level off after the year 1985 for all scenario assumptions and in almost all areas. After the year 2000, the *reference* scenario anticipates a reduction of deposition to its 1960s level, and the *optimistic* scenario a reduction to its level in the early 1900s.

Introduction

As pointed out in several papers of this volume, forest dieback in Europe has been attributed to a variety of anthropogenic and natural factors. One of these is the input of sulfur from the atmosphere: Gaseous SO_2 has been related to direct foliar damage to trees; sulfur deposition is connected with acidification of forest soils and subsequent stress to trees through release of aluminum into soil moisture (see e.g. McLaughlin, 1985). But rather than concentrate on the impacts of sulfur to trees, this paper instead examines the atmospheric aspect of this problem and tries to provide the reader with a brief temporal and spatial overview of sulfur inputs to Europe's forests. As part of this overview, we examine the link between human activities (through international pollution control policies) and the inputs of sulfur to forested areas.

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Method

To make the connection between policies and deposition we use the IIASA *RAINS* model which is an integrated model used to evaluate strategies to control acidification in Europe (Alcamo *et al.*, 1985, 1987). The model consists of several linked submodels that are used to compute SO_2 emissions, costs of control strategies, atmospheric transport of sulfur, forest soil and groundwater acidity, lake acidification, and direct impact of SO_2 on forests. The submodel used to examine SO_2 forest impact is described by Mäkelä in this volume. As background to the calculation of sulfur inputs to forests, we first review how the RAINS model computes SO_2 emissions and transport of sulfur in the atmosphere.

SO_2 Emissions. SO_2 emissions in the RAINS model are obtained for each of several economic sectors and in each of the 27 largest countries in Europe. Emissions are calculated in every sector using a simple mass balance equation which accounts for various fuels consumed in each sector, the sulfur content and heat value of fuel, the sulfur retained in each sector (rather than emitted to the atmosphere), and the fraction of sulfur removed by pollution control. Using this approach we can investigate how a change in energy policies or how different emission reduction plans affect the SO_2 emitted from each country.

Three emission scenarios are examined in this paper: an "Official Energy" scenario, a "30% Reduction" scenario, and a "Major Sulfur Controls" scenario. These are briefly explained in Table 1. From the point of view of environmental impacts the "Official Energy" scenario is pessimistic because it assumes no pollution controls despite the fact that many countries have already begun control actions. In comparison, the "Major Sulfur Controls" scenario is optimistic because it implies that each country will pursue rigorous pollution control (nearly 60% removal of all SO_2 emissions) by the year 2000 (see Table 1). Our reference scenario for this paper is the "30% Reduction" scenario since 21 countries have already agreed to reduce their emissions by this amount before the year 1993 relative to their 1980 emissions. More countries are likely to do the same. Moreover, countries that do not achieve this goal will probably be balanced by other countries that achieve greater than 30% reductions (Hordijk, 1986). As an aside, it is important to note that these SO_2 reductions can also be achieved by energy conservation.

Atmospheric Transport. After SO_2 emissions are computed, they are input to an atmospheric transfer matrix which estimates how these emissions are distributed as SO_2 air concentration and sulfur deposition throughout Europe. This matrix is derived from the EMEP long range transport model of sulfur in Europe (Eliassen and Saltbones, 1983). Meteorological data from 1978–1982 are used for the calculations. Mass balance equations for SO_2 and $SO_4^=$ air concentrations are solved along 96-hour back trajectories which originate at various receptor points in an European grid. Other equations are used to compute dry and wet deposition of sulfur.

The model has been extensively tested by both comparisons with data (e.g. Eliassen and Saltbones, 1983) and error analysis (Alcamo and Bartnicki, 1987). One may conclude from these evaluations that EMEP model results are more useful for examining the relative differences between scenarios than precise values of deposition for a particular scenario. As such, results presented in the following paragraphs should be interpreted qualitatively rather than quantitatively.

Synoptic Picture for Europe

The computed SO_2 emissions are summarized for all Europe in Figure 1. Emissions increased from about 18 Mt yr^{-1} to 30 Mt yr^{-1} as sulfur from 1960 to 1980. The 1980 estimate is close to other published results (Batterman, *et al.*, 1986). Note that the

Table 1. Scenario description.

a) *Official Energy Pathway*

As published by IEA* and ECE**; no pollution control assumed

b) *30% Reduction All Europe*

Based on the Official Energy Pathway,
SO_2 emissions are reduced by 30 % based on the 1980 level.

c) *Major Sulfur Control (MSC)*

As example of a user specified emission reduction strategy the MSC-Scenario implements in all countries (based on the Official Energy Pathway) strong pollution control in the following way (shown for the year 2000; the policy is assumed to be phased in from 1985 onwards):

Sector	Control option†	Share of energy treated	SO_2 removal efficiency	Resulting sectoral SO_2 removal
Conversion	FGD	0.90	0.90	0.81
Powerplants	FGD	0.90	0.90	0.81
Industry	FGD	0.50	0.90	0.45
Domestic	low S	1.00	0.50	0.50
Transport	low S	1.00	0.50	0.50

* IEA is The International Energy Agency in Paris.
** ECE is The U.N. Economic Commission for Europe, Geneva.
† FGD = flue gas desulfurization.
low S = low sulfur fuel.

three scenarios result in considerably different emissions in the year 2000; the most pessimistic estimate (Official Energy Pathway) is about 50% greater than the reference scenario (30% Reduction) whereas the most optimistic scenario (Major Sulfur Controls) is about 40% lower than the reference. Since it is difficult to anticipate the energy and pollution control situation more than 10 years or so in the future, we assume that emissions level off after the year 2000 up to year 2040.

The computed deposition pattern for 1980 (Figure 2) reflects the concentration of emissions in Central Europe and parts of the USSR and United Kingdom. To relate these deposition levels to forested areas we present a map of forest coverage in Figure 3. Background deposition ($<1\ g\ m^{-2}\ yr^{-1}$)* occurs in Northern Europe and parts of Southern Europe. Interestingly, this deposition level already exceeds the "critical load" of 0.2–0.4 $g\ m^{-2}\ yr^{-1}$ recommended by the Nordic Council to sensitive forest soils (Nilsson, 1986)*. A low-intermediate level (1–4 $g\ m^{-2}\ yr^{-1}$) covers much of Europe outside of the major emission areas. A higher level (4–6 $g\ m^{-2}\ yr^{-1}$) covers much of Central Europe, while the highest level ($> 8\ g\ m^{-2}\ yr^{-1}$) coincides with the high SO_2 emission areas of Central Europe and USSR.

Computed SO_2 air concentrations for 1980 (Figure 4) show that roughly one-half of Europe had SO_2 air concentrations greater than 5 $\mu g\ m^{-3}$**. SO_2 concentrations greater than 10 $\mu g\ m^{-3}$ cover most of Central Europe and parts of the United Kingdom and northern Italy. Concentrations greater than 20 $\mu g\ m^{-3}$ occur in the high emission

* Sulfur deposition in this paper is reported as sulfur.
* However this "critical load" refers only to wet sulfur deposition and assumes negligible buffering cations in precipitation. In sum, this may be a very conservative estimate of the total sulfur deposition tolerable to trees.
** SO_2 concentrations in this paper are reported as sulfur.

SO_2 Emissions — Europe (KT S yr^{-1})

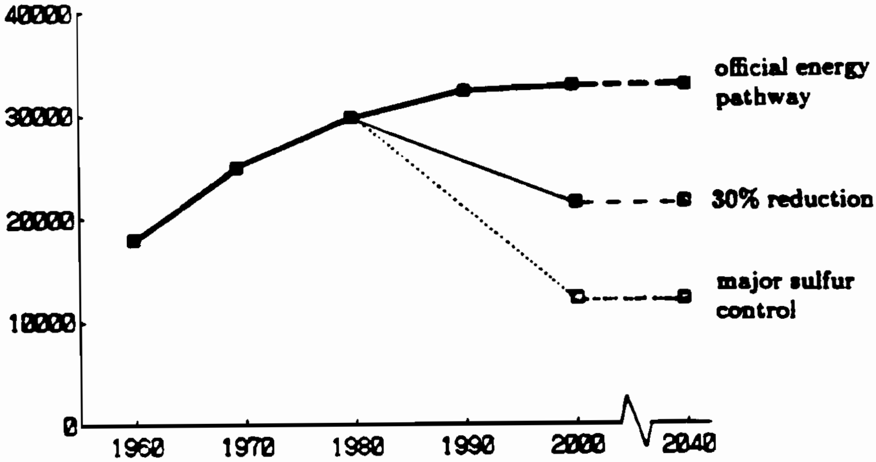

Figure 1. SO_2 emissions in Europe, including European part of USSR.

Total Sulfur Deposition (g S m^{-2} yr^{-1})

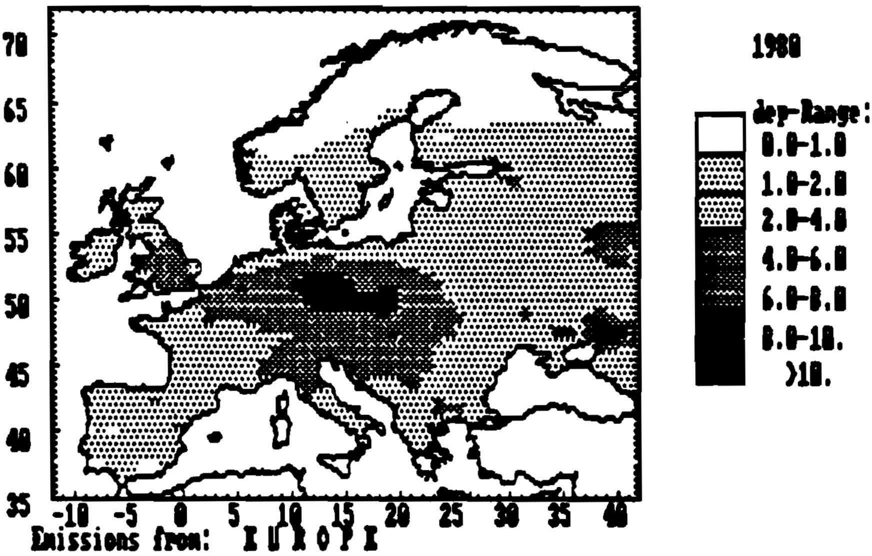

Figure 2. Computed total sulfur deposition in 1980.

FOREST COVERAGE

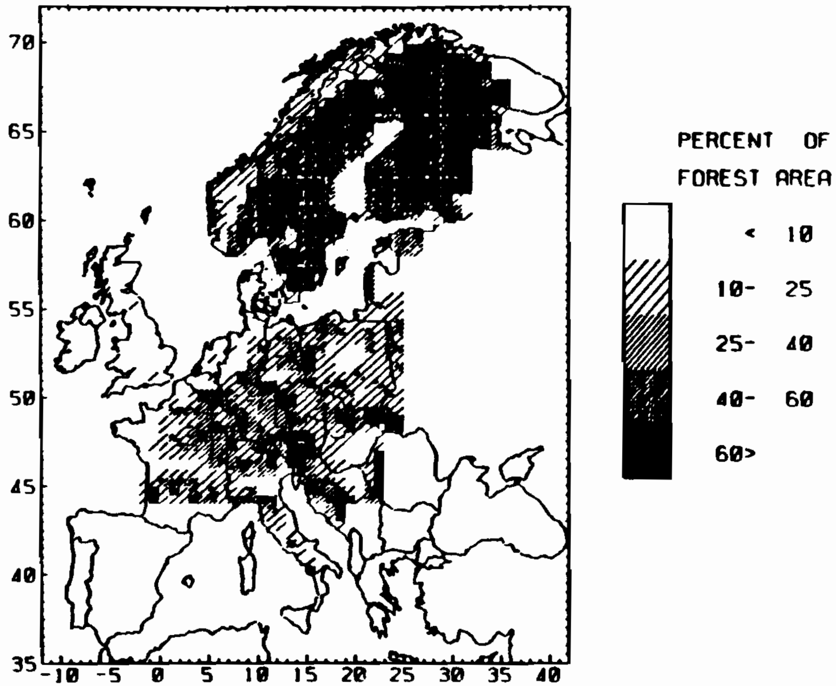

Figure 3. Percent coverage by forested areas. Data base does not include USSR, nor parts of Southern and Eastern Europe.

SO_2 CONCENTRATION – 1980 Annual Average ($\mu g\ S\ m^{-3}$)

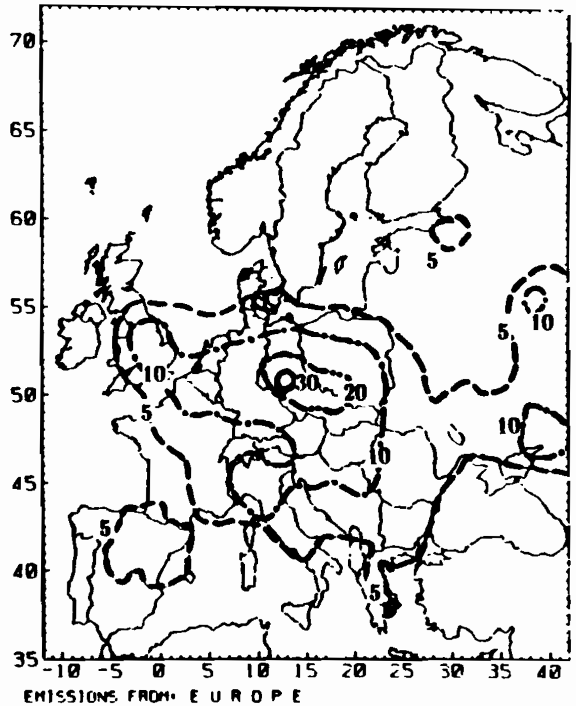

Figure 4. Computed locations of SO_2 isolines in 1980.

areas of Central Europe, and 30 $\mu g\ m^{-3}$ or greater occurs on the border of Czechoslovakia and the German Democratic Republic. For reference, some scientists believe that direct foliar impacts of SO_2 are observed around 50 $\mu g\ m^{-3}$ SO_2 or higher (e.g. see McLaughlin, 1985). On the other hand, Mäkelä (this volume) points out that these thresholds may not account for cumulative effects of long term exposure of trees to low SO_2 concentrations, nor do they take into account synergistic effects of climatic stresses. With these additional considerations in mind, some scientists believe that trees may be damaged by long term exposure to SO_2 air concentrations lower than 10 $\mu g\ m^{-3}$ as an annual average (see, e.g. Mäkelä, this volume). We therefore use the 10 $\mu g\ m^{-3}$ isoline to compare scenarios for the year 2000 (Figure 5). For the reference scenario (30% Reduction) the 10 $\mu g\ m^{-3}$ isoline covers a much smaller part of Central Europe than it did in the year 1980 (Figure 4). For the Major Sulfur Controls scenario it shrinks to a small area around the borders of the German Democratic Republic, Czechoslovakia, and Poland; the area covered by the Official Energy Pathway scenario is about the same as it was in 1980 with the addition of large parts of Bulgaria, Romania, and Yugoslavia.

Sulfur Inputs to Forested Areas

We now turn our attention from the synoptic view of Europe to a temporal view of selected forested areas indicated in Figure 6. The computed sulfur deposition and SO_2 concentration in Figures 7 and 8 for 1960–2000 are results from the RAINS model; deposition estimates for 2000–2040 come from the assumption that emissions level off after the year 2000. SO_2 concentration and sulfur deposition for the years 1900 to 1960 are roughly estimated by scaling down the 1960 value in proportion to the European total SO_2 emissions during that interval†. The reference for estimates of total European SO_2 emissions between 1900 and 1960 are Semb (1978) and Möller (1984).

The forested areas cluster into three groups according to their 1970–1985 deposition. The Finnish and Northwest USSR areas are in the lowest category (deposition $<< 5\ g\ m^{-2}\ yr^{-1}$), the Harz Mountains, Tatra Mountains, and Erzgebirge in a high deposition group ($>> 5\ g\ m^{-2}\ yr^{-1}$) and the Black Forest is between the two groups ($\sim 5\ g\ m^{-2}\ yr^{-1}$). The sulfur deposition trends for 1960–2000 resemble somewhat the European SO_2 emission trends. Deviation from these trends result from different temporal patterns of SO_2 emissions for different countries computed by the RAINS model. Unlike the trend of total European emissions, deposition peaks in 1980 for all regions except the Black Forest in which an apex is reached in 1974. Of particular interest, even the most pessimistic emissions scenario (Official Energy Pathway) causes a levelling or decline in deposition in all areas except the Tatra Mountains. The enormous range in magnitude of atmospheric sulfur flux to different regions is seen by comparing the Erzgebirge with the South-Central Finland and Northwest USSR (Figure 7). According to these calculations there is a factor of 10 difference in sulfur flux between these regions over 100 years, and a factor of 20 difference for around 50 years. Certainly this must influence the composition of these forest ecosystems.

The most likely scenario (30% Reduction) reduces deposition in all areas to their 1960s level and the optimistic scenario (Major Sulfur Controls) to their level in the early 1900s. Note also that the variation of computed deposition due to the different scenarios can be either large (e.g. Erzgebirge) or small (e.g. Southern Finland).

† This is of course only a crude approximation of the actual SO_2 concentration and deposition, and is useful only for reference purposes. In reality the older industrial areas of Europe such as parts of the United Kingdom, Germany or Italy had proportionately higher levels of deposition and SO_2 than other parts of Europe.

SO_2 CONCENTRATION - Annual Average

Location of 10 μg S m^{-3} isoline

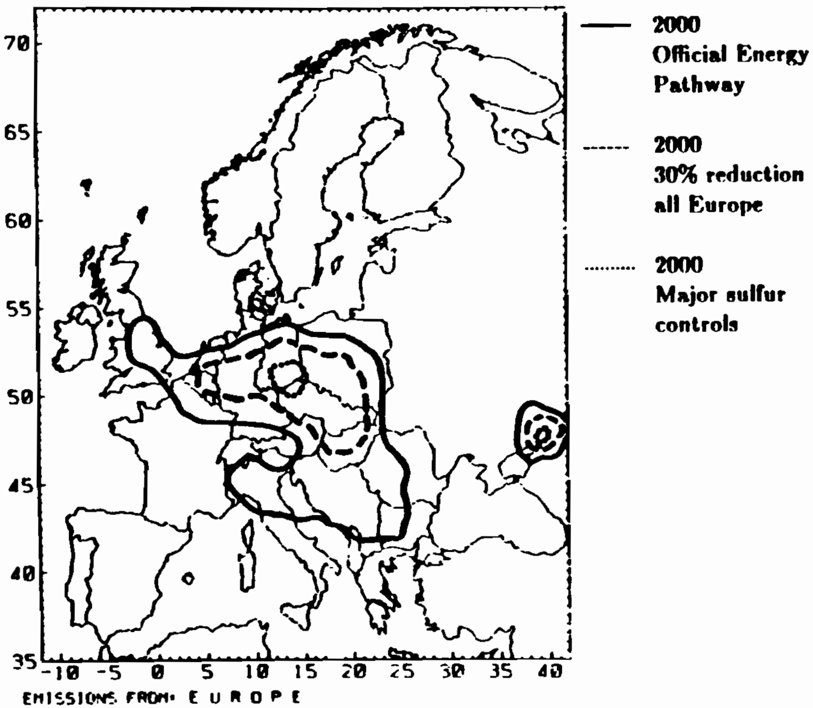

Figure 5. Comparison of 10 μg S m^{-3} isolines of SO_2 for three scenarios.

Some Forested Areas

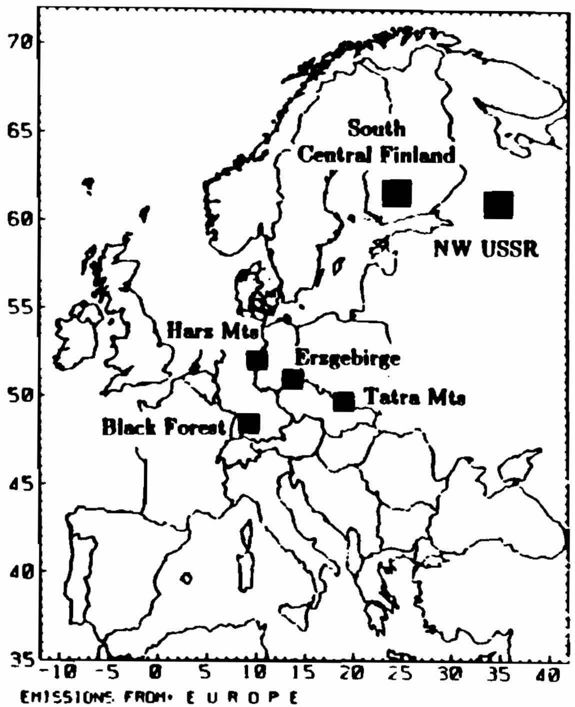

Figure 6. Forested areas for which time series of SO_2 and sulfur deposition are computed in this paper.

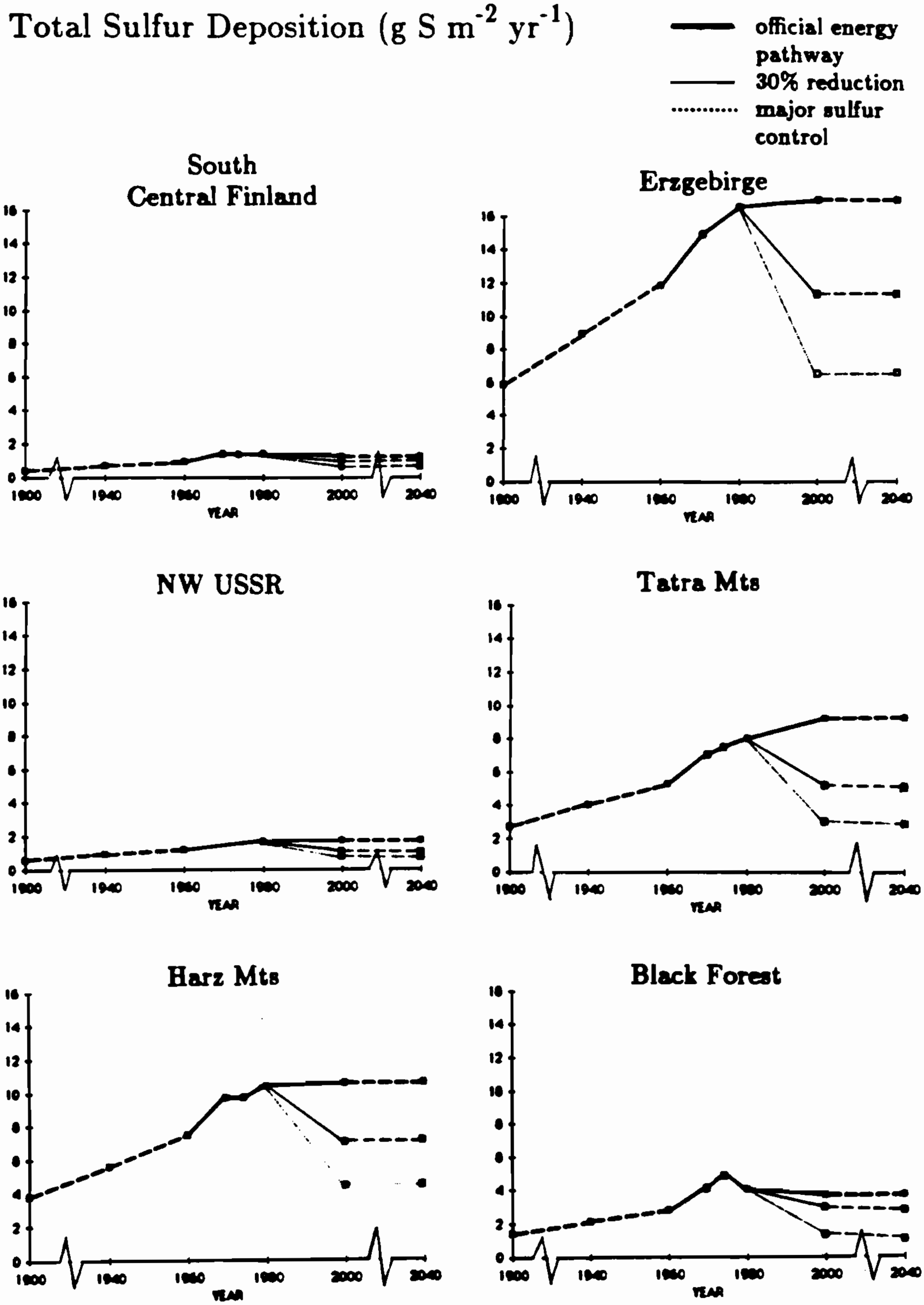

Figure 7. Sulfur deposition time series for forested areas in Figure 6.

Temporal trends of SO_2 air concentration in three of these areas are presented in Figure 8. Since these trends resemble their deposition counterparts, SO_2 figures are only shown for three areas. Note that in the Erzgebirge, SO_2 stays above 10 $\mu g\ m^{-3}$ for even the lowest SO_2 emission scenario.

Linkage With Forest Impact Calculations

It is important to note here that sulfur deposition and SO_2 calculations from RAINS, and similar, models should be used cautiously in assessing forest impact. We must keep in mind that the spatial resolution of the EMEP long range transport model used in RAINS is 150 km, which is typical of a model of this sort. Forest growth processes are, of course, of an entirely different scale. Also, the EMEP model, as other models of this type, assumes uniform mixing in a vertical layer extending up to a constant or dynamic mixing height which can range from 200 to greater than 2000 m. (The version of the EMEP model used for calculations in this paper uses a constant mixing height of 1000 m.) In reality, vertical SO_2 gradients commonly occur even though they may be less pronounced when averaged over seasons or one year. It is therefore unlikely that the SO_2 exposed to trees is the same as the vertical average SO_2 that is computed by the long range transport model. Also, total sulfur deposition calculations should not be directly taken as inputs of acid stress to forest soil without accounting for the ability of forests to "filter" SO_2 and other pollutants, and without incorporating the buffering affect of base cations in deposition (Kämäri, 1986).

Conclusions

For the forested areas examined (and with the above mentioned caveats in mind):

1. Deposition will level off after the year 1985 in almost all areas for the emission scenarios considered in this paper.
2. According to the most likely emission scenario (30% Reduction), deposition after the year 2000 will return to its 1960s level.
3. The different emission scenarios produce either considerable or negligible variation of computed sulfur deposition depending on the forest area considered.
4. The most optimistic emission scenario (Major Sulfur Controls) reduces deposition and SO_2 concentration to their early 1900s level.
5. Different forested areas of Europe are subject to very different levels of sulfur inputs: The difference in magnitude of deposition between certain areas could be a factor of 20 for 50 years and a factor of 10 for 100 years.
6. Computations of sulfur inputs to forests by long range transport models should be used with caution in forest impact studies because of the assumptions of the long range transport models such as complete vertical mixing, neglect of the special pollutant "filtering" ability of forests, as well as the differences in scale between atmospheric and forest growth processes.

SO_2 Air Concentration (μg S m^{-3})

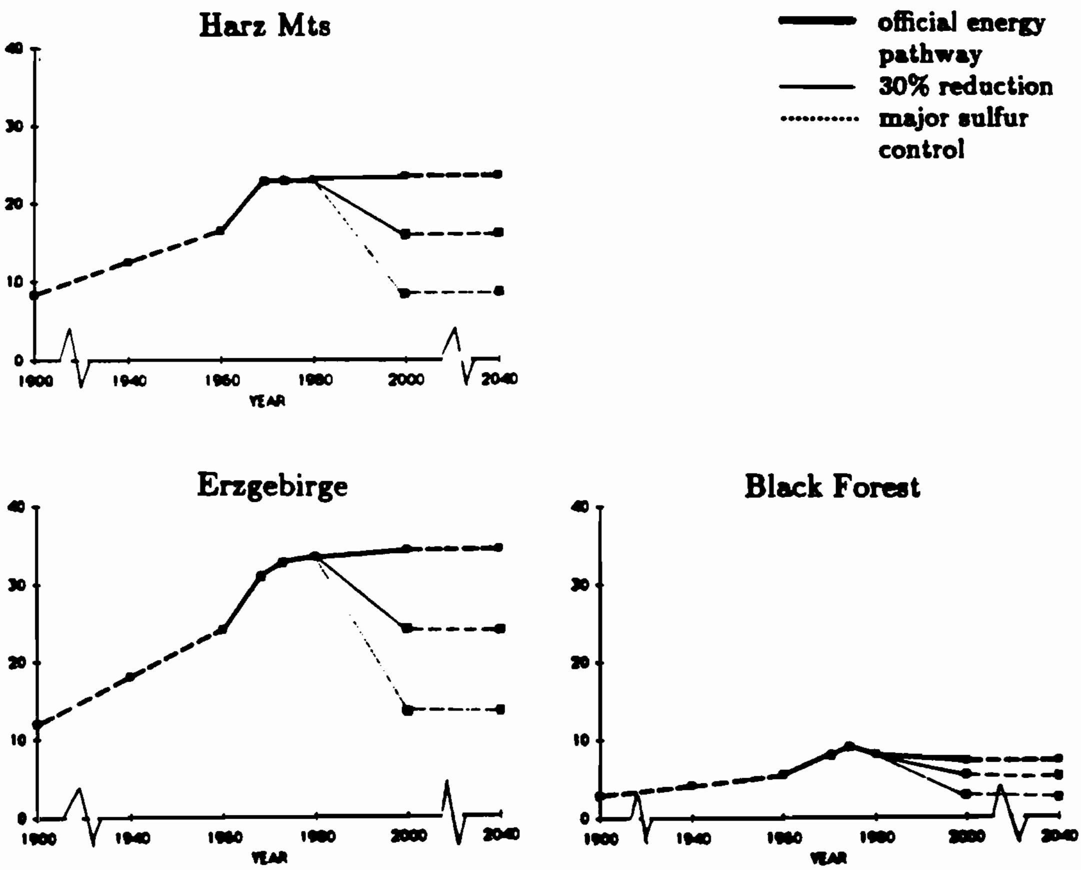

Figure 8. SO_2 time series for forested areas in Figure 6.

Acknowledgements

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2.3 DATA MANAGEMENT COMPUTER SYSTEM OF AIR POLLUTION IMPACT ON FORESTS USED IN THE BOTANICAL GARDEN OF THE POLISH ACADEMY OF SCIENCES AND ITS RELATION TO EXISTING SYSTEMS IN POLAND*

B. Molski, K. Głębicki and W. Dmuchowski
Botanical Garden
Polish Academy of Sciences
Warsaw, POLAND

1. INTRODUCTION

Research on environment pollution with the use of bioindicators have been carried on in the Botanical Garden of the Polish Academy of Sciences since 1974 by the Laboratory of Plants' Ecology. The experiments are characterised by relatively large scope and diversity of scale. The subject of our studies may be a single emitor, urban-industrial agglomeration, province, macroregion or a country. We use various indicator plants. Recently, we have organised the research group, members of which come from different centers dealing with specific methods and indicators (soil fauna, lichens, mosses, *Tradescantia*, biomonitoring of mountain regions).
In order to fully interprete all the obtained results we have to correlate them with climatic and geomorphologic data. For this very reason, as well as due to the increase of the number of our own data we had to implement data management computer system in the Garden.

2. INFORMATIC SYSTEM OF ENVIRONMENTAL BIOMONITORING IN THE BOTANICAL GARDEN OF THE POLISH ACADEMY OF SCIENCES

Experiments carried on in the scale of country, region or province consisting in collection of indicator plant samples are the main source of data for our system.
For the sake of simple and clear coding of the place of samples collection, Poland was divided into 62 big squares (80 km x 80 km) named H2, C5, etc. Every big square was further divided into 100 basic squares (8 km x 8 km) named n1, p2, etc. (Fig. 1).
For every big square, a random choice of 5 among 100 basic squares has been made with the help of the computer (Molski et al. 1983).
The number of a sample is its basic identificator. Together with date, place of collection and the age of plant material it makes up the record of an input file which is called the CATALOGUE of a given indicator plant.
Such a record is extended with a field comprising additional information on samples collection conditions. Numbered samples are taken to the laboratory. Here, they are analysed in respect of the content of chemical elements. Different elements are analysed - both these which fulfill physiological functions as well as those which are considered pollutants. Results of these analysis together with a sample number constitute the record of a file called ANALYSIS of the indicator plant.
Having such a data base at disposal it is relatively easy to create the so called source files necessary for drawing maps of environment threat.
While still not having our own computer equipment we started to build up the system in cooperation with the Polish Society of Soil Sciences, an organisation which has constructed BIGLEB - an information system containing a great number of valuable information about natural environment

*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

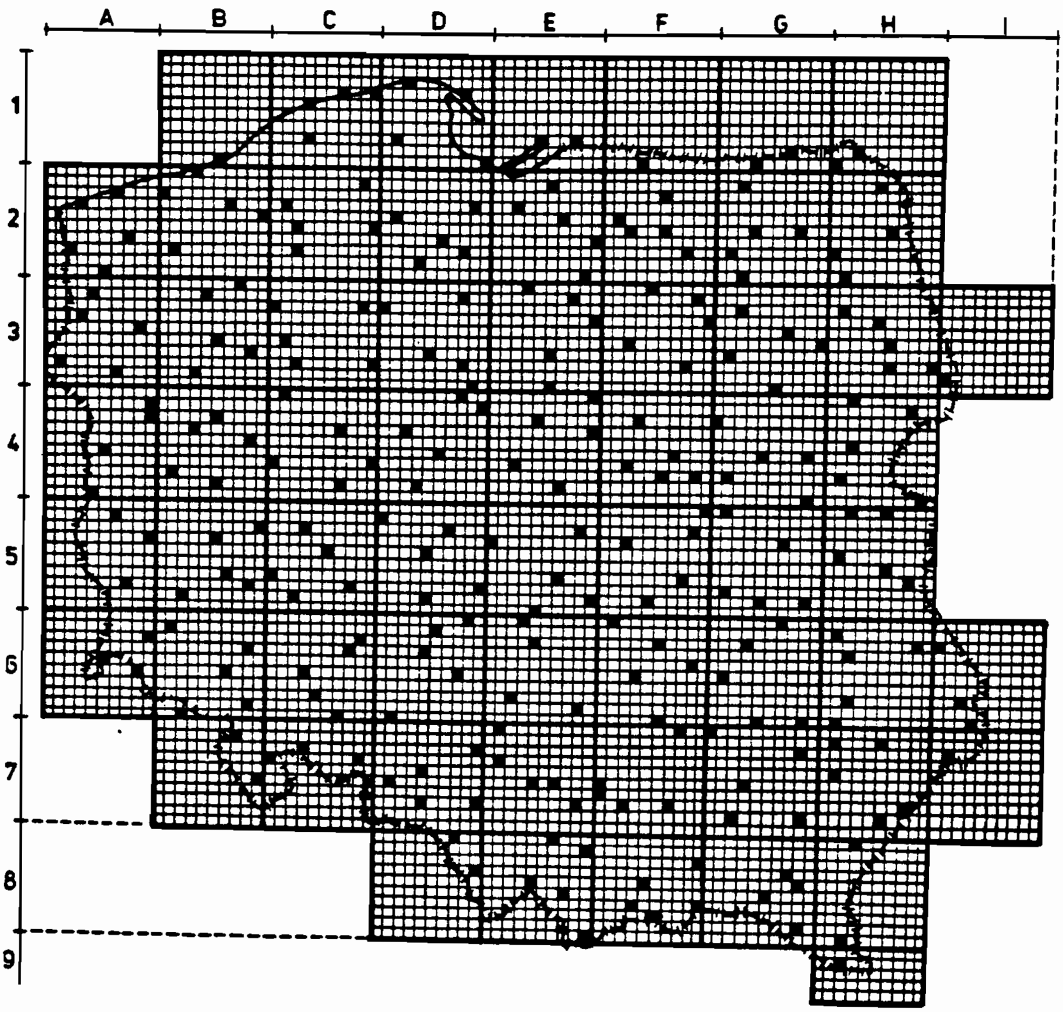

Fig.1. The method of random choice of the areas for needles collection is following: Poland is divided into 62 big squares /80km x 80km/. Every big square is divided into 100 basic squares /8km x 8km/. For each big square computer has made a random choioce of 5 among 100 basic squares. On the map the area where the samples have already been collected is enciecled. The llowed to eliminate any of the systematic, man-made errors.

As a result, we obtained programmes necessary for drawing maps by means of isolines methods (Dytczak et al. 1987).

ISOLIN is a FORTRAN package generating and plotting contour lines. Both screen and plotter graphics routines are included in the package. Maps can be plotted in different scales, multicolor plotting on a plotter are supported. Package can operate on a very big data sets even on such a small computer as IBM PC. For example one can generate the isolines for a grid as big as 20000 points in reasonable time. ISOLIN can generate contour lines from data about value of given function F(X,Y) at irregularly distributed points. Moreover the package can approximate the specified data assuming smooth surface of the function F(X,Y). This can sometimes be very valuable because output values of function F(X,Y) are given on much denser grid. ISOLIN can prepare data file for automatic update of information of the BIGLEB data base. The structure of data file is suitable for transfer it via an external network. It is even so compact that it is possible to transfer data using a 360KB diskette, which is an usual resort (at least so far in Poland).

The package has been split into several separate programs, each program performing dedicated task. All the communication between the modules is through the disk files. All the disk files but one are generated by the program. The exception being, of course, the input-data file which must be supplied by the user. The benefits of subdividing the package into separate modules are twofold:

First, the program has very modest memory requirements, Secondly, the user can separate different tasks at a time, so the rest of operations may be postponed. Or he can return to the once generated data and plot different contour lines (suitable data files should, of course, be kept on either hard disk or diskettes).

The code is entirely written in FORTRAN 77 and as such conforms to ANSI X3.9-1978 standards. The program was compiled with a Microsoft FORTRAN-77 version 3.30 compiler. Current version of the package supports only an IBM Color Graphics Adapter and Roland plotters, this is because on such configuration the system has been developed. Due to the internal structure of the package the system may be tailored to any IBM PC (or compatible) installation. For example it could, after some modifications, run on a system with a screen driven by either Hercules Graphics Card or Enhanced Graphics Adapters. Here the only warning is that recompilation of the program on other systems is not all that should be done. ISOLIN uses libraries (eg. graphic library) which are dedicated to this package and particular configuration of the system, so more changes are needed to install the package on other systems.

The ISOLIN package contains the following modules:

1. ISLINP - ISoLin data INPut module.
2. ISLGRI - ISoLin GRId generation module.
3. ISLGEN - ISoLin contour lines GENeration module.
4. ISLOPT - ISoLin contour lines OPTimization module.
5. ISLPLO - ISoLin screen PLOtting module.
6. ISLMAP - ISoLin plotter MAP output.
7. ISLUPD - ISoLin data base UPDate module.
8. ISLREC - ISoLin RECords unpacking module.

Each module will be briefly described below.

EISLINP - this module should be called first, user-supplied data file is read here by the program. The user can deliver data about coordinates of randomly distributed points and values of any function at these locations. Two dimensional case is considered, therefore values at the defined points represent certain function of two variables (coordinates) X and Y. This module produces a file which can be read by the ISLGRI module.

EISLGRI - this module generates standard grid for performing contour lines analysis. All the necessary modifications to the data file supplied by the user are performed here. Those modifications originate from the following arguments:

1. The function of interest should be "smooth", in other words there should be no sharp edges between the points where the value of this function is explicitly specified.

2. An irregular grid of points specified by the user is transformed into a regular quasi-orthogonal grid. So there is a set of newly (artificially) defined points by the program where value of the function can be calculated by means of suitable interpolation or extrapolation.

3. The grid supplied by the user should be optimized to minimize CPU time needed for computations and to make it better suited for performing any interpolations. The above mentioned grid optimization is only optional, the user should decide if he needs it to be performed.

This module generates two files ISL.SCR and ARRAY.ISL. The former file contains information about quasi-orthogonal grid arrangement, the later file holds values of the quantity (function) of interest at all the grid nodes.

ISLGEN - this module generates the contour lines required. The user is prompted for the title of the map and values of isolines he needs.The rest of data is read from the files prepared by the ISLGRI module. The results are written to the file ISL.RES. The isolines generated by this module consist of sets of straight lines drawn between two points. On output a list-structure containing information about the coordinates of begin and end points and value of function along the line, for all the set of lines, is generated.

ISLOPT - This module optimizes the list-structure generated by the ISLGEN module, so all the input is taken from the file generated by the ISLGEN module. The list searched for lines that could be joined, if found such lines are joined to give a polyline (line formed by several straight segments). On output one gets the file ISOLIN.DAT which holds a list-structure significantly shorter than this of ISL.RES file. The main task of the ISLOPT module is not only to shorten the file, but first of all to speed-up the process of plotting the contour lines. A polyline can be plotted (especially on a plotter) much faster than a line built from separate line segments.

ISPLO - this module performs all the screen plotting on a graphics monitor driven by the IBM Color Graphics Adapter. By default the program reads a file ISL.RES, so the file generated by the ISLGEN module. If the user made a run of the ISLOPT module (he is advised to do so if he wants to plot the map on a plotter), he should rename the file ISOLIN.DAT to ISL.RES prior to entering the ISLPLO module.
Contour lines are not labelled on a screen in this version of the ISLPLO module. The user is recommended to review all the maps prior to drawing them on a plotter. The reason for this is at least that the ISLPLO module is much faster than the ISLMAP module. The ISLPLO module doesn't produce any new files.

ISLMAP - this module performs all the final drafts on a plotter. On input the ISL.RES file is required, no output files are generated. A map which is a product of this module looks far nicer than this drawn on the screen by the ISLPLO module. All the contour lines may be labelled, maps can be drawn to specified scale, the user may choose the palette of colours he wants to use. All the above options are set by the user friendly

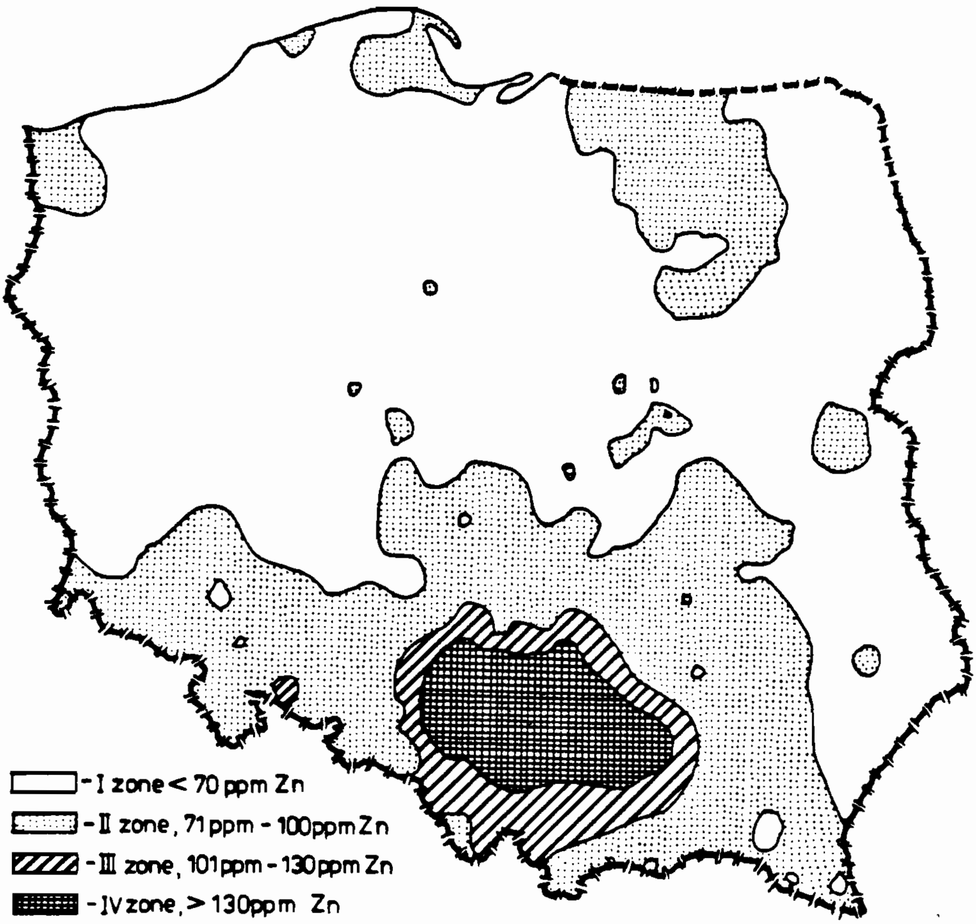

Fig.2. Accumulation of zinc in pine needles in different parts of Poland. The method of random choice of the areas for needles collection is presented on figure 1. The normal zinc content in pine needles is about 40-50ppm. The highest accumulation, more than 250% of the normal level is found only in the areas of very intensive industry and traditional centres of zinc and other metals mined over many centuries. High zinc pollution has highly destructive effect on soil and may affect vegetation.

interactive session (via a menu of prompts) with the program.

ISLUPD - this module serves as an interface between the contour lines program and the BIGLEB database. The information which is graphically represented by a plotted map (on a screen or a plotter) can be digitized automatically. It means that the module ISLUPD can read the files produced by the ISLGRI module, transform them to the coordinate system of the BIGLEB database and write the digitized map to the output file ISLUPD.RES. Fundamental differences in the coordinate systems used by the ISOLIN package and the BIGLEB database, make transformation process very complicated and time consuming.

A file ISLUPD.RES produced by this segment is in the so called compact form, it means that to use it one must unpack it. A compact storage scheme enables to transfer data via an external network (TRANSNET, PC-NET, etc.). This file contains continuous stream of data, only values of the function at grid points are stored.

ISLREC - this module performs unpacking of the compactly stored ISLUPD.RES file.

So far, with the help of this package we have managed to draw a map of environment pollution with sulphur (Molski, Dmuchowski, 1986) and zinc (fig.2, Molski, Dmuchowski,Chmielewski, 1986b). This map was drawn on the basis of the quantity of sulphur and zinc accumulation in pine needles. Before drawing the map we went through a series of methodical experiments confirming applicability of our method (Dmuchowski, Molski, 1985).
Some months ago we purchased IBM PC/XT in full configuration. Considering great operational possibility of this equipment the Garden has become independent in respect of its own materials processing.

It is obvious however, that one scientific unit or a group of people is not able to collect and process all information about the environment necessary for the interpretation of results.It is crucial to make use of information comprised in various data basis (climatic and geomorphological information, sculpture of the earth surface, distribution and size of pollutants emission sources etc.).

However, it turns out to be extremely complicated due to very few possibilities of combining different systems existing so far. There seem to exist three most important reasons for the above situation:
- inconsistence of applied grid
- incompatibility of hardware and software
- unregulated law aspects of the access to data

3. CONCLUSIONS

- Computer system allows for efficient collection of data and all manipulation necessary for obtaining information in form of maps or figures.
- We believe that due to the appearance of a great amount of equipment compatible with IBM PC standards exchange of information stored on magnetic disks will become possible and common.
- It was only recently that Poland faced the possibility of easier renting of telephone cables for transferring computer information. It can be thus inferred that a group of interested users will create a dispersed net among themselves. This would be a moment when we will have to decide whether biomonitoring system should not have a mainframe computer.
- Moreover, it is necessary to settle formal and law aspects of acces to already existing information about environment.

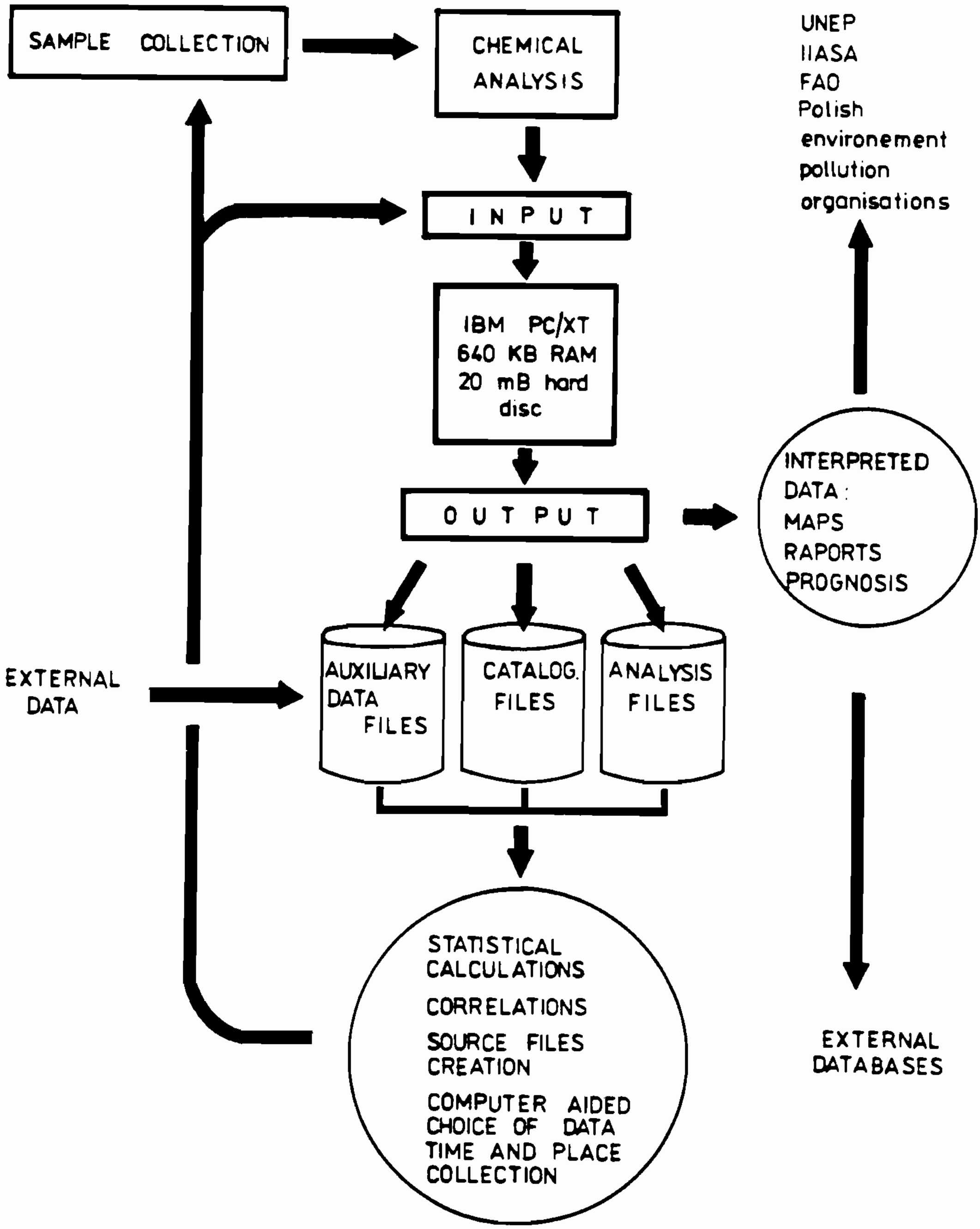

Fig.3. A flow of information in the informatic system of biomonitoring in the Botanical Garden of the Polish Academy of Sciences. The files CATALOGUE and ANALISIS are described in the text. The auxiliary data files contain the external information both available on diskettes or deriving from digitizing materials obtained by the Garden in the form of maps.

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A C K N O W L E G E M E N T S

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2.4 REMOTE SENSING OF AIR POLLUTION AND FOREST DAMAGES*

J. Walczewski
Institute of Meteorology and
Water Management
Kraków, POLAND

1. INTRODUCTION

The possibility of reducing or stopping the forest decline depends very much on the possibility of recognition and forecasting of the destructive processes in the forests. Time factor plays here an important role. Generally, 3 methods - with 3 corresponding time scales - may be used for forecasting the forest decline /Fig.1./.

A long-period forecast can be based on the expected amount of emission of air-pollution substances potentially harmful to the forests. This type of approach is often based on the possible scenarios of economical development, with corresponding emission forecasts. Prognostic periods can be extended up to several tenths of years, but the degree of uncertainty is high.

Other two methods are based on empirical data: observed input of pollutants to some forest complexes, or observed symptoms of beginning processes of forest damage. The data used here can be obtained with application of different kinds of measurements and observations. The in-situ measurements need highly developed networks and systems for acquisition of information. Where large forest areas are to be controlled, more and more preference is given to the remote-sensing methods. Use of these methods makes possible the acquisition of data from large areas in comparatively short time, with low values of cost index per unit of information. Remote-sensing is especially effective when applied for general recognition of situation, whilst in-situ measurements may be used in the next step, for detailed investigations in selected sites.

In this paper we are considering some applications of remote-sensing in reference to two empirical methods of the forest decline forecasts mentioned above. A very broad literature exists concerning remote-sensing applications, but the problem of finding inexpensive and simple methods remains actual, especially for countries which have limited access to the highly advanced technologies.

2. REMOTE-SENSING OF AIR-POLLUTION INPUT TO THE FOREST AREAS

Different space-based, airborne and ground-based methods may be used for remote-sensing of air-pollution input to the forest areas. As an example two methods will be described which were

*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

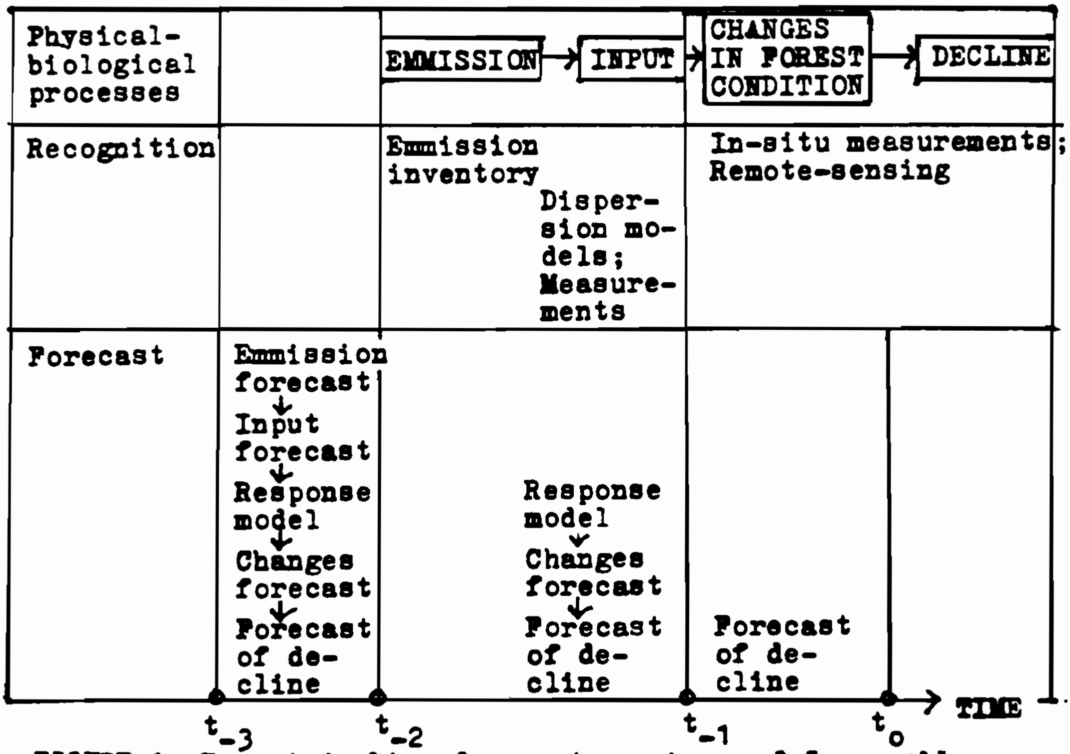

FIGURE 1 Forest decline forecast - scheme of 3 possible approaches

applied in the investigations of Niepołomicka Forest, a big /110 km^2/ forest area situated in Poland, in the vicinity of urban-industrial complex of Cracow.

LANDSAT-satellite images were used to assess the influence of dust emission from different sources on Niepołomicka Forest. The 100 m resolution of images enables the recognition of bigger industrial smoke plumes, especially in the MSS-4 and MSS-5 spectral channels /0.5-0.6 and 0.6-0.7 µm/. The images of Cracow region were available in a limited number only, but they were taken in different seasons, thus - in different time intervals after Sunrise /because the time of observation remains nearly constant/. The dependance of the range of smoke plumes on the time after Sunrise was determined; the range is decreasing in morning hours because of the change of atmospheric stability /transition from the nocturnal stable situation to the instability in daytime/. An index N_g was defined, called "the geometrical index of the emitter impact in reception point":

$$N_g = 365 f \cdot 24 k = 8760 f k \qquad \text{hours/yr}$$

where: f - percent of days in year with wind direction equal or nearly equal the direction: emitter-reception point; k - percent of hours in day with atmospheric stability corresponding with dust plume range $L > L_r$, where L_r - distance emitter-reception point.

The evaluation of the coefficient f was made on the basis of the upper-winds data statistics. For evaluation of k an empirical model was used, describing the diurnal course of appearance of the atmospheric stability categories. This model is developed on the basis of results of a 6-year series of acoustic sounding of the atmosphere in Cracow /Walczewski, Bielak 1985/.

One of the methods used to investigate the inflow of SO_2 to the area of Niepołomicka Forest was measurement with use of vertical-looking, mobile correlation spectrometer. The instrument measures the total burden of SO_2 in a vertical column; a vehicle may be used to make the measurement along a prescribed route /Hamilton et al. 1978/. Using mobile correlation spectrometer one can measure the flow of SO_2 across a vertical surface intersecting the Earth surface along the route of measurement. In this case, the wind speed versus height should be known and some assumptions are made concerning the structure of flow field.

In the Niepołomicka Forest a closed measuring route was traced, 55 km long and surrounding the main part of the forest. A series of measurements was made to determine the situation of gas plumes and directions of their invasion. In 50% of cases it was possible, too, to assess the value of inflow-outflow balance and resulting deposit value. The method is subjected to some limitations and some specific problems have to be solved to make the results dependable. An experienced staff can perform the measurements of inflow and deposit values with accuracy characterized by standard deviation value $\sigma = \pm 33\%$ /when pilot-baloon is used for measuring upper winds/. Fig.2. presents an example of SO_2-plume location over Niepołomicka Forest; the detection and tracking of plume was made with method described above. The plume was emitted from a source in distance of 70 km.

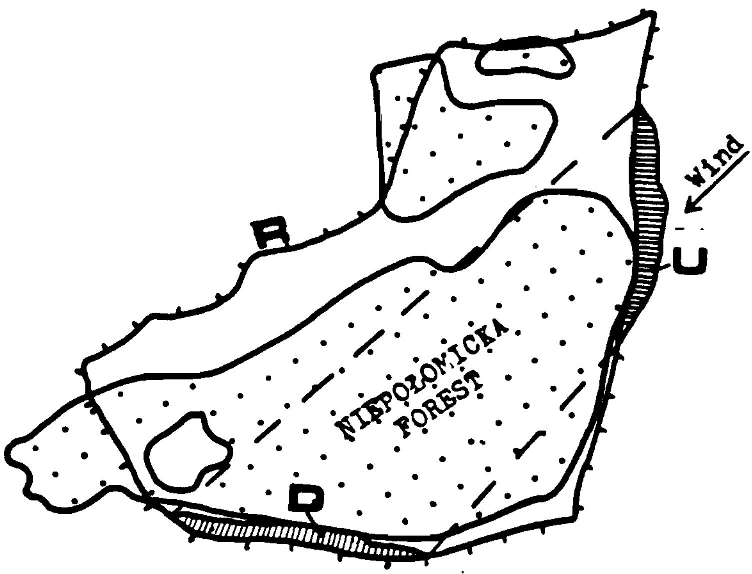

FIGURE 2 SO_2 plume over Niepołomicka Forest. R - route of the vehicle equipped with correlation spectrometer. U, D - instrument response on upwind and downwind segments of the route.

3. EARLY RECOGNITION OF DAMAGES - A REMOTE-SENSING APPROACH

As it is generally known, the decay of physiological condition of vegetation is connected with decrease of reflectance in the near-infrared, and this decrease appears earlier than any symptoms in the visible part of reflected radiation /Fig.3./. This phenomenon is applied for diagnosis of forest condition, using different methods, like multispectral photos or scanner images and IR-false-colour photography. Airborne or space-borne platforms are used for data acquisition and resolution value better than 100 m is necessary /Fig.4./. The images are available on commercial basis and the cost of information is rather high when imaging of large areas must be repeated many times. Thus, independently of many existing sophisticated techniques, some simple and inexpensive technologies may be useful if they offer minimum of necessary information.

In the research programm in the Niepołomicka Forest the technique of radiometric profiles was applied. The profiles were obtained by means of an airborne profile radiometer RAP /Walczewski et al. 1981/. In comparison with scanning radiometers the instrument is very simple and inexpensive and it can be installed even in a small sporting aircraft. The information obtained is limited to the profile - and thus far from the richness of the photography, but the spectral characteristics can be determined in more accurate way.

The radiometer with optical axis pointing vertically down measures the intensity of radiation reflected by forest-covered surface, in 2 spectral channels: 670-680 nm /red/ and

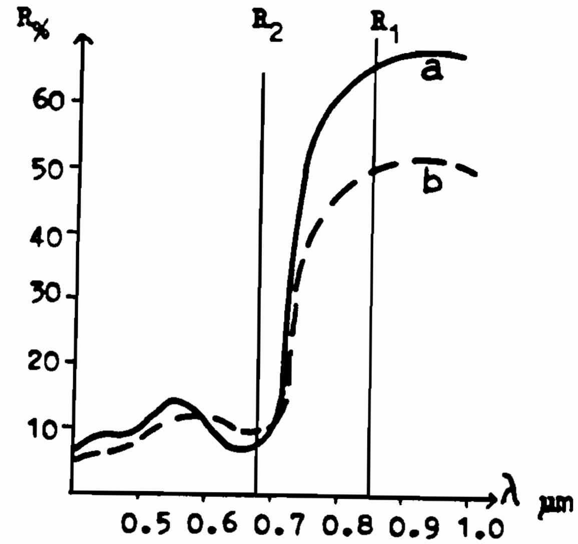

FIGURE 3 Reflectance R versus wavelength for green trees in healthy condition /a/ and damaged /b/. R_1, R_2-spectral channels of profile radiometer RAP.

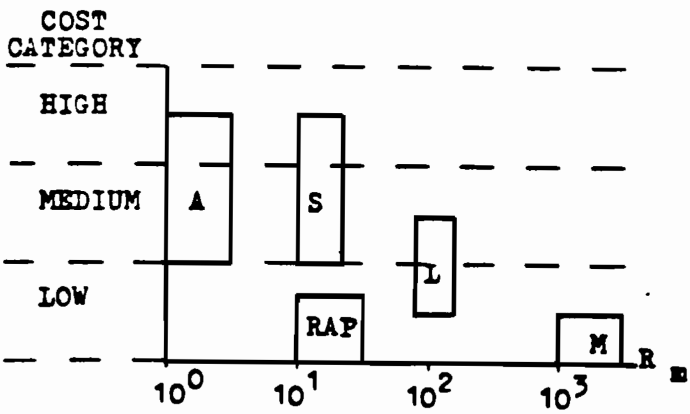

FIGURE 4 Cost/resolution characteristics of spectral information obtained by aerial photography /A/, satellite systems /S-SPOT, L-LANDSAT, M-Meteo satellites/, and airborne profile radiometer RAP

845-855 nm /near IR/ - Fig.3. The instrument is recording ratio $S = S_1/S_2$ where S_1 is the response in IR channel, and S_2 - the same for the red one. Index S, therefore, presents the relation of near-IR reflectance maximum to the minimum in red. This relation contains information on the physiological condition of vegetation. Index S may be used for computation of the "Vegetation Index" VI defined by Tucker /1977/:

$$VI = (S - 1) / (S + 1).$$

The conditions of measurements are subjected to some limitations resulting from the assumptions accepted in the scheme of the measurement, and from the operational circumstances.

A series of measurements was made using 2 fixed flight routes crossing the forest in N-S and W-E directions. The recorded data were digitalized and computer-processed. It was found, that the value of S does not correlate with individual species of trees /because of the specific forest structure/ but with the types of vegetation communities, in following sequence: wet hornbeam-oak wood /highest S-value/, transitional decidous wood, transitional mixed wood, wet oak-pine forest. For individual communities the signal value depends on the location of the site. In general case, a specific plant community "i" is represented on some segments of the measuring route. For a given measuring route and for an individual measurement at time "t" following values of S are calculated:

- mean for route: S_t;
- mean for community "i": S_{it} /for i = 1 ... k/;
- mean for community "i" and for segment "j": S_{ijt} /j= 1...m/;

For a series of measurements in a season /$t = t_o \ldots t_p$/ mean values S, S_i, S_{ij} are determined, respectively. Index:

$$q_{ij} = S_{ij} - S_i \quad \text{or} \quad \hat{q}_{ij} = 100\, q_{ij} / S_i$$

may be used for finding the segments in which detailed ground-based investigations should be made because forest communities are probably in the worst condition there. Fig.5. presents some values of $\hat{q}_{ij}$ obtained in Niepołomicka Forest for WE route. Numbers 11...44 are symbols of route segments; "a" denotes oak-pine forest, "b" - transitional mixed wood, "c" - transitional decidous wood.

This schedule of analysis may be followed if maps of forest communities are available. If not, recognition of communities must be performed at first, using index $c_i = S_i - S$, or

$$\hat{c}_i = 100\, c_i / S ,$$

and absolute values of S_i.

4. FINAL REMARKS

We have considered above two characteristic problems connected to the problem of forecasting forest decline. These problems may be solved with use of different means. The methods described are only examples of options characterized by moderate technological and financial effort. In practice, the selection

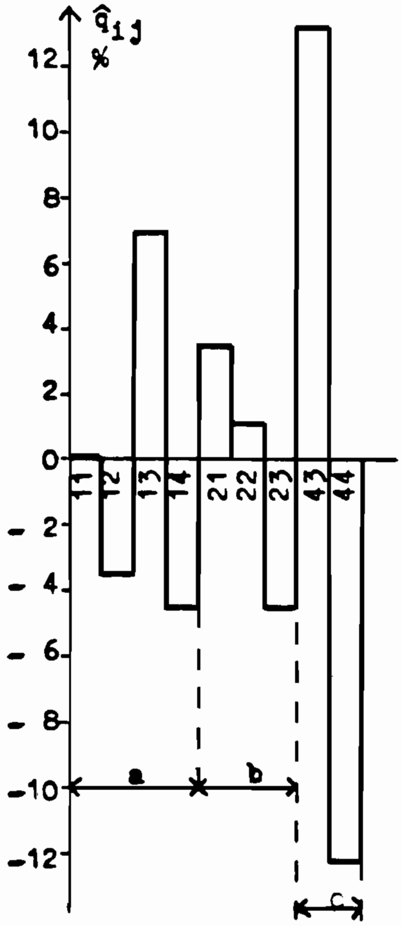

FIGURE 5. Normalized spectral index q_{ij} for different forest vegetation communities in Niepołomicka Forest

of method is performed in some technological and economical environment, specific for individual countries, and under different limitations. It may be seen, thus, that there is a need for systematic approach to the problem of assessment and selection of systems for monitoring the forest areas. A method which was developed earlier in more general aspect, may be adopted for this purpose /Walczewski 1980/. In this method an important role is played by a morphological matrix which is used to characterize the task /requirements for monitoring system/, and - in similiar way - to characterize the abilities of some specific system to fulfill the task.

Following kinds of requirements are taken into account:

A - Type of observation or measurement /i.i.: A1 - Determination of category of forest damage/;

B - Accuracy

C - Size of area covered by observation /km^2/;

D - Resolution in space /m/;

E - Resolution in time

F - Duration of planned observations;

G - Maximum acceptable time between the moment of observation and delivering the information in form useful to interpretation.

Proposed form of "requirements matrix for problems considered here is given in Fig.6. Marking proper frames one can formulate the characteristic of actual requirements, like in Fig.7. for the task "A1" - determination of forest damage categories in European countries.

Characteristic of system ability to fulfill the task may be obtained in similiar way. In Fig.8. "system matrix" is given for a realistic system of monitoring forest condition by aerial photography. Comparison of "system matrix" with "task matrix" /i.i. by superposition of transparencies/ is an easy way for finding the answer for the question how useful will appear a technical system in solving of given monitoring problem. For example, from comparison of figures 7 and 8 conclusion may be drawn that aerial photography is not perfectly suited for monitoring of large forest areas, because in most practical accomplishments /not in theory!/ it is difficult to obtain more than one set of pictures per year and processing of material takes too much time. This analysis should be supplemented by analysis of limitations and of the economical index /cost of the unit of information/.

	B	C	D	E	F	G
1	Qualitative recognition /"yes-no"/	up to 10^2 km^2	up to 10 m	days	days	days
2	Relative evaluation	$10^2 \ldots 10^3$	$10 \ldots 10^2$	weeks	up to 1 year	weeks
3	Approximate evaluation /categories/	$10^3 \ldots 10^4$	$10^2 \ldots 10^3$	months	several years /limited time/	months
4	Measurements	$10^4 \ldots 10^5$	$10^3 \ldots 10^4$	years	many years /unlimited time/	
5		$10^5 \ldots 10^6$				
6		more than 10^6				

FIGURE 6. Categorization of requirements for forest monitoring systems. A...G - kinds of requirements, 1...6 - categories for individual kinds of requirements.

	B	C	D	E	F	G
1						
2			●			●
3	●			●		
4					●	
5		●				
6						

FIGURE 7. Matrix of requirements for monitoring of forest areas in Europe /compare with Fig.6./.

	B	C	D	E	F	G
1			●			
2						
3	●					●
4				●	●	
5		●				
6						

FIGURE 8. Matrix of characteristics of the system of aerial photography applied to forest monitoring duties. Compare with Figs. 6 and 7.

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3. CAUSES AND INDICATORS OF FOREST DECLINE

3.1 THE NATURE, AND ELUCIDATION OF CAUSES, OF FOREST DECLINES*

F.T. Last
Dept. of Forestry & Natural Resources
The University, Kings Building
Mayfield Road, Edinburgh, Scotland, U.K.

1. PERCEPTIONS

When thinking about "Forest decline" it is as well to be reminded of one of the definitions of plant pathology - the study of plants in health and disease - a requirement including 'abnormalities' attributable to abiotic agents such as nutrient deficits, frost, drought ... in addition to those related to attacks by pests and pathogens. To be able to write with conviction about trees in decline, it is essential to have a sound basic knowledge of the behaviour and development of trees in health. As mentioned by Marshall Ward in the late 19th century "... disease is a condition of abnormal physiology ... the boundary lines between health and ill-health are vague and difficult to define." Regrettably, and despite protestations to the contrary, the essential information is not available. If nothing else, the present concern for forest decline has highlighted how little is known about the behaviour of one of the World's major assets, its forests. Our forest managers, 'general practitioners' in medical parlance, seriously lack the minimum essential fundamental understanding of the form, function and responsiveness of trees that in medicine is provided by specialists - too few resources have been made available for the study of tree biology.

What is 'forest decline'? It was defined by Manion (1981) as a complex disease caused by the interaction of a number of interchangeable, specifically ordered abiotic and biotic factors. In it, that is forest decline, a stress of biotic or abiotic origin alters tree metabolism and in so doing renders the tree susceptible to further loss of vigour. How can forest declines be recognised? In Europe and N. America concern has been focussed on both coniferous and broadleaved trees notably silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and european beech (*Fagus sylvatica* L.) in Europe, and red spruce (*Picea rubens* Sarg.), white birch (*Betula papyrifera* Marsh.) and sugar maple (*Acer saccharum* Marsh.) in eastern N. America (Anon, 1986a). Many descriptions of decline have been published. Outwardly the visible indications of decline are all, in some way, associated with foliage loss/retention, foliage coloration/discoloration and changes in the growth of leading shoots and lateral branches. As is instantly obvious these descriptors include virtually the whole of the limited array of ways in which trees can outwardly respond to adverse circumstances - they lack specificity. Interestingly there are few if any references to foliar mottling which, if present, might suggest damage done by ozone. However, the absence of mottling should not be interpreted as indicating that ozone cannot be implicated. In this regard results obtained at the Central Electricity Research Laboratories, Leatherhead, U.K., and reported by Davison and Barnes

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(1986), are of potential importance. After fumigating, without any immediate apparent effect, one plant of each of ten clones of Norway spruce with 0, 100, 200 or 300ug ozone^{-3} for 60 days during summer, it was found that the plants of three clones fumigated with the two largest concentrations of ozone developed severe needle necrosis when the minimum air temperature dropped in the autumn to -5^{c}C. While these observations should be regarded with caution until the experiment has been repeated, they indicate the complexity of plant responses. In doing so they suggest that observations of macroscopic damage, to foliage and shoot growth, are insensitive indicators of alterations at the biochemical/cellular level. It is inferred that the summertime fumigation with ozone, although without an immediate effect on leaf coloration and persistence, elicited an unnoticed persistent biochemical/cellular change associated in some clones with a predisposition to frost damage.

Following the example set in the Federal Republic of Germany (Anon 1984), a manual - Methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests - has been prepared, with the assistance of the United Nations Environment Programme (UNEP) and the Secretariat of the United Nations Economic Commission for Europe (UNECE), as part of an International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Trees. While I personally would have preferred to see the manual used, without alteration, to assess the status (normal/not normal) of forest trees without suggesting that deviations may be attributable to the effects of pollutants, the effective use of the manual with its records of needle/leaf loss, needle/leaf retention, patterns of defoliation, degree of foliar discoloration, needle/leaf sizes and amounts of foliar necrosis etc. linked to diameter at breast height, should provide a better understanding of the 'norm'. But what about roots and mycorrhizas? Events in soil must not always be considered as a 'black-box' beyond the realm of routine examination. Ways and means must be found of evolving a routine which will provide worthwhile data without being too labour intensive. It should be recognised that damage to roots may precede damage to "tops" (foliage, stem increments and branching patterns). In some instances this root damage may be attributable to adverse soil conditions but in others it is likely to be the first outward sign that plants are subject to adverse aerial conditions. For instance root growth of some plants is more adversely affected and sooner than that of tops when the latter are colonized by pathogenic fungi that are restricted to leaves (Last, 1962; Baenziger et al. 1979). Similarly Freer-Smith (1983) found that the growth of roots of Betula pendula Roth. was more severely decreased than that of stems, branches and leaves by concentrations of SO_2, and $SO_2 + NO_2$, that did not cause foliar blemishes.

For the present it has to be accepted that most series of observations of forest health/decline are undesirably incomplete. This being so, how can existing records be interpreted recognising that forest pathologists and physiologists tend to focus on leaf function whereas dendrochronolgoists, by definition, concentrate on tree-ring analyses. It tends to be tacitly assumed that the premature loss of needles from conifers is necessarily 'damaging'. But is this assumption correct remembering that old needles, to maintain themselves, are likely to take nutrients from trees without returning assimilates to be apportioned between roots, stems, branches, foliage and reproductive structures? Stein (1955) found that stem increments were not deletriously affected when the canopies of Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) were decreased by 25% by removing the lowest sections. But, as found with tomatoes and cucumbers, it is likely that the effects of defoliation will depend greatly upon the ages of the leaves removed, the removal of young leaves having a disproportionately adverse effect which cannot be explained solely in terms of the immediate products of photosynthesis (Smith et al.

1969a & b). With silver fir, the species in greatest decline in Europe, Kenk et al. (1984) found that decreases in the widths of annual rings in Baden-Württemberg were associated with (i) chlorosis of needles, also yellowing particularly of the upper surfaces of old needles, (ii) the premature loss of needles, particularly the older needles and (iii) decreased height increments. However in Norway spruce, the relation between needle losses and changes in stem increment seem to be less closely related with increment decreases rarely appearing before 30 to 50% of needles have been lost (Kenk in litt.).

Clearly our understanding of the relation between foliage loss and stem increment needs to be improved. But, in the meantime, what can be learnt about the possible cause/s of decline from records of foliage losses and discoloration? At the FAO/ECE Workshop held in Freiburg im Breisgau, Federal Republic of Germany (FRG) in October 1985, Bengtsson reported the outcome of the 1984 Inventory of Forest Damage in Sweden. In agreement with colleagues in other Nordic countries 'his team', primarily concerned with the abundance of living needles, restricted its observations to the upper halves of Norway spruce canopies (observations were made on the upper two-thirds of Scots pine). In the event, greater proportions of the standing stock of Norway spruce had lost 20% or more of needles in (i) southwestern Sweden and (ii) western parts of northern Sweden than elsewhere in that country. These data highlight some of the problems of characterizing forest decline, also some of those concerned with interpretation. Although specimens of Norway spruce in widely separated parts of Sweden had similarly extensive losses of needles those losses were most unlikely to be attributed to the same cause/s. Tentatively it was suggested that foliage losses in the north were probably attributed to inclement weather whereas the comparable losses of needles in the southwest, where the summers of 1982 and 1983 had been unseasonally dry, overlapped, in a geographical sense, with the area in Sweden which would be predicted to have the largest concentrations of the "most important pollutants".

However, at this stage and before focussing more sharply upon the possible role of atmospherically dispersed pollutants, it is necessary to recognize that declines have been attributed to factors other than pollutants for example cyclic occurrences of inclement weather. Wachter (1978) has pointed-out that silver fir, in parts of continental Europe, has been subject to several cycles of decline during the last two centuries. While describing the present-day occurrence of mortality in red spruce in the montane forests of New York, Vermont and New Hampshire in the U.S.A. Johnson et al. (1986) noted that something comparable seems to have occurred towards the end of the nineteenth century when it was unlikely that industrial pollution could be implicated. Decline in red spruce with 'classical' symptoms of crown thinning and altered patterns of branching, progressing from the tops of trees downwards and from outside inwards (Johnson and Siccama, 1983), occur at increasing frequencies towards the altudinal limit of this species (c. 1200m in the northern Appalachian Mountains). Apparently, the reductions in tree ring widths (at breast-height)which have been sustained for 20 to 25 yr were substantial from the start. When arguing the etiology of red spruce decline - needle loss is not associated with prior symptoms of nutrient deficiencies - Friedland et al. (1984) and Johnson et al. (1986) have suggested that the development of red spruce, particularly near the limit of its natural distribution, may be adversely affected when the late-summers are warmer than average and the early periods of winter weather are colder than average. They emphasize the apparent increase in amounts of winter damage suggesting that the extent of frost hardiness may have been decreased by (i) a lack of hardening and/or excessive cuticular transpiration (that is, natural stress factors of particular importance near the geographical limit of a species) and (ii) a general decline in vigour. Added to these, Johnson and his colleagues recognize that pollutants (in their instance wet, or more probably occult, deposition) may exacerbate the predisposition to winter damage by further decreasing the ability of red spruce, near its geographical limit, to winter harden. They noted that red spruce mortality was directly related to foliar concentrations of nitrogen (Johnson et al. 1984) and that the deposition of nitrogen, in wet and occult precipitation at high altitudes, where decline is sometimes particularly prevalent, namely 37.5 to 44.1kg N $ha^{-1}yr^{-1}$ (Scherbatskoy and Bliss, 1984) was likely to be much larger than the 6.5kg N $ha^{-1}yr^{-1}$ deposited at low altitudes (Likens et al. 1977). Additionally amounts of H^+, SO_4^{2+}, and some heavy metals e.g. lead, are also likely to be larger at high altitudes while, bearing in mind the experience reported by Davison and Barnes (1986), it would be unwise to disregard the not infrequent occurrence of ozone episodes with at least 100ppbV (Burgess et al. 1984).

From what has been written so far, and as must be obvious from an examination of the two volumes recording the Proceedings of the International Symposium on Acidic Precipitation, held at Muskoka, Canada in 1985, the nature of forest decline lacks definition: there are also many uncertainties about the cause/s of forest decline. In summarizing the position in Europe in relation to Forest Decline, Krause et al. (1986) emphasized that it was widespread between latitudes 46° and 53°N. Accepting that there are inevitably inexactitudes when subjectively assessing the extent of needle loss, the main arbiter of decline, the surveys of 1984 suggest that 17% of conifers (spruce + pine + fir) in the FRG have lost in excess of a quarter of their needles compared with 13% in the Netherlands and 8% in Switzerland. As in France Rehfuess (1985), working in the FRG, indicated that there are large regional differences in the extent of needle loss, also in the importance of other characteristics for example the occurrence of:

(i) needle yellowing at high altitudes in central FRG
(ii) crown thinning at intermediate altitudes in central FRG
(iii) needle reddening in older stands in southern FRG
(iv) needle yellowing on calcareous soils in southern FRG
and (v) crown thinning in northern coastal FRG (Anon, 1986b).

In many areas where the atmospheric concentrations of mixtures of SO_2 and oxides of nitrogen are small the cause/s of decline, Neuartigen Waldschäden, still need to be clarified but in others, for instance the Fichtelgebirge and Erz Gebirge regions of (i) western Czechoslovakia and (ii) north east Bavaria, where concentrations of these gases are relatively large most research workers would expect SO_2 and oxides of nitrogen to be among, if not the, major primary contributory factors albeit their influences may be exacerbated by the simultaneous occurrence of ozone, hydrocarbons, fluorides and adverse weather. While propounding this association in northeastern Bavaria, Rehfuess (1987) suggested that the extent of damage caused by relatively large concentrations of sulphur dioxide (and oxides of nitrogen) might be significantly related to the way in which they predispose Norway spruce to frost damage. To the south, where SO_2 concentrations are smaller, he identified two sets of conditions where parent rocks are either calcareous as in the Bavarian alps or granitic, schist-like as in the Black Forest. In the latter he associated decline at the higher altitudes with interactions between photo-oxidants, acid deposition, intense radiation and frost shocks. It has been suggested that trees in the Black Forest go into decline because the supplies of soil magnesium are insufficient to allow root uptake to replenish the leaching losses from foliage following the disruption of leaf cell membranes by photo-oxidants, the losses being aggravated when extremely acidic droplets (as in occult deposition) are deposited during periods of cloudy/misty weather - it has been suggested that magnesium deficiency may be one of the factors that predispose Norway spruce to frost damage. In the calcareous regions of the Bavarian (Swabian) Alps Rehfuess places greater emphasis on abiotic stress factors other than atmospheric pollutants.

These ideas on a more selective geographical approach to the elucidation of forest decline in Europe have been further elaborated by Rehfuess (1987) and in doing so he is not at variance with Krause et al. who favour the idea that the different forms of Neuartigen Waldschäden are more likely to be explained by a combination of natural (frost, drought) and man-made(pollution) stresses rather than by either alone. They also stressed that climates are constantly changing with antecedent and present-day combinations of (i) temperature, rainfall, solar radiation ... and (ii) atmospheric pollutants probably being unique. However with the widespread and more or less simultaneous awareness (I intentionally didn't write 'occurrence') of Neuartigen Waldschäden, not only in Europe but also in eastern N. America, it doesn't seem unreasonable to suggest that there might have been a synchronizing factor such as some attribute of weather for example the long timescale warming trend characterized by Jones et al. (1986) when analysing global air temperatures between 1861 and 1984. Five of the nine warmest years, in the entire record of 134 years, have occurred since 1978 with 1980, 1981 and 1983 being the warmest with many parts of Europe experiencing severe droughts in the late 1970s and early 1980s. To an extent drought and warm temperatures are linked with periods of intense solar radiation probably also favouring the formation of photo-oxidant pollutants. On the other hand drought per se might have augmented the acid pulses which Ulrich (1981) recorded as occurring when the moisture deficits of particular soils increased. But, while considering the role of warmer than usual temperatures it is important not to underestimate the possible significance of periods of severe frost as occurred in parts of Europe during the winter of 1978/79 and the spring of 1981. In short, the available circumstantial evidence suggests that the elucidation of the nature and cause/s of the different forest decline syndromes must take account of the possible contributory influences and interactions between weather and mixtures of pollutants, with variations being recognised both in time and space.

2. POLLUTION CLIMATES AND CLIMATE CLASSES

Although it should have been self-evident, it is nevertheless true that the existence of distinct pollution climates is only now being fully appreciated (Benarie, 1980; Last et al. 1986). Thus, in parts of central England, eastern Belgium, the Nordrhein-Westphalia (FRG) and western Czechoslovakia annual inputs of pollutants are dominated by the dry deposition of relatively large amounts of SO_2 and NO_2: wet deposition accounts for about 25% of total deposited sulphur and nitrogen, with ammonium significantly adding to the latter. Potentially phytotoxic concentrations of ozone occur on about 40 days per year (Fowler et al. 1987).

In contrast in southern parts (Baden-Württemberg) of the FRG, and most of Switzerland, there are relatively small concentrations of sulphur dioxide and nitrogen dioxide with slightly larger inputs of sulphate and nitrate in wet deposition. On a relatively large number of days, about 50 per year, there are potentially phytotoxic concentrations of ozone.

These 'definitions' of some of the pollution climates that can be identified, illustrate their complexity which is even greater when due allowance is made for diurnal and seasonal fluctuations. Clearly, nothing should be presumed for even within the second region (Baden-Württemberg and most of Switzerland) there are appreciable influences of altitude. In the higher areas (>1000m) the same relatively small concentrations of sulphur dioxide and nitrogen dioxide occur as at low altitude but there are much larger inputs of sulphate and nitrate in precipitation. Additionally mists, 'occult deposition', contribute significant amounts of sulphate, nitrate and hydrogen ions and very importantly annual average ozone concentrations may be up to 30% larger at high, than at low, altitudes with episodes not unusually persisting 24 hours or more at the former (Reiter and Kanter, 1982).

These definitions serve many purposes. They characterize the different pollution climates and in doing so indicate that plants, and other targets, are subject to complex mixtures of pollutants. Despite the upsurge in pollution effects research in recent years, the effects of very few of these mixtures on trees can be predicted. As yet there are no "rules" and this is likely to be the position until more is known about the effects of pollutants at the sub-cellular level (see Koziol and Whatley, 1984). In their review of the limited number of pollutant combinations that had been investigated Reinert et al. (1975) indicated that the effects of some combinations were less than the additive effects of the separate pollutants (antagonistic), greater than the additive effects of the different pollutants (synergistic) or equal to the additive effects of the different pollutants. It is worth citing two examples, the first of which is now regarded as a 'classic'. In elucidating the cause/s of chlorotic dwarf of eastern white pine (*Pinus strobus* L.), Dochinger et al. (1970) found that the symptoms were attributable to mixtures of ozone and sulphur dioxide which were acting synergistically. In the second example Freer-Smith (1984) concerned with the responses of six species of broadleaved trees to mixtures of SO_2 and NO_2 concluded that the responses to these pollutants differed from species to species and very importantly depended upon 'duration of exposure' and 'time of year'.

We have become increasingly aware of our deficient knowledge of the effects of mixtures of pollutants: while we know something about some mixtures of gases, which are subject to dry deposition, virtually nothing is known of the interplay between them and pollutants reaching their targets by other 'routes' namely wet and occult deposition. But in recent years it has been learnt that plant sensitivity and responsiveness to pollutants are both strongly dependent upon patterns of weather (light intensity and temperature (see Mansfield et al. 1986) and winter stress (Davison and Barnes, 1986)). Thus when arguing and debating the nature and causes of forest decline it is necessary to have knowledge not only of pollution climates but also of the different attributes of weather. This applies just as much to North America as to Europe, Asia etc. Whereas it was extremely difficult if not impossible to combine more than two factors with the techniques available in the 1950s, Jones and Bunce (1985), with the help of multivariate analytical methods and with data related to (i) mean monthly air temperatures (°C) and amounts of precipitation (mm) for January, March, May, July, September and November (ii) latitude and (iii) distances from the Atlantic Ocean, were able to identify eleven climate classes with distinct collections of attributes - 4 northern and montane classes, 4 temperate classes and 3 Mediterranean classes. Using pollution climates and climate classes it is possible to establish a matrix of environmental variables that should allow a more calculating approach to the problems of forest decline which would doubtless be improved by a consideration of bedrock geology and soil types.

3. DIRECT AND INDIRECT EFFECTS

To my mind research into forest decline has been hindered by the neglect of Koch's postulates, the bulwark of pathology whether human, veterinary or plant. Koch (1891) proposed three criteria for characterising the cause/s of disease:

1. The suspected causal organism/s must be constantly associated with the disease

2. The causal organism/s must be isolated and identified

and 3. When inoculated into a healthy plant the causal organism/s must reproduce the original disease.

Because of probable cumulative influences, investigations of trees are technically demanding, more particularly as it is virtually impossible to mimic, in a meaningful way, the influences of cyclically changing patterns of weather. On the other hand it is possible to do a variety of useful experiments testing the significance of pollutants either by their exclusion or addition, always taking note of the characteristics of the different pollution climates. For these purposes it is necessary to modify Koch's postulates by substituting 'pollutant/s' for 'organism/s' and rewriting the third postulate to read

3. Pollutants deposited on plants (by wet and/or dry deposition) must help reproduce the original disease.

By inserting 'help' I am not presuming that pollutant's are the primary cause/s: I am allowing for the possibility that plants may be predisposed by other variables (climatic?), also that exposure to pollutants may predispose plants to damage by frosts, droughts etc.

In the literature dealing with the effects of pollutants there is some confusion over the use of the word 'indirect'. On the one hand it is applied to effects on roots consequent upon the direct exposure of foliage to atmospheric pollutants while on the other it refers to the influences of pollutants which are not directly deposited onto plants for example the effects occurring when roots are growing in soils polluted with, and altered by, acidic deposition. To avoid confusion it seems desirable to restrict the use of the words direct and indirect -

direct being applied to effects when parts of a plant come into direct contact with dry, wet and occult deposition

and indirect being applied to the effects of influences exerted by pollutants through an intermediary, e.g. soil, such as may happen when soil properties are altered by acidic deposition.

If this were to be agreed, it would then be feasible to consider a further subdivision into primary and secondary influences. Thus, in considering the direct effects of atmospheric pollutants it is possible to identify primary influences on the activities of leaves and buds and secondary influences, because of altered assimilate production and transport, on roots. In contrast when considering indirect effects, the primary focus of attention is likely to be root metabolism and the secondary focus the altered activity of leaves and shoots consequent upon the interference with root function. In addressing themselves to the problem of forest decline how many research teams with expertise in the study of direct effects attempt to assess the relative importance of both direct and indirect effects by utilizing a range of soils including some that have been subject to appreciable amounts of acidic deposition (wet and dry) for many years. Circumstantial evidence recently presented by Tamm and Hallbäcken (1986) supports Ulrich's contention (1983) that alterations to soils attributable to acidic deposition, including acidification, can be appreciable. Tamm and Hallbäcken indicated that the pHs of some forest soils in Sweden have become 0.3 to 0.9 units more acid over a period of about 60 years. Conversely, how many teams concerned with indirect effects have taken the precaution of experimentally testing the interpretation of some of their observations by ensuring that some of their plants are growing in 'clean' atmospheres? Without having reciprocal-experiments of this sort it will be a long time before resolving some of the many questions posed at the Muskoka '85 Conference by Krause, Arndt, Brandt, Bucher, Kenk and Matzner when discussing the development and possible causes of forest decline in Europe (Krause et al. 1986).

4. OBSERVATIONS ON THE EXPERIMENTAL ELUCIDATION OF CAUSES OF FOREST DECLINE

The problem: to separate cause/s from effect/s. To do this, when there is no one single obvious cause, it is even more important, than in other circumstances, to adopt an epidemiological approach to the problem of forest decline. Series of successive observations must be made with the time intervals between successive observations geared to biological events. For example, with fine roots there is a continual process of make-and-break which might profoundly affect the development of mycorrhizas if the fungi involved, also their rhizoplane competitors, respond differently to seasonally fluctuating environmental conditions (Last et al. 1983). Furthermore we should remind ourselves that assessments of roots mainly restricted to the weights of structural roots ($>$0.5cm diam.) are likely to be relatively unresponsive to change bearing in mind that they are the summation of increments made over many years. In a stand of sitka spruce (Picea sitchensis (Bong.) Carr.), 16 years-old, the structural roots contributed 80.4% of the total root biomass (20,100 of 25,000kg ha^{-1}) but the structural root increment (3,150kg ha^{-1}) during the sixteenth year was only 37.4% of the total root increment in that year the remainder being attributed to smaller, finer roots. In the sixteenth year the production of roots $<$0.2cm. diam. accounted for 62.2% of that year's root production but because of their continual make-and-break these roots contributed only 14.1% to the surviving root biomass (Deans, 1981). Epidemiologically, I am certain that we should be more concerned with fine roots than structural roots (see Ulrich, 1983) and, if this is so, then these data emphasize the need to target our sampling procedures appositely.

As has been indicated two major groups of stress factors are thought to be involved in forest declines - pollution climates and possibly appreciable changes in longterm patterns of weather. The significance of the former can be checked relatively simply but the actual effects of changes in weather are more difficult to identify with certainty, recognizing that in both instances the problem is much more difficult with trees (perennials) than with annual plants. An effect of little or no significance in annuals may, with annual intensification, become of great importance to the vitality of longlived perennials.

Johnson and his colleagues (1986) recognized the lack of winter hardiness as a possible contributory factor to the incidence of red spruce decline. In doing so they suggested that this lack may be attributed to a general longterm decline in vigour attributable to changed weather patterns and/or to the effects of relatively large amounts of pollutant nitrogen deposited in wet, and occult, precipitation. Working with Sitka spruce Redfern and Cannell (1982) analysed the history of events when current year needles were damaged by early autumn frosts. They found that the damage, needle browning, occurred when the first autumnal frosts were preceded by warm weather which may have delayed frost-hardening or have stimulated temporary dehardening. However their observations of plots of Sitka spruce with, or without, added nitrogen or potassium do not seem to support the suggestion made, re altered frost sensitivity, by Johnson et al. (1984). However the position with phosphorus was both different and more complex. Malcolm and Freezaillah (1975) found that the application of relatively large amounts of phosphorus prolonged the periods of shoot elongation and made those shoots prone to frost injury. However, in contrast Redfern and Cannell (1982) observed that the degree of frost hardening, after the cessation of shoot elongation, was inversely proportional to the amounts of added phosphorus. Needles of sitka spruce, 6 years-old, given 100kg P ha^{-1} were less frost sensitive than those without phosphorus additions, the decreased sensitivity possibly being associated with increased concentrations of proteins, lipids and nucleic acids (Glerum, 1976). Bearing in mind the scattered distribution of affected trees in areas where forest decline is prevalent it is worth recalling that Guinon et al. (1982) found "tremendous plant-to-plant variation in frost resistance with populations" (of Sequoiadendron giganteum (Lindl.) Buchholz). This aspect of variability has also been stressed by Scholz (1981) when considering both the influences of (i) forest decline on the genetical constitution of out-breeding trees and (ii) the varying inherent differences in sensitivity, within a population, on the spatial occurrence of forest decline. If pollutants were to be important in the etiology of decline it should not be surprising to find neighbouring individuals of the same species responding very differently. To the experimentalist this very large extent of variation poses a major problem when seeking statistical significance. It is either necessary to use very large populations or resort to the exploitation of vegetatively propagated clones. The former is usually impractical whereas the latter, while being relatively simple, creates problems of interpretation when extrapolating to field conditions. How many clones should be tested? Should they span the sensitivity/tolerance range? On the other hand, by using grafts from mature trees, as is being done by Drs Skarby and Selldin in Sweden, it may be possible to determine if tissues from young and mature trees react similarly or differently.

To the author there has been insufficient overt indication that lessons have been learnt from the earlier investigations of "chlorotic decline" of ponderosa pine (Pinus ponderosa (Dougl.)), whose history in the San Bernardino Mountains was described by Parmeter et al. (1962) and Taylor (1973). This condition, which came to the fore during a protracted period of drought extending from 1946 to 1960, is associated with the production of fewer and smaller needles, a yellow mottling of needles, the premature loss of all but the current season's needles, a deterioration in systems of fibrous roots, decreased stem increments (both height and girth), and ultimately the loss of trees. Having eliminated pests, pathogens and graft transmissible agents (viruses) as the primary causes of chlorotic decline, the different teams involved, with a clear desire to fulfil the requirements of Koch's postulates, were eventually able to show, in strictly controlled experiments, that 'chlorotic decline' could be induced in field conditions by ozone (Miller et al. 1963; Richards et al. 1968 and Miller and McBride, 1975). To some extent these investigators may have been fortunate in identifying the primary cause of chlorotic decline so speedily but instead of being satisfied with correlations, which may or may not be causal, they did experiments in which some of their replicate trees were exposed, to the inferred causal agent while the others, 'the controls' were maintained in conditions which, excepting the absence of the inferred causal agent, were identical. Fortunately there are now signs of an increasingly experimental approach to the present wave of forest declines, but there is a need to become still more analytical. Essentially there are three groups of research workers concerned with the investigation of forest declines. One, composed mostly of foresters, is concerned with the influence of patterns of weather, the effects of fertilisers etc., while the other two groups are focussed on the involvement of pollutants, one of the two concentrating on their direct effects and the other on indirect effects. Because of the difficulties already encountered it is likely that declines will in due course be attributed to an interacting mixture of causes, the relative importance of any one facet differing in different circumstances. These groups should therefore not work in isolation; instead they should be arranged in teams as emphasized when discussing Direct and indirect effects.

In following the example set by Miller and his colleagues in California, Flückiger et al. (1986) experimented in Switzerland with pot-grown beech, Norway spruce and lime (Tilia cordata Mill.) in chambers supplied with ambient air or charcoal filtered ambient air. Their observations suggest that the growth of these trees in ambient air was being restricted by agent/s, possibly photo-oxidants including ozone, whose effects could be lessened/removed by charcoal filtration. However, and perhaps surprisingly the growth of the species most afflicted by decline in central Europe, namely silver fir, did not respond to charcoal filtration. However even if direct proof is subsequently obtained to show that the benefit of charcoal filtration is attributable to the removal of photo-oxidents it would be unwise not to interrelate this effect with others. Flückiger and his colleagues found that leaves of affected trees had larger than expected nitrogen/potassium ratios which they attributed to the loss of potassium when leaves were wetted with acidic rain. When analysing the circumstances of forest decline it is important not to disregard possibly important pieces of circumstantial evidence. Thus in southern Germany, also in northeastern U.S.A., decline was first noted in the altitudinal range 800 to 1000m: it has since been recorded between 350 to 500m. Furthermore it seems that dominant trees and those at the fringes of forest stands are more commonly affected than the other trees in forest ecosystems (Prinz et al. 1982; Schmid-Haas, 1985). Together these altitude and positional effects suggest that in addition, or instead, of ozone - ozones episodes are often of greater duration at high than at low altitudes - the damage may be related to the direct and/or indirect effects of occult precipitation which is more acidic and with larger concentrations of NO_3^- and SO_4^{2-} than rain (Dollard et al. 1983) and which occurs more frequently at high altitudes: it is likely to be readily filtered from the atmosphere by dominant trees and those at the fringes of forest stands (Evers, 1985). In the latter instance the pollutants carried in occult precipitation may be directly impacting on foliage and/or adding to the pollutants deposited on, and altering, soil.

In a balanced review Ulrich and Matzner (1984) considered the ways in which atmospheric pollutants may, after deposition, affect soil properties and significantly alter tree growth. They discuss the importance of the longterm acidification of sensitive soils, as confirmed by Tamm and Hallbäcken (1986) also the role of short-term "acidification pushes". When detailing the effects on root growth, which they acknowledge can be adversely affected when fewer assimilates reach roots in plants whose foliage is subject to gaseous pollutants, they refer to two series of mechanisms (i) acid toxicity and (ii) the restricted uptake of Ca^{2+} and Mg^{2+} either because of soil deficiencies (Zottl, 1983) or inhibition by the presence of Al^{3+} in soil solution (Evers, 1983).

To support their veiw that the indirect effects of atmospheric pollutants seriously disadvantage root systems Ulrich and his colleagues have attempted to relate the weights of fine roots per unit of soil with the pH of soil solutions or with the concentrations of nitrates in soil solution. However, more convincingly, they have examined the growth of roots, of Norway spruce, from an acidified soil at Solling, FRG, into 'ingrowth cores' with the acidified soil either with or without added lime (Matzner et al. 1986). It was found that the addition of lime increased the dry weight of fine roots in the upper soil horizons, also the proportions of living roots. For the future it would be interesting to follow the results of factorial experiments testing the effects of (i) lime and ingrowth cores and (ii) chambers/cuvettes supplied with filtered or unfiltered atmospheres possibly with or without the injection of additional pollutants. Such a series of experiments should be extended to include fertiliser supplements in an attempt to obtain a more complete assessment of causes and effects. To what extent can the application of fertilisers decrease and/or ameliorate the incidence of forest decline (see Kenk et al. 1984)? When testing factorial combinations it should be remembered that virtually all trees in natural conditions are associated with mycorrhizal fungi whose influence seems to extend beyond the mediation of supplies of phosphorus and nitrogen to include the control of metal accumulations. Brown and Wilkins (1985) have given convincing evidence that the two mycorrhizal fungi that they have tested in controlled inoculations can greatly increase the tolerance of B. pendula Roth. and B. pubescens Ehrh. to zinc; they suggest the same is true of lead. While the concentrations of zinc were larger (98.3 umol g^{-1}) in roots with mycorrhizas (Amanita-type) than in those without them (65.3 umol g^{-1}) as also found by Bowen et al. (1974), the effects on foliar concentrations of this element were reversed (36.3 and 16.3 umol g^{-1} on plants without, and with, mycorrhizas respectively). These results and experimental procedures could be of value if heavy metal accumulations were to be implicated - mycorrhizas seem to control the disposition of these elements.

For a former pathologist to write about forest decline without mention of pests and pathogens (including viruses) might be unexpected but it reflects my assessment of the position. Although large populations of pests may be associated with trees in decline, the evidence from strictly controlled experiments suggests that these increases are the "effects" of decline and not the "causes" unless there are appreciable quantities of hydrogen fluoride (Weinstein, 1977). Dohmen et al. (1984) showed, using charcoal filters, that ambient concentrations of pollutants (SO_2 and NO_2) in London, favoured the development of black bean aphid, Aphis fabae, on field beans, the effect being entirely mediated by the effects of the pollutants on the metabolism of field beans. In Switzerland, Flückiger and Braun (1986) obtained a similar effect on the development of the aphid, Phyllaphis fagi colonising beech seedlings, this time the effect being attributable to ozone. It is thought that pollutants favour insect pests by increasing the concentrations of asparagine, glutamine, arginine, proline etc. in phloem exudates.

At this stage, foresters might well be overwhelmed by the potential complexity of problems concerned with forest declines. These problems may, in part, be related to "acts of God" but even when considering the cyclical changes of weather it would be unwise to overlook the role of man in augmenting atmospheric concentrations of carbon dioxide. Predictably these amounts will continue to increase and with a more or less equal level of probability the consequent changes in weather patterns will have significant effects on forest development. In addition to acts of God there are others immediately and clearly related to the activities of man. To identify the relative importance of these different factors it is essential to adopt a more complete, 'holistic', and epidemiological approach to forest decline making repeated observations on experiments testing factorial combinations of key factors. But in the last resort we will only be able to adopt a rational approach when more is known, in detail, of the responsiveness of trees - it is essential to adopt a more sophisticated approach to tree physiology seeking knowledge at cellular and biochemical levels. Traditionally leaf activity has been considered in terms of discoloration, area, longevity, photosynthesis and respiration and within the last few years attention has turned to root: shoot ratios but now it is becoming clear that specific leaf area (SLA, $cm^2 g^{-1}$) is an attribute that is responsive to different stresses. Thus leaves of birch exposed to mixtures of SO_2 and NO_2 are heavier per unit area than those of birch growing in unpolluted atmospheres. This result suggests that plants either react to pollutants by positively allocating a greater allocation of dry matter towards the production of leaves or the assimilates that are produced in polluted atmospheres are not transferred to roots because the mechanisms of phloem transport are blocked, at least partially (Freer-Smith, 1985). Would it be profitable to devote more of the resources accorded to the investigation of forest declines to the study of phloem loading and phloem transport? Although doubtless an esoteric subject in the eyes of most forest managers, the evidence suggests that a more structured and less pragmatic approach to forest decline is essential. Descriptions of what occurs rarely enable predictions to be made. Instead it is essential to gain a better understanding of mechanisms if our forest resources are to be managed rationally. The opportunity to elucidate the declines already causing concern should be used to help understand the possible alterations, direct and indirect, that may ensue as a result of climate changes triggered by increasing concentrations of CO_2.

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3.2 PRODUCTS OF PHOTOOXIDATION AS THE MAIN FACTORS OF THE NEW FOREST DECLINE – RESULTS AND CONSIDERATIONS*

W-D. Grossmann
Rysergasse 21
A-1230 Vienna, AUSTRIA

ABSTRACT (1)

Many of the important hypotheses on the new forest decline were checked in the systemic pilot-project Forest Rosalia ("Application of the method of maps over time in Austria"); most have low explanatory power in that research site. Only ozone will cause considerable, but not all damage. Other factors seem to exist which have not been explored until now. Evidence and calculations are supplied that these might be the aldehydes, organic acids, oxidants including peroxides and radicals. These pollutants act together (perhaps even synergistically) with the ozone in a way which might explain extent and form of the new forest decline in wide areas of Austria. (1)

KEYWORDS: New forest decline, photooxidants, maps over time, hierarchic methods

METHOD

The pilot-project "Demonstration-Forest Rosalia- Application of the Method of 'Maps over Time' in Austria" was a systemic combination of observations, measurements and models. Applied were false-color infrared photographs compared with ground truth, transport models of pollutants compared with measurements and

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(1) The work was done within the following research projects:

- Application of the Method of "Maps over Time" in Austria (Integrated Systems Project Rosalia) funded by Ministry for Science and Research, Vienna and Federal State Lower Austria
- Advice to the Ministry for Science and Research Vienna on the problem of forest die-off and systems methods/Grossmann
- Evaluation of Hypotheses Regarding Forest Die-Off with Application of Dynamic Feedback Models and Area-Related Balancing. Chair for Landscape Ecology Technical University Munich and ESRI Munich
- Man and Biosphere Project 6 Berchtesgaden. Chair for Landscape Ecology Technical University Munich, ESRI/Munich
- Study on Hydrocarbons of the Austrian Environmental Fund, Vienna. Meisterhofer et al. 1986.
- Forest Sector Project. IIASA Laxenburg
- Micro-Ecological Management System. IIASA Laxenburg

The discussions and collaboration with A. Krapfenbauer, Viennese Agricultural University, were very helpful. A. Kopsca, Austrian Research Center Seibersdorf, produced the maps.

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simulation models translated into maps over time (a map over time shows the geographic distribution of one or a few characteristics such as forest damage for a specific time) to anticipate damage which were compared with ground truth. A hierarchical three-layer approach (Grossmann 1983) was used to plan the research, guide the subprojects and evaluate and synthesize the results. Measurements of products of photooxidation other than ozone became available (Puxbaum and Ober 1986) only after the first publication of the calculations and hypotheses given below (Grossmann 1987a) confirming many of our conclusions. This demonstrates what can be achieved by combining systems methods and conventional procedures (see also von Osten and Rami 1986 who require such systemic procedures after several years of exclusively conventional research).

1. SITUATION IN THE ROSALIA FOREST

The research site was the Rosalia Demonstration-Forest of the Viennese Agricultural University 80 km south of Vienna and 20 km south of Wiener Neustadt with 35 000 inhabitants. In the north to north-west a motorway passes the Demonstration-Forest at a distance of about 20 km. The Demonstration-Forest has a varied orography. Measuring towers exist at an elevation of 300 m and 700 m. With the two towers concentrations of ozone are measured above the tree-top, in the middle of the crown and in the lower crown. SO2, NO, NO2, ozone and climate are measured in an additional and independently run measuring station . Tree damage was surveyed by a group of the Viennese Agricultural University, Sagl 1986. The criterion was loss of needles for coniferous species and vitality for deciduous trees:

Damage class	Spruce %	Fir %	Larch %	Pine %	Beech %
1 (healthy)	22	15	82	17	55
2 (slightly damaged)	49	37	14	56	35
3 (ill)	25	32	1	25	5
4 (severely ill)	3	11	1	1	1
5 (dying)	0	5	0	0	0

Table 1: tree damage in the Rosalia-Demonstration Forest in 1985. Source: Sagl 1986. (Areas missing to 100% were not sampled).

SO_2, NO_x: The concentrations of SO_2 and NO_x were very low. (Mean annual value of each was 7 (all values are given in micrograms per cubic meter), max. monthly mean of SO_2 was 27, max. daily mean was 108, NO was most of the time below 1 (Kolb and Scheifinger 1986). Data were measured and additionally calculated using transport models. Wentzel 1983 specifies the most rigid lowest annual mean for SO_2 to guarantee the health of the coniferous at 15 ug/m3. For NO_x the most drastic limit is set by the Swiss Federal Parliament to guarantee that NO_x will not even in synergistic combinations with other pollutants cause tree damage. This limit is a mean annual value of 30 ug/m3. In the Demonstration-Forest both SO_2 and NO_x are far below these respective limits.

Other primary polluting gases: not measured. They should not be important in the Demonstration-Forest according to the catalog of emissions of the Federal State Lower Austria because there are no high emissions nearby. No remarkable concentrations were measured in the soil, in branches, leaves and needles. There was also no over-supply with nitrogen (base: analysis of elements including Pb, S and N, Krapfenbauer et al. 1986). Halogenated hydrocarbons: tree damage was surveyed in a nearby area with emissions of several chlorinated hydrocarbons (a fountain in a small clearing where polluted water was stripped from chlorinated hydrocarbons which were released in the air). The trees around the clearing were healthier than those nearby exposed to the motorway (1 km away). (This observation does not preclude that halogenated hydrocarbons could significantly contribute to tree damage after chemical transformation during transport).

Soil (analysis 1986): no pH-value beyond 3.8. Comparatively good nutrient-supply in the soil. (Mg in leaves was 0.8 ug/gram. This is on the upper limit of Mg-deficiency, which according to Zoettl 1985 starts at 1 ug, according to FBW at 0.6 to 0.7 ug/gram. Supply with other nutrients in leaves, needles and branches was within the normal ranges, Krapfenbauer et al. 1986). Above average damage of young stands on limy soils.

Ozone: High peak concentrations and considerable average concentrations. Mean annual value 31 ppb, mean value in summer 1985 38 ppb, and during 30% of the summer around 60 ppb, episodes above 100 ppb (and even higher in the sunny summer 1986). Considerable damage of many tree species is a likely consequence of these concentrations (Heck and Brandt 1977, Jacobson 1977, SRU 1983, Guderian 1984, Guderian et al. 1984, Prinz et al. 1984 and Heck et al. 1986).

NOT ALL DAMAGE CAN BE EXPLAINED WITH IMPACT OF OZONE:

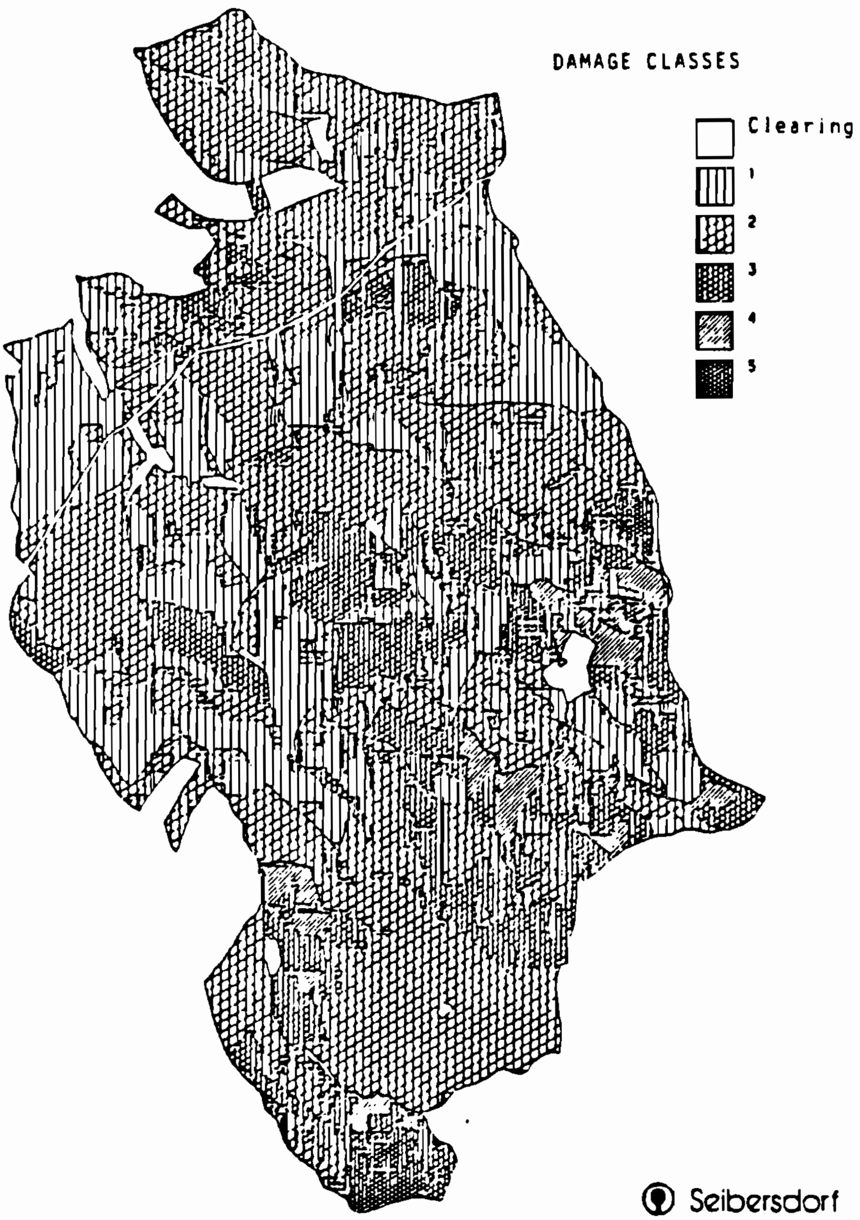
(A): No damage could be induced in fir with 6-8 weeks of fumigation with ozone at a concentration of 300 ppb (experiment of the LIS (Landesanstalt für Immissionsschutz, Essen, North-Rhine Westfalia, Prinz et al. 1984). According to table 1 only 15% of fir is still healthy and 8% severely damaged. Damage in beech was induced in the experiments of the LIS already after 8 weeks of fumigation with ozone at 75 ppb).

(B): The pattern of ozone damage was calculated from the distribution of the ozone dose in its dependence on elevation. This distribution was translated into a map over time (map 1) and compared with the actual pattern of the damage (map 2). The damage was in general systematically overestimated with height (map 2). This is not only attributable to differing resistance of subspecies to ozone, as much of the forest is planted. The development of damage over time was calculated with a computer model based only on impact of ozone, fig. 1. The calculated damage ("ozone") was systematically lower than the actual damage ("synergism").

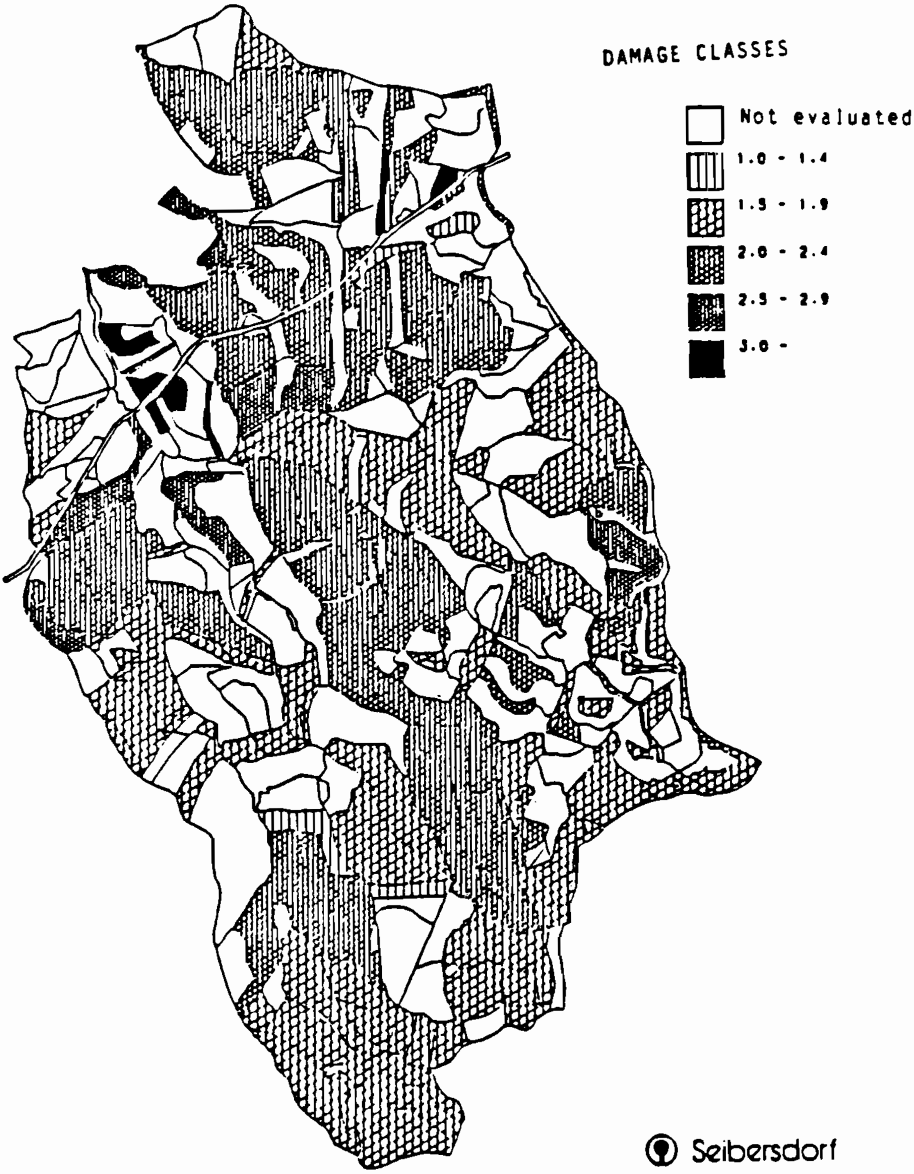
(C) The symptoms of damage in the Rosalia Demonstration-Forest are not typical ozone symptoms but are very much alike to the well known symptoms of the respective species in comparable geographic locations.

Synergisms of damaging factors: Prinz and colleagues 1985 and Guderian et al. 1985 have shown several synergism of damaging factors. Fig. 2. is the systems diagram of the acting together of important damaging factors. This diagram is based on an overview of the results of the German research on forest die-off prepared by scientists from the chair for Landscape-Ecology, Technical University Munich-Weihenstephan. The amount of the damage cannot even be explained by adding up all of these damaging factors. In particular all synergisms involving SO2 or NOx fail. This is true for additive expression (g(SO2,NOx) + h(Ozone)) of a synergism with functions g,h because g is small and it is even more true for multiplicative expression gh, because the small value of g suppresses the effect of h in the product gh. This also holds for wet deposition of SO2, NOx and derivatives. Rain pH-values are available from several stations in Lower Austria. The background station Exelberg is also located in a rural part of Lower Austria like the Rosalia-Forest. In this station the weighted average of rain pH-values for 1985/1986 was 4.68 (4.98 in summer, 4.33 in winter). Extreme values were measured during two extremely short rainfall events with pH-values of 3.62 and 7.38. The sum of precipitation with a pH-value below 4 was 30 mm, total rainfall in that year was 933 mm (from Puxbaum and Ober 1986). Smidt (1984, 1986) reports comparable rain pH-values for six more stations in Lower-Austria (annual means between 4.2 and 6.09 for the years 1983 to 1985). The leaching experiments of the LIS (Prinz et al. 1984) were done with rain with a pH value of 3.5.

Therefore neither a synergism of the three polluting gases SO2, NOx and ozone, as described by Guderian 1985, can explain the damages nor a synergism of ozone and rain, acidified by mineral acids, as described by Krause et al. 1983 and Prinz et al. 1984.



Map 1. Spatial distribution of forest damage computed for impact of only ozone. Source Grossmann 1987b.



Map 2. Actual distribution of damage. Source: Sagl 1986, computerized by the Austrian Research Center Seibersdorf. This map differs technically from map 1 because here all trees below 41 years of age have been left out. Moreover by averaging damages all extreme values (damage classes 1, 4 and 5) are no longer visible. In so far the maps 1 and 2 are not immediately comparable. Source Grossmann 1987b.

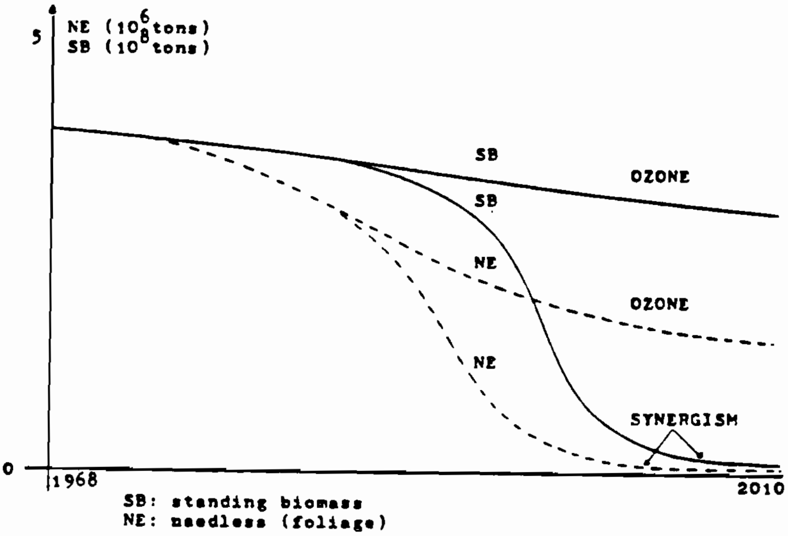


Figure 1. Development of forest damage over time computed with the model POLAUSTRIA (Grossmann and Grossmann 1985). "Ozone": impact of all measure pollutants. "Synergism": actual historic and anticipated future development.

Additional damaging factors must exist to explain the actual damage. Insects, climate stress (e.g. dryness or sudden frost) and diseases can only cause part of the damage due to the considerable diversity of sites and tree species in the Rosalia-Forest. Damage was observed in all species and sites. Forest management was adequate; species and sites usually fit well. (It is a general result of German research that insects and diseases do not contribute significantly to the new forest decline, FBW 1986).

Ozone is the only known factor that will cause forest damage in the Demonstration-Forest. Apparently none of the usual factors including SO2, NOx and derivatives could contribute significantly to the damage there. Hence an additional unknown damaging factor should exist. To find out more about this factor, evaluations were done using the data in their spatial distribution combined with models (methodology described in Grossmann 1986). One map

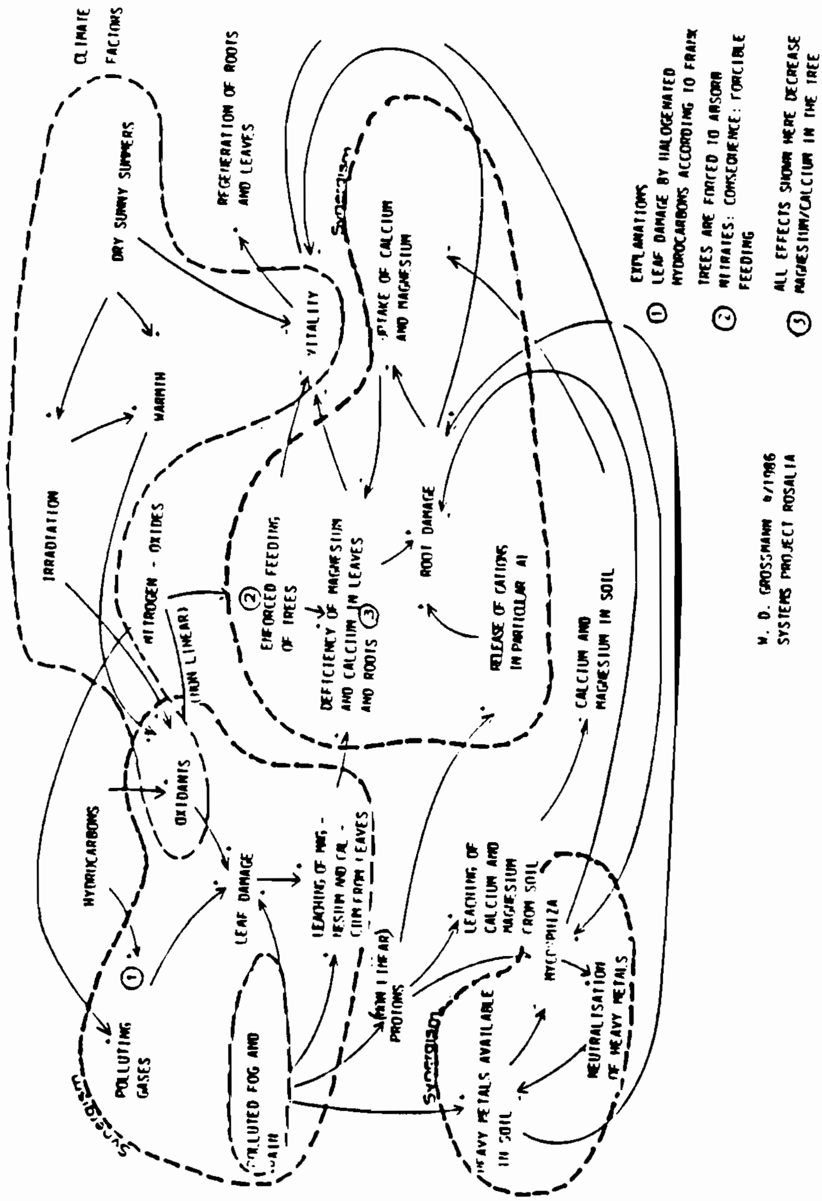


Figure 2. Systems diagram of the most important factors of the new forest decline based on a summary done by Haber and colleagues of present research. Nearly all damaging factors can decrease content of magnesium and calcium in the plants.

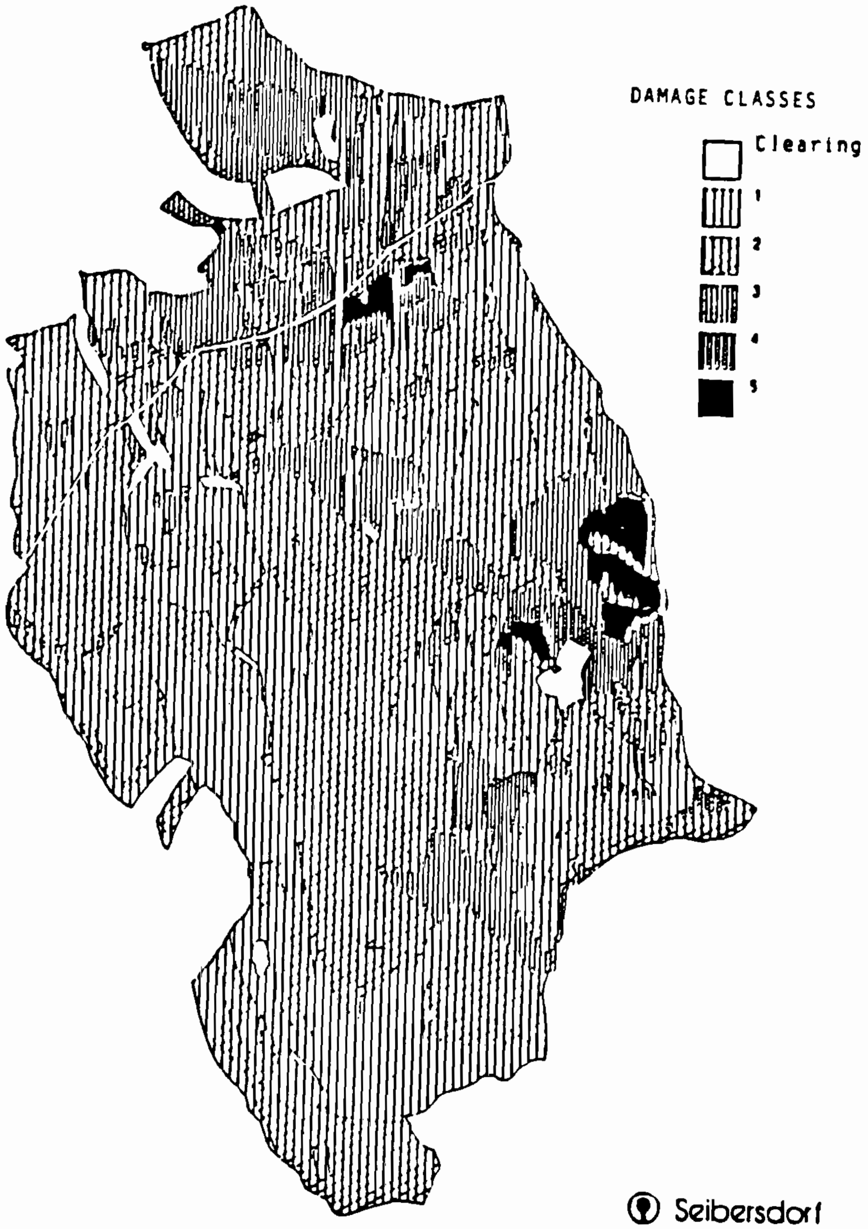
over time was based on a synergistic increase of the ozone impact by an additional unknown airborne factor. This map takes into account the prevailing wind directions and orography of the sites. This map (map 3) corresponds comparatively well to the actual distribution of damage. This hint was further pursued.

2. HYPOTHESES ON FOREST DAMAGE BY PRODUCTS OF PHOTOOXIDATION

In the reactions producing ozone many other oxidants are formed as well as aldehydes, organic acids and radicals. Phytotoxicity is proven for many of these substances, see 2.2. The production of these substances was roughly calculated to find out whether they might contribute to the forest damage in the Rosalia area. The calculations were compared with national and international measurements and results.

2.1 FORMING OF OZONE AND OF OTHER PRODUCTS OF THE PHOTOOXIDATION

Ozone is formed as a consequence of reactions between hydrocarbons and oxides of nitrogen and due to the oxidation of carbon monoxide under irradiation of the UV-component of the sunlight. The production of ozone is ultimately limited by the supply of carbon monoxide, methane and other hydrocarbons, if NOx is available (WMO 1986). One molecule of ozone may be formed for each molecule of CO, while the yield of ozone from oxidation of methane could be as large as 3.5 (WMO 1986). Derwent and Hov use a factor of 2.2 molecules of ozone per C-atom for non-methane hydrocarbons with additional forming of ozone for each H-atom. Hence the factor 2.2 can be used as a lower limit to estimate the number of ozone molecules possible from non-methane hydrocarbons. Table 2 is a summary for Austria of the emissions of these substances and of the resulting ozone potential. Emissions and concentrations of NOx are sufficiently high so that they should not be a limiting factor in the forming of ozone (based on, among others, Bruckmann et al. 1980, Kelly 1985, the study behind Meisterhofer et al. 1985 and WMO 1986).



Map 3. Computer-calculated map depicting forest damage in 1985 from impact of ozone and additional assumed impact of an unknown airborne damaging factor. Source Grossmann 1987b.

SUBSTANCE	EMISSIONS (1000 t/year)	MOLECULES OZONE PER MOLECULE MAX.	OZONE POTENTIAL (1000 t/year)
Non-Methane-HC.	250 (4) - 380 (5)	2.2 (6)	1750 - 2700
Methane(*)	150 (1) - 400 (2)	3.5 (3)	1500 - 4000
CO (+)	1100 (7) - 3000 (5)	1 (3)	1800 - 5100
Maximal ozone potential per year (1000 t):			5050 - 11 800
Comparison with the emissions of the "classical" pollutants:			
SO2 (1000 t/year)			135 (5)
NO2 (1000 t/year)			220 (8)

Table 2: Emissions of ozone precursors and the maximal possible production of ozone and the emissions of SO2 and NO2 per year in Austria. (*): Methane is often not regarded as an important precursor for ozone. This should be incorrect at least in a global view, WMO 1986, Krapfenbauer 1986a. (+): Although CO is usually neglected, it could contribute considerably to the forming of ozone, Marenco 1986, also WMO 1986. Sources: (1): Krapfenbauer 1986a, (2): calculated for Austria based on Derwent and Hov 1982, (3): WMO 1986, (4): Meisterhofer et al. 1986, (5): Krapfenbauer 1985, (6): Derwent and Hov 1982, (7): Energiebericht 1985 and Lenz 1985, (8): Schmidt 1983.

The actual production of ozone was estimated using the calculations of Derwent and Hov 1982 and additionally using the ratios of emissions in Austria to concentrations in rural areas.

(A): Production of ozone during a high pressure situation according to Derwent and Hov 1982.

Emissions: NO2: SO2: O3 (potential) = 1: 1.5: 27

Concentrations: NO2: SO2: O3 (concentration) = 1: 1.35:14

According to these numbers the potential for the production of ozone is utilized to 50% (14: 27). Less ozone is formed during non-high pressure situations or during the winter corresponding to a lower utilization of the potential.

(B): Production of ozone in Austria (from measurements in the Rosalia-area which fulfills the requirements of a "rural area"):

Emissions	SO_2: NO_2: O_3 (potential) =	1: 1.5: 40;
Concentrations	SO_2: NO_2: O_3 (concentration) =	1: 1 : 25 (*)
		: 10 (+)
		: 8 (o)

(*) High pressure situation in summer
(+) Average concentration of ozone in the summer 1985
(o) Annual average for 1985,
calculations based on Kolb and Scheifinger 1986 and Lenz 1985.

These two independent calculations are in sufficient agreement. Hence in the order of between 1 to 3.5 million tons of ozone could be formed per year in Austria. This amount appears high compared to the emission of 135 000 tons SO_2/ year which is comparably phytotoxic.

Considerable damage of tress is a likely consequence of these ozone concentrations, as was outlined above. But reasons were also given why it seems unlikely that all damage can be attributed to ozone.

Considerable amounts of other products are formed in the photooxidation of all hydrocarbons (and to some extent also of CO). This is known from the photochemical reactions (Derwent and Hov 1982, McRae and Russel 1984, Fox 1986, WMO 1986) and was nationally and internationally confirmed in measurements both in the laboratory and in the outside environment.

Measurements of products of photooxidation in Austria are available from the Exelberg where concentrations of SO_2, NO_x and ozone are comparable to the Rosalia-area. Vienna's contribution to the ozone concentration seems to be not important according to Puxbaum and Ober (1986). (Vienna lies between Exelberg and Rosalia). The measurements from the Exelberg should be a reasonable orientation for the situation in the Rosalia-area.

Formic acid: Concentrations in the Exelberg-area were between 1.0 and 12 ug formic acid /cubic meter in the summers 1985 and 1986 with a mean of 6 ug and peak values of 21 ug (Puxbaum and Ober 1986). The concentrations of ozone during the measurement times were about 60 ppb. Hence the ratio of formic acid to ozone was 5% This is in good agreement with the range given by Altshuller 1983 where formic acid is between 3.5% to 6.9% of oxidant concentrations. All following calculations neglect influences from differing deposition velocities etc. to get a quick rough first estimate what might be relevant for further research and measurements. A list of research needs is given at the end of the paper. A ratio of 5% formic acid to 1 to 3.5 million tons ozone corresponds to the production of 50 000 to 175 000 tons formic acid per year in Austria. (These numbers would be even higher if oxidant concentrations would be used instead of ozone concentrations).

Acetic acid: average concentration measured in the Exelberg station were 2.1 ug in summer 1986 (Puxbaum and Ober 1986), corresponding to a forming of 20 000 to 60 000 tons/year.

Measurements in the US of the acidity of fog have shown that frequently between 10%- 60% are due to organic acids (Mulawa et al. 1986, Chapman et al. 1986) , in particular formic and acetic acid. Measurements may easily give too low values without proper conservation of samples (Chapman et al. 1986).

Formaldehyde: Concentrations in a number of studies in the US ranged from 15% to 30% of average oxidant concentrations although both lower and higher percentages have been reported (Altshuller 1983). The overall average ratio of formic acid to formaldehyde in several stations in California was 23% with 90% of the daily values within 23% +- 10% For Germany lower concentrations of both oxidants and formaldehyde are reported (BMJFG 1984). The ratios in the Exelberg station are similar to those reported in Altshuller 1983. 15% -30% of typical average ozone concentrations of 60 ppb during 30% of the summer in eastern Austria would correspond to concentrations of formaldehyde of 18-36 ug/m3. The fourfold of the measured concentration of formic acid of 6 ug/m3 is 24 ug which is within this range. 15% - 30% of 1.5- 3 million tons ozone correspond to the production of 225 000 - 900 000 tons formaldehyde per year.

Hydrogen peroxide: Concentrations in California were between 10-50 ppb in the gas phase (Altshuller 1983). A concentration of 2 ppb in the gas phase can lead to a calculated concentration of 3 ppm in rainwater (Kok 1980). Measured concentrations are lower. One reason is the consumption of hydrogen peroxide in heterogenous oxidation of SO2 and NO2. 10 - 50 ppb hydrogen peroxide in the gas phase correspond to calculated 15- 75 ppm in rainwater. Masuch et al. report measured concentrations in the order of 5 ppm, Kok reports measured 1.5 ppm.

Nitric acid: The ratio of nitric acid to ozone was 2%- 18% according to Altshuller (1983). Puxbaum and Ober 1986 have measured concentrations between 0.2 to 14 ug/m3 with a mean value of 6 ug corresponding to about 5% of the ozone concentration.

The measured average of the sum of formaldehyde, formic acid, PAN and nitric acid to ozone was 36-38% (Altshuller 1983). This result also holds for the Exelberg-Rosalia area, if the estimate given above for formaldehyde is correct and if the measurements of PAN from Birmensdorf, Switzerland are also reasonable for Austria. The ratio of PAN to ozone was about 5% (in agreement with those of Altshuller), Landolt et al. 1985. Insofar it can be assumed that one third of the potential for ozone is converted into ozone and that about 12% (36% - 38% of one third) is converted into these four products, corresponding to a production of between 600 000 - 1 200 000 tons per year.

This summary on the ratios of concentrations of ozone to other products of photooxidation shows that ozone can be regarded as an indicator for these other products, but it also shows the limits of ozone as an indicator. All of these products of photooxidation will be named products, in agreement with Altshuller 1983. These shall also include those compounds that are related to photooxidation but may also be formed without irradiation, for example in chemical reactions during nighttime.

2.2 PHYTOTOXIC EFFECTS OF PRODUCTS OF PHOTOOXIDATION

Formaldehyde is 3.3 times as phytotoxic as SO2 (compared at a concentration of 100 ug/m3, van Haut and Prinz 1979). The estimated possible production of formaldehyde of 225 000 - 900 000 tons/year would correspond to 800 000 to 3 000 000 of SO2. Emissions of SO2 peaked 1980 with 350 000 tons/year (Energiebericht).

Acetic acid is as phytotoxic as SO2 (van Haut and Prinz 1979).

Hydrogen peroxide in fog in concentrations varying between 0 and 5 ppm was sufficient to cause detrimental changes of leaves of beech, Masuch et al. 1985. Such concentrations were measured, higher concentrations were calculated.

Formaldehyde is not only phytotoxic. It is also highly toxic for microorganisms and is used to sterilize soil. If deposited on the soil, it is not immediately neutralized (Wurst 1986, Krapfenbauer 1986). Hence it might damage mycorrhiza. Formic acid also damages microorganisms (preservative).

The measured concentrations of organic acids in fog and rain could damage leaves and could leach nutrients and even assimilates from damaged leaves as it was shown by Krause et al. 1983 and Prinz et al. 1984 for mineral acids.

The "smog-fog-smog" cycle (Hileman 1983) may be another key actor in forest damage: fog is formed near the ground where the concentrations of products are often high. Many products are highly water-soluble leading to their enrichment in fog (calculated factor about 1000, e.g. 1500 for hydrogen peroxide Kok 1980. In reality this factor is more between 10-100, for example Schwarzenbach 1987). This could explain the often extreme damage in areas with frequent fog.

Many other phytotoxic effects of products seem to exist. Not much is known about the effects of most peroxides and even less about the effects of radicals. Stärk and Stauff 1986 have observed vegetation damage by enrichment of high molecular peroxides on needles of spruce. Frank 1985 and Schenk 1985 report indirect phytotoxicity of halogenated hydrocarbons under irradiation.

All paths of proven and potential, direct and indirect plant damage by products are depicted in fig. 3:

- Damage of leaves and needles by gaseous and dissolved oxidants, in particular peroxides and in addition radicals

- Damage of mycorrhiza by deposited aldehydes and possibly formic acid

- Damage of roots by products that are deposited by precipitation

- Leaching of minerals and perhaps assimilates by precipitation containing organic (and mineral) acids

- Other phytotoxic effects by substances such as oxidants, aldehydes, organic acids, peroxides including high molecular peroxides and radicals

- Local variations of damage by "classical" factors such as direct and indirect impact by SO_2, NO_x, their derivatives, HF, dusts or heavy metals. The synergisms proven by Prinz and colleagues and Guderian et al. were mentioned above. According to our results the importance of these factors in extended areas (as opposed to local damage) may sometimes have been overestimated. The synergistic damage function developed by a group together with the author (Grossmann et al. 1984) did most probably overestimate the role of SO_2. (Impact of aerosols of nitric and sulfuric acid may in general have been underestimated. Measured concentration of sulfuric acid in the Exelberg were sometimes above 20 ug). Many oxidants and seemingly even more so formaldehyde and formic acid are decisive in the oxidation of SO_2 and NO_2 in heterogeneous reactions (Müller 1986, Hahn 1986). Hence some classical damaging factors could locally and occasionally decrease the effects of products of photooxidation on vegetation. The impact of products on vegetation is probably more severe in clean-air areas. In addition there is always a (complex and varying) interaction with climate extremes. insects and other edaphic, biotic and abiotic factors.

All of these pathways of damage together form a kind of "super-synergism". This super-synergism may be highly important due to the measured and likely high concentration of many products in air and precipitation and the often considerable phytotoxicity of many products. These factors together (taking into account the past development of emissions of precursors) allow a correct historic development of forest damage if evaluated with the above mentioned computer model POLAUSTRIA. For this run the synergistic

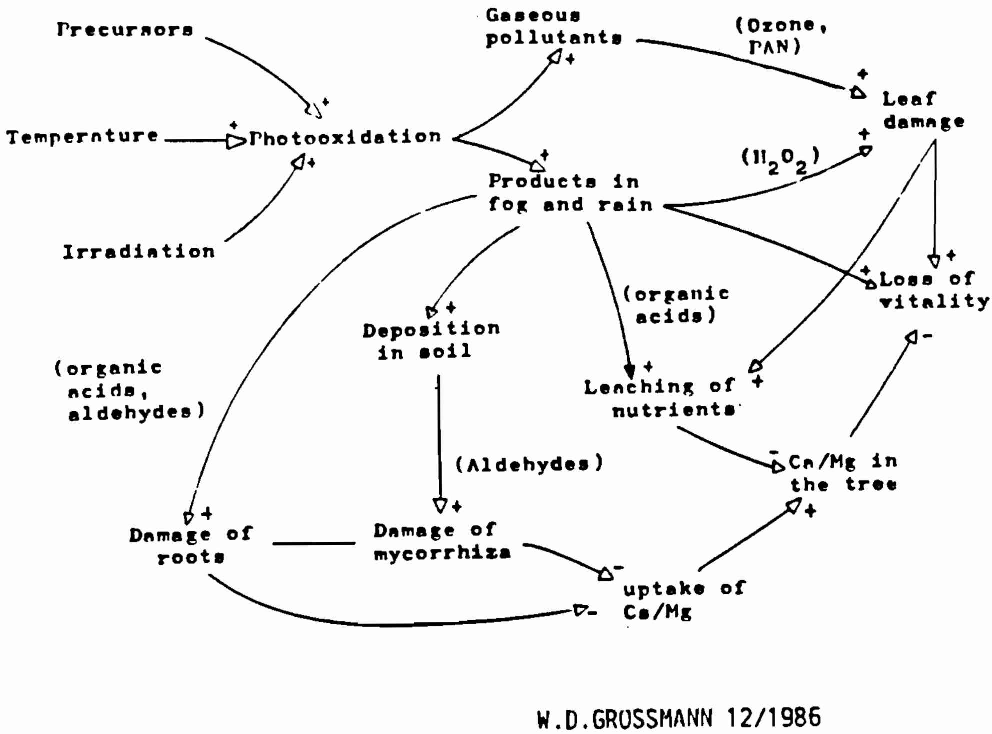


Figure 3. "Super synergistic" impact of products of photooxidation on vegetation

damage function developed for Pfaffenhofen (Grossmann et al. 1984) was used, but the impact of primary pollutants was replaced by the effects of products other than ozone as described above. Also, the impact had to be decreased: forest die-off was by far too rapid in the model, if all concentrations given above are inserted with the respective phytotoxicity. As was mentioned before a map over time gave a good fit that was based on such an airborne factor which might well be these products.

Subsequently the ozone concentrations measured in the Rosalia-area were compared with measurements from stations all over Austria. Concentrations were on average only lower within towns and their immediate environment; a well known effect (e.g. SRU 1983). Concentrations of other pollutants (SO_2, NO_x) were usually higher. Ozone can to some extent be used as an indicator for other products, as was outlined before. If ozone and the accompanying products can cause high vegetation damage even if concentrations of classical damaging substances are so low as in the Rosalia-area then they will cause comparable damage in regions throughout Austria. This damage will be locally increased or decreased by classical factors, as was outlined above. Products of photooxidation could be the main factors in the new forest decline in Austria.

Research needs: many of the calculations and suggestions are tentative and serve as a starting point for new research. Important problems are:

- To what extent is damage of leaves caused by formaldehyde, formic acid and hydrogen peroxide in the gas phase?

- Is leaching of Mg/Ca and perhaps even of assimilates caused by organic acids?

- Is mycorrhiza damaged by aldehydes and perhaps formic acid?

- Are roots damaged by aldehydes/organic acids/other products?

- Do gaseous products including peroxides and radicals decrease the vitality of the trees; what are the pathways of damage?

- How is vitality affected by products in rain and fog?

- Are there products besides hydrogen peroxide that cause leave damage?

- Measurements: concentrations of formaldehyde and hydrogen peroxide in the gas phase and in rain and fog. Adequate techniques for conservation of samples. Deposited amount of formaldehyde taking into account its very short residence time. Measurements of radicals, in particular HO_2.

- Model calculations: how correct are the above estimates for products
- Is the synchronicity of the beginning of the new forest decline on the Northern Hemisphere a consequence of the impact of products, due to the long residence time of many precursors (Grossmann 1987a)?

Preparations and discussions with several research institutes are under way to solve some of these questions within a new, systems oriented research project.

Many questions persist, many new questions have emerged. But according to many measurements, research results and estimates the impact by products of photooxidation could be the main cause of the new forest decline.

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3.3 A REGIONAL MODEL FOR RISK TO FORESTS BY DIRECT IMPACTS OF SULFUR*

A. Mäkelä
Acid Rain Project
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, AUSTRIA

INTRODUCTION

Although definitive theories and refined practical tools are not yet available for a comprehensive analysis of forest dieback, partial insight and answers can be obtained. In seeking these goals, the RAINS (Regional Acidification INformation and Simulation) model has been developed at the International Institute for Applied Systems Analysis (IIASA) to provide a framework for ecological impact studies. The model simulates sulfur emissions and transport as a function of energy use and sulfur abatement strategies, and uses the resulting deposition and sulfur concentration patterns as input to environmental impact submodels (Alcamo *et al.*, 1985; Hordijk, 1986; Alcamo *et al.*, 1987). The soil acidification submodel of the RAINS model has already been used to provide indicators of forest dieback (Kauppi *et al.*, 1986).

The contribution of direct, foliar impacts of sulfur to present-day forest damage is a controversial issue. According to some 'dose-response' studies, the threshold concentrations for both foliage injury and yield losses in trees are well beyond the highest concentrations prevailing in the field (Roberts *et al.*, 1983). On the other hand, these studies have been subject to criticism because (1) they applied short exposure times which did not allow for the development of possible cumulative effects, and (2) they did not involve synergistic effects with natural stress factors. For instance, Materna (1985) concluded that the direct impacts of sulfur dioxide concentrations as low as 20 ppb can ultimately lead to the deterioration of whole stands when occurring together with low natural resistance, such as that found at high elevations. It has been pointed out as a significant pathway of damage, that it is often only after an inciting event of natural stress such as drought and frost, that the latent, long-term strain turns into injury (Huttunen *et al.*, 1981; Friedland *et al.*, 1984; Laine *et al.*, 1984; Dässler and Ranft, 1986).

If these criticisms are valid, airborne sulfur may well be one of the major causes of forest dieback in at least some sensitive areas in Europe. We pursue this line of argument within the RAINS framework so as to gain further insight into its long-term, regional implications.

In order to quantify forest dieback caused by direct effects of SO_2, three possible approaches can be adopted: (1) *statistical-empirical*, (2) *indicator analysis*, and (3) *simulation modeling*. While simulation models and process-based indicators are being developed both in the Acid Rain Project and elsewhere (e.g. Luxmoore, 1980; Bossel *et al.*, 1985; Hari *et al.*, 1987; Mäkelä and Huttunen, 1987), and more comprehensive data sets for statistical analysis are currently being compiled for Europe, our first approach has been very simple: to draw from local evidence and extrapolate. We have

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formulated a statistical-empirical model of 'effective SO_2 dose' (Mäkelä *et al.*, 1987) which is based on empirical studies in Czechoslovakia's Erzgebirge (Ore Mountains) (Materna, 1985). The Erzgebirge study was chosen because some of its features make it simpler to generalize than many other similar field studies (Knabe, 1970; Lux, 1976; Wentzel, 1979; Freedman and Hutchinson, 1980; Bucher, 1984; Molski *et al.*, 1983). These features include both the variability of the natural environment and the pollutant concentrations, the dominance of sulfur in the pollutant profile, and the 20-year length of the monitoring period.

This paper reviews the main results from Erzgebirge (Materna, 1985) and describes the 'effective SO_2 dose' model based on these results. The model is used for deriving a regional indicator of risk to forests which is applied in the RAINS framework, and scenarios concerning the European forests are presented. The possibilities of improving the model by more systematic treatment of data are considered, and the limitations of the approach are discussed.

DAMAGE DEVELOPMENT IN INDIVIDUAL STANDS

Observations

Pollutant concentrations and forest damage have been monitored in the Erzgebirge since 1966. Currently the measurement network comprises *ca*. 60 meteorological stations, and forest measurements are conducted in the neighbouring stands, the majority of which represent Norway spruce (*Picea abies*). The pollutant measurements at the stations include daily SO_2 concentrations and other substances such as HF (hydrogen flouride) and NO_x at longer intervals. The pollutant emissions of the neighbouring industrial area have also been recorded (Materna, 1981). Observations of forest damage concern the percentage of 'heavily damaged' individuals, the degree of damage being judged on the basis of thinning of the foliage (Materna, 1983).

It has been concluded that the annual average sulfur dioxide concentration provides a sufficient description of the pollutant environment in the Erzgebirge. First, sulfur was found to be the only relevant pollutant species - no long-lasting concentrations of HF or NO_x could be detected at any of the measurement stations. Secondly, the annual average concentration showed a highly significant correlation with the percentile of high concentrations, e.g. 97.5 (Materna, 1981).

The analysis of the relationship between damage and sulfur concentration was guided by the dose-response approach, and the objective was to explain the variations in time-period from the beginning of exposure to occurrence of damage in terms of sulfur dioxide concentration and environmental factors. Occurrence of damage was defined as the beginning of disintegration of the stand, i.e. the time when a certain percentage of the trees was heavily damaged. No significant correlations were found between the ambient SO_2 and the required time of exposure if the whole study area was considered at a time. However, if the study area was classified according to environmental factors, *altitude* appeared to explain best the differences in the response (Kucera, 1979; Materna, 1983). Since the nutrient and water relations of the soils at different altitudes are variable, whereas many characteristics of the climate correlate with elevation, the results were interpreted as evidence for the direct impact pathway in interaction with climatic factors (Materna, 1985).

Regionalizing the results

The sensitivity variable, altitude, is not a causal factor in damage and cannot hence be generalized for larger areas. The good explanatory power is attributable to the fact that many climatic variables that are known to affect foliar injury and tolerance, correlate locally with altitude. Among these are occurrence of fog, amount of precipitation, windspeed, intensity of solar radiation, and most of all, temperature (e.g. Taylor, 1976). We have chosen to describe the effect of altitude with the *effective temperature sum* (ETS), which is probably the most aggregate index available for the purpose.

ETS is defined as the annual sum of daily temperatures, T_i, that exceed a threshold value, T_0, conventionally 5 °C, less the threshold:

$$\text{ETS} = \sum_{i=1}^{365} \delta_i \, (T_i - T_0) \tag{1}$$

where

$$\delta_i = 1 \quad \text{if } T_i > T_0$$

$$\delta_i = 0 \quad \text{if } T_i \leq T_0$$

It is therefore an integrated measure of the length and warmth of the growing season. Owing to the approximately linear lapse rate of temperature along an elevation gradient, ETS is almost linear in altitude (*Figure 1*). It is therefore as capable of explaining the observed damage pattern as the altitude itself.

There is also some ecological support for the choice of ETS as a resistance variable. ETS has been found to describe the regional variation in potential productivity reasonably well in those parts of Europe where the aridity of climate is not an outstanding growth-reducing factor (Kauppi and Posch, 1985; Sarvas, 1972). Productivity, in turn, has often been related to the surplus of carbohydrates available, e.g. for eliminating stress effects (Waring and Schlesinger, 1985). Further, it has been argued that foliar injuries occur faster if the winter is longer because the frost and winter-time drought stresses act synergistically with air pollutants (Materna, 1979; Huttunen *et al.*, 1981; Friedland *et al.*, 1984; Laine *et al.*, 1984; Feiler, 1985). Clearly, long winter and low ETS correlate; however, the correlation may vary from maritime to continental areas.

Model structure

The data set is not large enough for reasonable comparisons between alternative model structures. We adopt the conventional dose-response model (O'Gara, 1922) as the simplest possible starting hypothesis. Denote the dose accumulated by time t with $Q(t)$. The accumulation of dose is directly proportional to the sulfur dioxide concentration, S, less a threshold value, S_0. The threshold depends on the nutritional status of the plant. Since we focus on direct rather than indirect effects, we assume that S_0 is a spatial (and temporal) constant. Hence

$$\frac{dQ}{dt} = \begin{cases} (S - S_0) & \text{if } S > S_0 \\ 0 & \text{if } S \leq S_0 \end{cases} \tag{2}$$

The dose-response model assumes that there is a critical dose Q_0 which corresponds to standard damage, e.g. that 50% of the trees in the stand are heavily damaged. In our approach, the critical dose depends on the sensitivity variable ETS. Hence, standard damage occurs when

$$Q(t) \geq Q_0(\text{ETS}) \tag{3}$$

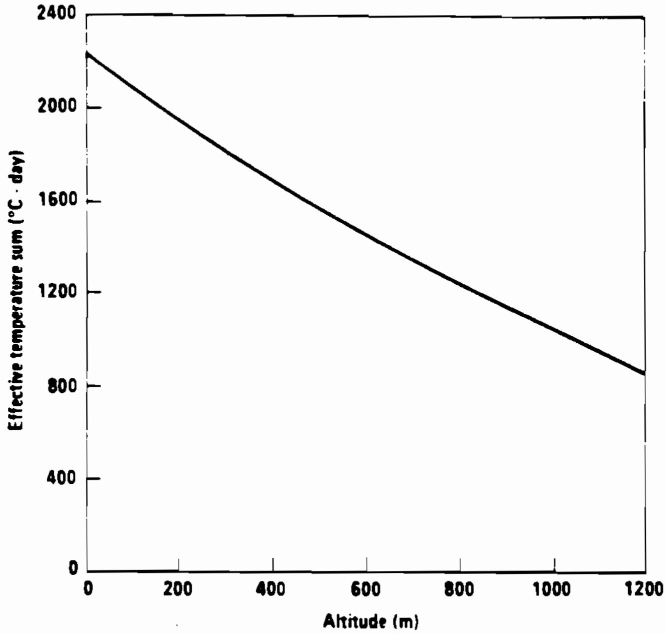

Figure 1 Relationship between ETS and altitude in the Ore Mountains. The method used for calculating the ETS is explained in Chapter 5.

Eqs. (2) and (3) constitute the conventional dose-response model (O'Gara, 1922), with the modifications that it is in differential instead of static form, and that the threshold dose, Q_0, has been parameterized in terms of ETS. Note that the model does not include reduction of strain. Although it is known that recovery may occur (Drummond and Wood, 1967), it was not possible to identify such a term from the measurements because the trend in pollutant concentrations was primarily ascending at the annual time scale employed. On the other hand, the empirical conclusions indicate very long delay times.

Parameters

The results of the Erzgebirge study were used for estimating the parameter values for the model as regards Norway spruce (*Picea abies*). The data available are of the type shown in *Table 1*. The original altitude classes (Materna, 1985) were converted to ETS classes using the method of Henttonen and Mäkelä (1987), already referred to in *Figure 1*. The higher and lower bounds correspond to those of the monitoring area, viz. 200 m and 1240 m.

If the temporal average of S is S_{av} and for all times t the actual concentration exceeds the threshold, $S(t) > S_0$, it can be seen by integrating Eq. (2) over time that the following holds at the time of damage occurrence:

$$(S_{av} - S_0)t_f = Q_0(\mathrm{ETS}) \qquad (4)$$

Given S_0 and data points $(S_{av}, t_f, \mathrm{ETS})$, we can now select the function $Q_0(\cdot)$ empirically, to fit the left-hand side of (4).

Table 1. Cubes in the (S_{av}, t_f, ETS) space used in parameter estimation.

ETS S	850-950	950-1150	1150-1500	1500-1950
20-30	19-21	30-40		
30-50		20-30	20-30	50-60
50-70		10-20	15-20	15-20
70-90			10-15	30-40
90-110			5-10	20-30

The information in *Table 1* is the only source of data that has been available for parameter estimation to date. Instead of a collection of points in the (S_{av}, t_f, ETS) space the table provides cubes where such points are most likely to be located, but we have no information on the actual occurrence of points within each cube. So as to estimate model parameters on the basis of this information, we drew points from the cubes at random from a uniform distribution and fitted the model to these fake data points using the conventional least squares method. The quadratic function

$$Q_0 = a_0 + a_1 \mathrm{ETS} + a_2 \mathrm{ETS}^2, \tag{5}$$

with the parameter values given in *Table 2*, proved to be the best choice for $Q_0(\cdot)$. The corresponding best value for the threshold S_0 was found to be 5 $\mu g/m^3$ (Mäkelä *et al.*, 1987).

RISK LEVELS OF FOREST AREAS

When applying the derived model for assessment of risk, we have to take into account the time span of the future projections and the spatial scale of the desired output, and attempt to simplify the regional-temporal output to be informative in a large-scale system also. Therefore, let us consider a forest area with a distribution of stands of various ages in the year t. We say that there is no risk of damage that year if the accumulated dose for the eldest stand in the area has not reached the critical dose. If it has, the degree of risk can be measured for instance as the areal fraction of stands that have received the critical dose.

Let $T_M(t)$ denote the age of the youngest stands that have reached the critical dose by the year t. By definition and Eqs. (2) and (3), $T_M(t)$ satisfies the condition

$$\int_{t-T_M}^{t} \max\{0, (S(\tau) - S_0)\} d\tau = Q_0 \tag{6}$$

The theoretical maximum time of accumulation of pollutant dose due to direct, foliar impacts is the lifetime of the tree. If the critical dose is not achieved in this time, damage will not occur. From the point of view of forestry practice, an important requirement is that the critical dose is not achieved within the rotation time.

The average growth rates of stands vary according to the climate. Consequently, the generally applied rotation times vary. This variation roughly follows the effective temperature sum which is an indicator of the average growth rate. We have used information from an international questionnaire to estimate the relationship between the rotation time, T_R, and ETS. Rotation times were provided by region and altitude in a

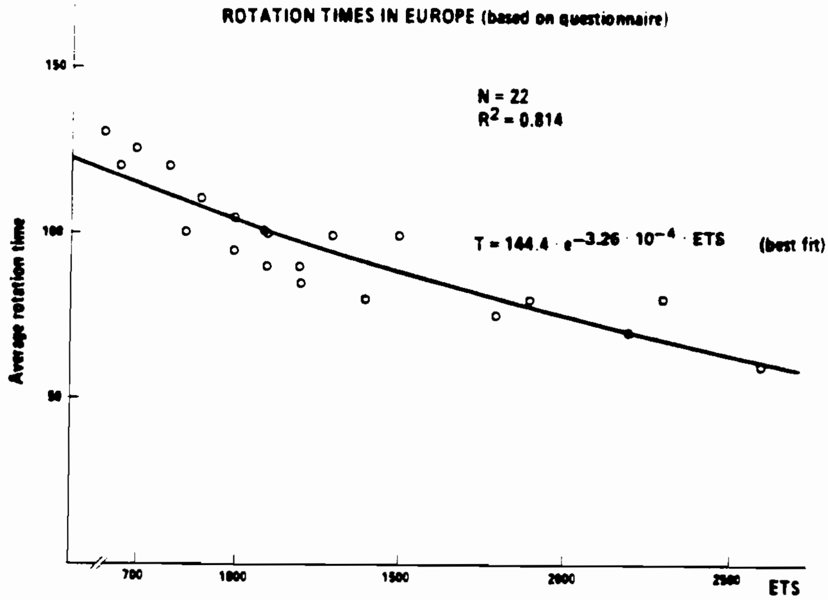

Figure 2 Rotation times of spruce forests as a function of ETS. The data points represent Sweden, Norway, Finland, Austria and Hungary.

number of countries. The corresponding ETS values were calculated at the center points of the region and the altitude class using the method of Henttonen and Mäkelä (1987). An exponential function,

$$T_R = a e^{k\,\mathrm{ETS}}, \tag{7}$$

was fitted to the points with the least squares method (*see Figure 2*).

As an example, *Figure 3* shows the age distribution of forests in Austria. It illustrates that the maximum age of forests is often of the order of three halves of the rotation time, and the age of approximately one half of the forests is below one half of the rotation time. Having this consideration in mind, we define the following three risk categories:

(1) high risk $T_M \le \frac{1}{2} T_R$

(2) medium risk $\frac{1}{2} T_R \le T_M \le T_R$

(3) low risk $T_R \le T_M \le \frac{3}{2} T_R$

where T_M is the maximum lifetime of trees under the prevailing pollutant conditions, and T_R is the rotation time. *Table 2* summarizes the model parameters for Norway spruce.

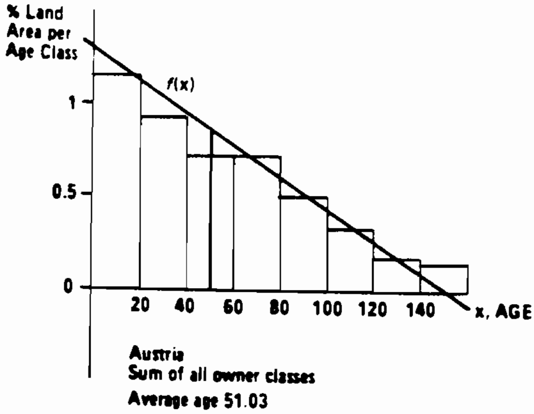

Figure 3 The age distribution of forest area in Austria (Osterreichische Forestinventur 1971–1980).

Table 2. Parameter values.

Symbol	Value	Unit
S_0	5	$\mu g\ m^{-3}$
a_o	367	$\mu g\ m^{-3}$ a
a_1	-0.895	$\mu g\ m^{-3}$ (°C d)$^{-1}$
a_2	1.11 10^{-3}	$g\ m^{-3}$ (°C d)$^{-2}$
a	144.4	a
k	-3.26 10^{-4}	°C^{-1} d^{-1}

MODEL RESULTS IN EUROPE

In this section examples of model results are presented, as they result from different sulfur emission scenarios in Europe for the period 1960–2040. The RAINS model is used for projecting the ambient sulfur levels, and ETS and forest area are obtained from a three-dimensional, geographic data base.

Input

The ***sulfur dioxide*** scenarios are obtained from the energy and emission submodules of the RAINS model (Alcamo *et al.*, 1985, 1987). In addition to the standard scenarios of RAINS which cover the period 1960–2040, we initialize the model with a "historical sulfur emission scenario" by setting the SO_2 concentrations between 1900 and 1960 proportional to estimates of European scale SO_2 emissions by Möller (1984) and Semb (1978). The principal spatial resolution of the system is 150 × 150 km^2. Three scenarios are used in the example runs: (1) the ***official energy pathway***, as published by the International Energy Agency and the Economic Commission for Europe, (2) ***30% reductions*** in sulfur emissions from the 1980 level, and (3) ***major sulfur controls***. The scenarios are described in Alcamo (this volume).

For estimating the *effective temperature sum*, we use the same principal spatial resolution as for the sulfur scenarios, but the area is additionally subdivided into altitude classes. The resolution of the vertical axis varies with respect to the maximum altitude, comprising 300 m in Central Europe and 100–200 m in Northern Europe. ETS values are calculated at the centre point of each grid element and altitudinal range. The ETS values for each location are calculated from corresponding estimates of monthly average temperatures (Ojansuu and Henttonen, 1983). The monthly mean temperatures are interpolated from standard weather station data, taking into account the spatial coordinates (latitude, longitude and altitude) and the distance from the sea. The 30-year data from 1088 weather stations are included, with dense networks in Austria, Britain and Scandinavia, and a sparser network for the rest of Europe (Müller, 1982). The method is described in detail in Henttonen and Mäkelä (1987).

Only *forest area* is considered in the calculations. The distribution of forested area in Europe is stored in the data base with the resolution of 1° latitude and 0.5° longitude. The distribution of forested area was obtained from two map series, both including the altitudinal variation and forest cover (1404 World, 1:500,000, topographic map series, and TPC 1:500,000, aeronautical map series).

Output: risk levels

Figure 4 shows model prediction of the distribution of high risk areas in Europe in the year 2000, under different energy pathways. As the sulfur history is the same until 1980 for all scenarios, and the reductions do not become really effective until after 1990, there are only minor differences between the three scenarios. In accordance with the assumptions, the model picks out those high altitude areas where the SO_2 concentration is permanently high. The model implies relatively high risk for the Alps, probably mainly because of the altitude factor. The Black Forest of the Federal Republic of Germany, where heavy damage has been reported, does not seem to be susceptible to foliar effects of sulfur.

Figure 5 repeats the comparison of scenarios for the year 2040. The differences between the scenarios now become apparent. The official energy pathway implies an increase in the high risk areas, and the 30% reduction scenario more or less conserves the situation of 2000, with the only exception that the risk area around the Harz Mountains has disappeared in the 2040 situation. The major sulfur controls scenario produces a significant reduction in the area of high risk.

DISCUSSION

The 'effective SO_2 dose' model is built upon two basic assumptions; that (1) foliar injury can cause an accumulation of strain which is not discharged, and (2) the effective temperature sum aggregates the climatic variables that are relevant for resistance of strain. As already noted, the first assumption relates to the observation that there is a considerable delay between beginning of exposure and occurrence of damage on one hand, and the failure of soil acidification to explain the pattern of damage in the Erzgebirge on the other hand. However, since the process of soil acidification provides an explanation for a delay, whereas the mechanisms of a delayed response to foliar injury have not yet been successfully explained, we cannot rule out the possibility that soil processes were responsible for the damage.

The fact that the model fails to account for the possible impacts of climatic factors not correlated with ETS, is particularly important as regards wind speed and occurrence of mist. The former has been claimed to increase pollutant uptake by the canopy, and the latter has an impact on the rate of cuticular erosion caused by sulfur (Materna, 1986). Both effects thus increase the rate of foliar strain development. As

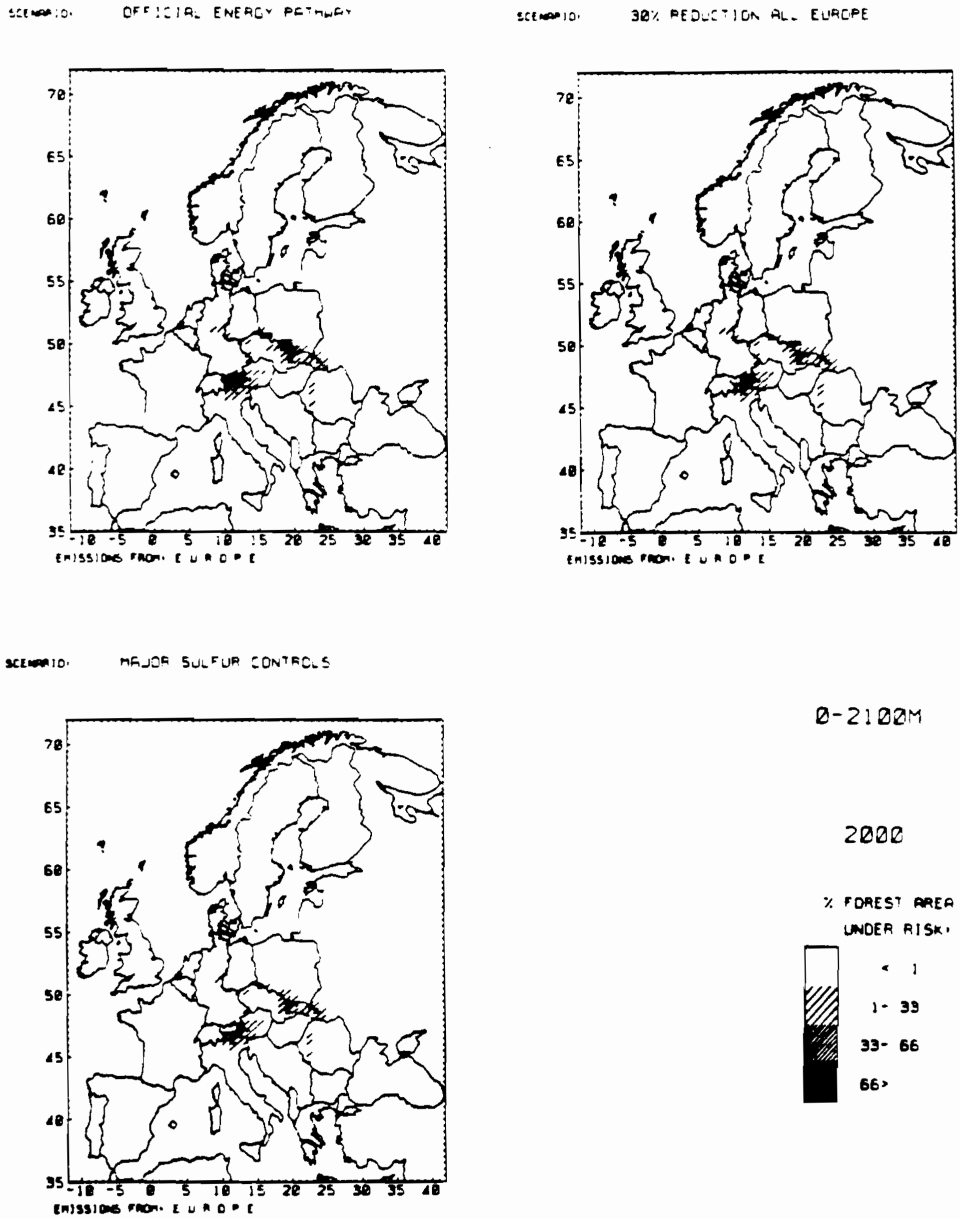

Figure 4 Areas of high risk ($T_M \geq 1/2\ T_R$) for the year 2000. (a) official energy pathway; (b) 30% reductions in S emissions; (c) major pollution controls.

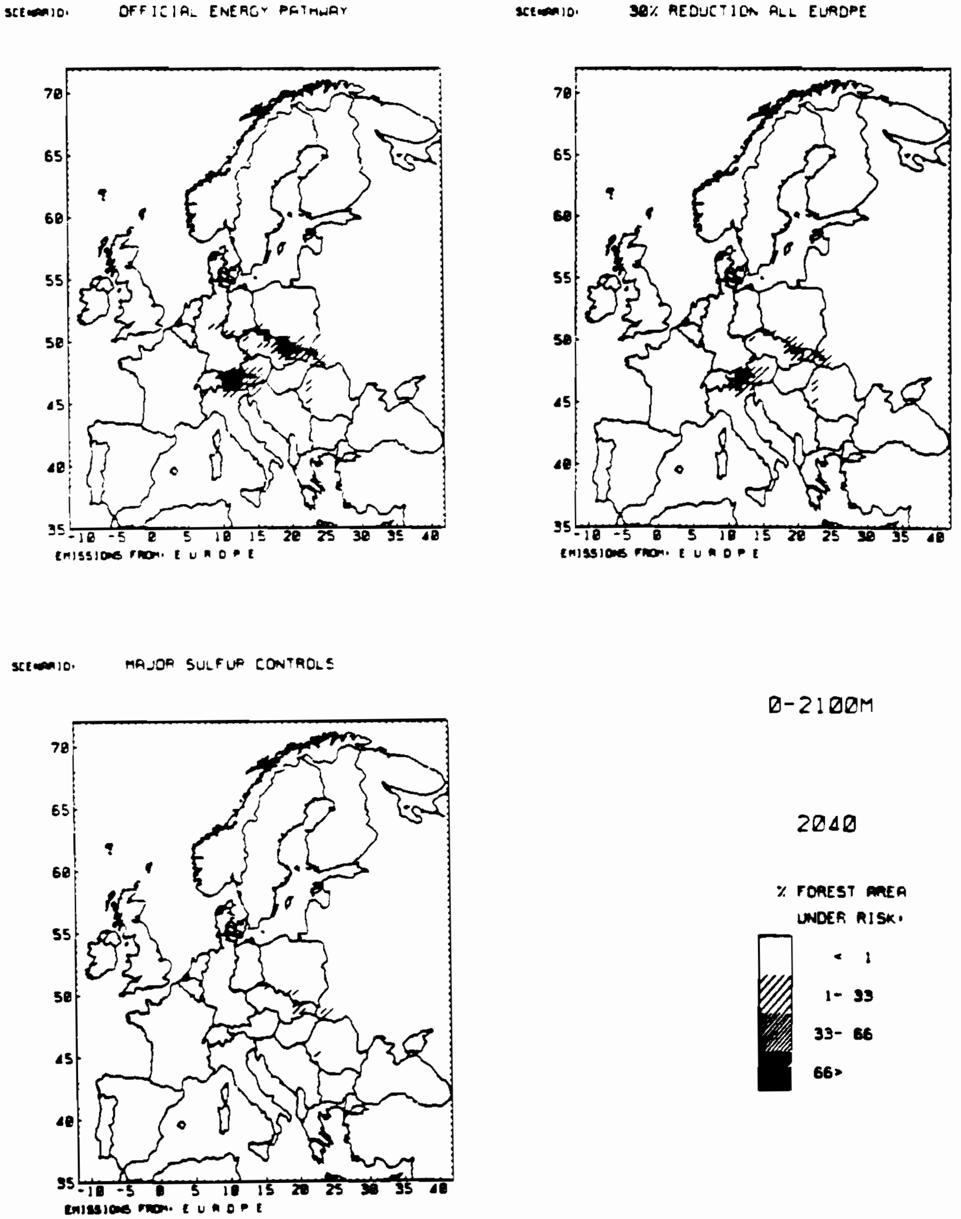

Figure 5 Areas of high risk ($T_M \geq 1/2\ T_R$) for the year 2040. (a) Official energy pathway; (b) 30% reductions; (c) major pollution controls.

regards the reaction of the whole tree to the foliar strain, factors such as site class and stand age have been deliberately excluded from the model, because (1) the empirical observations do not provide enough material for deriving proper relationships, (2) the main interest was in direct impacts, and (3) in the regional application the site quality and age classes have high resolution and are likely to average out over the grid elements.

Although these questions cannot be properly settled without studying the actual mechanisms of damage development, a better interaction between model building and the analysis of data could probably also help in solving some of them. In the described study, the authentic measurements were not available for model identification. Instead, we drew from conclusions obtained independently, and fed these conclusions into the general model structure of Chapter 3 in a more or less *ad hoc* way. This drawback can hopefully be overcome in the future, and the model can be tested against the actual observations.

The regional application of the model includes some technical assumptions that emphasize the indicator character of the results. For instance, all the empirical results concern Norway spruce only, yet the application covers total forest area. This has not been considered fatal because (1) we were interested in a relative measure of risk, and (2) Norway spruce is by far the most common commercial species in Europe, comprising 25% of growing stock. This is particularly true of the areas which the present model regards as the most sensitive: In the Nordic countries and Central Europe the fraction of spruce is nearly 60% (The Forest Resources of the ECE Region, 1985).

In summary, the 'effective SO_2 dose' model displays some regional, long-term implications of conclusions based on an individual field study. No matter how comprehensive the field study, the evidence remains circumstantial and the conclusions must be regarded as empirical generalizations. We trust that the numerous ongoing studies on forest dieback will help test and improve the model in relation to the ecophysiological pathways of damage.

ACKNOWLEDGEMENTS

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3.4 FIR AND PINE PHLOEM AND WOOD GROWTH RETARDATION DUE TO AIR POLLUTION*

B. Molski
Botanical Garden
Polish Academy of Sciences
Warsaw, POLAND

1. INTRODUCTION

There is now a general agreement that dry and wet air deposition of pollutants, especially sulphur dioxide, ozone and oxides of nitrogen, can alter the physiological processes of plants and affect patterns of growth. They have direct effects on photosynthetic systems, leaf longevity and patterns of photosynthates allocation within plants. Wood production is affected as the first result of this limited allocation (Keller, 1985, Larcher, 1980).

Trees can have suppressed root growth due to air pollution.Suppresion of root growth may also make trees more vulnerable to periods of limited water availability or strong winds (McLaughlin, 1985). There is evidence that pollution caused reductions of photosynthates allocation to roots extends beyond the plant itself and affects symbiotic relations with mycorrhize (McCool, Menge, 1978) and nitrogen - fixing microbes as well as (Tingey and Blum, 1973) reducing nutrient and water availability for plants, and therefore good supply of leaves producing photosynthates.

Demand of roots for their function is quite significant. Experiments with translocation of photosynthates in conifers showed that young trees *Pinus recinosa* with mycorrhiza translocated 54% of radioactive photosynthate, while without mycorrhiza only 5% in the same time. But the translocation is controlled by the physiological state of the shoot (Nelson, 1964). There is a seasonal variation in translocation to the roots. It is very often related to shoot growth. In temporate climate in May there is a high rate of translocation, but in June, July and August, the rate is very low, due to the shoot growth, and in September, October and November, again there is an increase in translocation. Root growth takes place twice a year: in spring and in early fall (Nelson, 1964).

In spring carbon taken up by old leaves can meet a large part of the needs for production of new leaves, but the rest comes from reserves in stem and roots if they are there in sufficient quantities. Moreover, the sufficient photosynthates is needed for cambial growth.

Trees existence in areas of air pollution depends not only on efficient photosynthates production in order to produce new shoots with new leaves for proper regeneration of photosynthetic system, but also for production of new roots with the whole system of fine roots, or roots hair which determine proper water and nutrients uptake from soil, as well as production of new layers of wood and phloem which determine the proper transmmition of water and nutrients from roots to leaves and photosynthates from leaves to roots to enable them the function normally. The two later areas (roots and phloem-wood) were not extensively investigated in relation to air pollution. Therefore, the Botanical Garden of Polish Academy of Sciences started in 1986 studies in the area of phloem growth in relation to wood growth as a preliminary problem to root studies in the near future. The results of phloem studies are presented herewith.

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*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

2. TREE FUNCTION IN AIR POLLUTED AREAS

The whole plant carbohydrate economy disturbance due to various toxic substances such as air pollutants affecting trees directly from air or through soil, or usually both, eg. action of acid rains, first of all leads to a decrease in the net photosynthetic production and the associated diversion of carbohydrates to less mobile and potentially toxic secondary substances leading to a poor development of leaves, and fine roots and mycorrhizae (Schutte and Cowling, 1985; McLaughlin, 1985).

A decrease in the carbohydrate production and a reduction of radial growth of trees cause also a disturbance in the phloem growth. Sieve tube elements function only for a few months and to ensure permanent supply of organic substances from the tree crown to roots, there has to be a continuous growth of the new layers of phloem through the whole tree trunk.

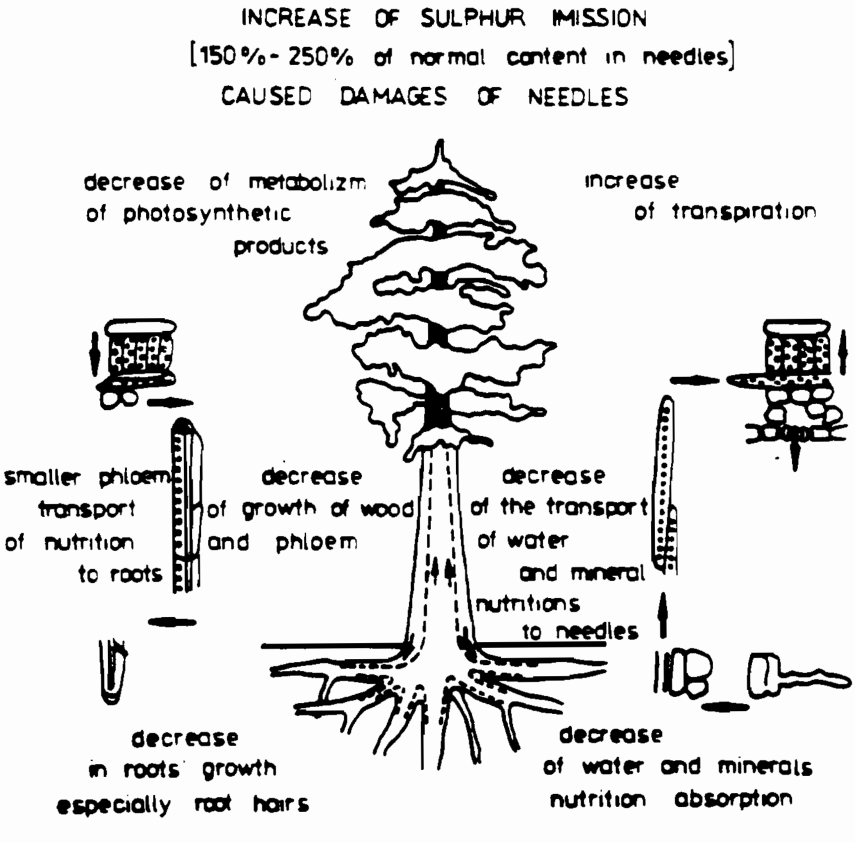

Fig.1. Diagram showing a death spiralle of tree functioning in environment with heavy air pollution. A decrease of carbohydrates production due to air pollution leads to a decrease of wood-phloem growth and root growth. These, in result decrease water with minerals uptake causing smaller supply with them to the leaves and further lowering photosynthesis. This mechanism functions in a compressing halter fashion leading to the complete death of a tree.

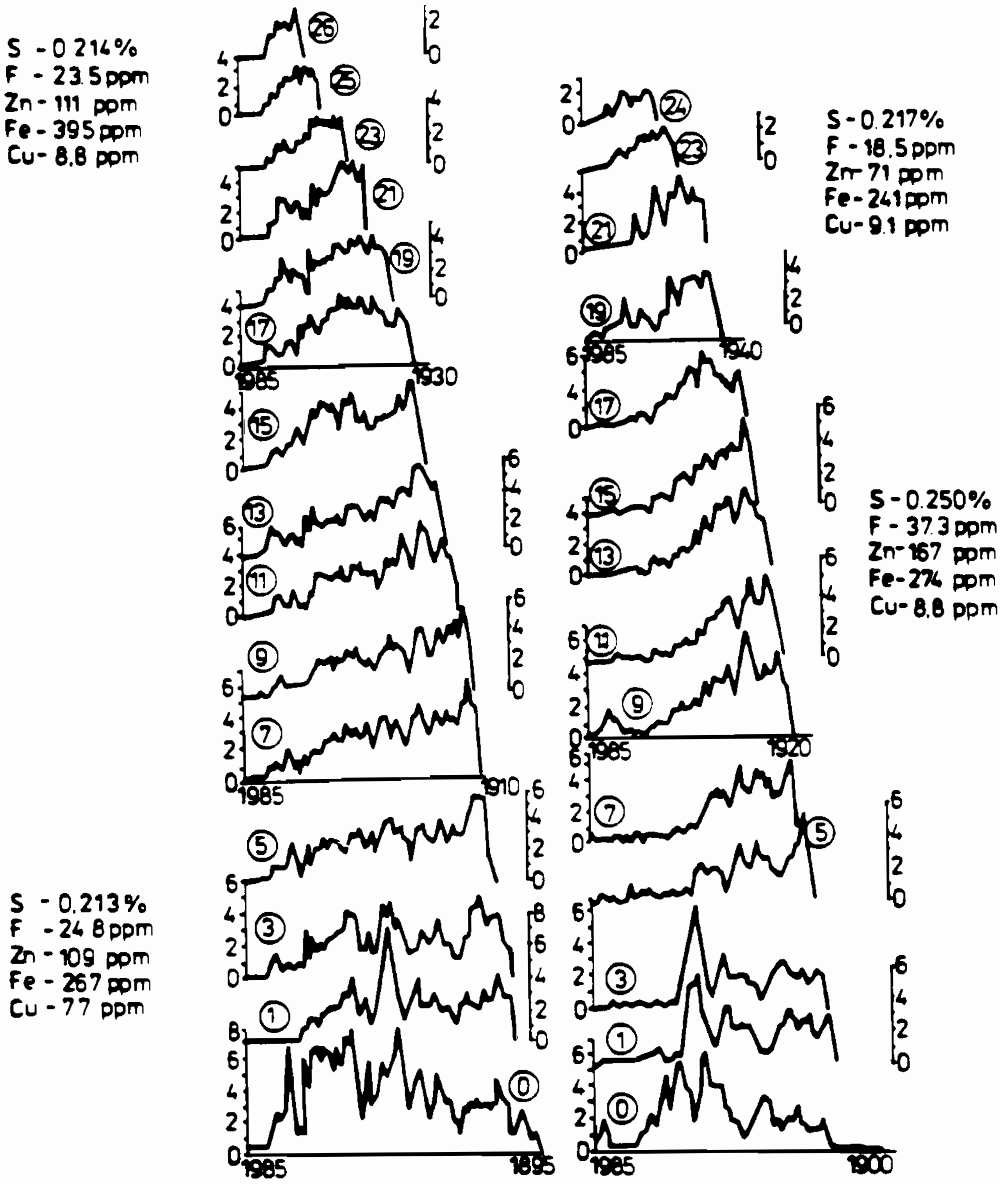

Fig.2. Diagrams representing growth of two firs *Abies alba* in heavily polluted forest stand /zone IV - above 60 micro gramms of sulphur dioxide/m3/ on very good soils rich in lime. The left diagram represents fir with many branches on the trunk from the top to 3.6 m above the ground. Tree was growing very well for many years /it was 93 years old when it was cut in 1986/ only the last 10 years have smaller growth rings indicating slow process of dying but the tree could be alive for the next 15-20 years if it were not for cutting down the tree. The second diagram represents fir from the center of the forest stand with branches starting about 13 meters above the ground. The process of dying of this fir started about 30-35 years ago and the tree will stay alive not more than a few years longer. Curves represent size of growth rings in mm at the respective height above the ground /see figures in circles/. Figures in four blocks represent pollutants content in leaves at the respective hights.

Any decrease in this pathway leads to the starvation of the root system including the continuous growth of fine roots which condition the proper uptake of water and mineral nutrients as well as the starvation of mycorrhizic fungi. In this way a decrease in the foliar function due to air pollution causes a decrease in the roots function as to water uptake. This reduction of water uptake has deleterious effect on the crowns function leading finally to a further decrease in the photosynthetic activities of leaves (see Fig. 1). A tree without fine roots behaves as a piece of branch put in a bottle of water - a mechanical water uptake can not ensure a normal growth and leads to the death of a tree.

3. WOOD AND PHLOEM PRODUCTION IN TREES OF POLLUTED AREAS

When the cambium is dormant the size is at a minimum, usually 2-4 cells. When cambial activity is initiated in the spring the number increases to 12-40 cells in fast growing trees and 6-8 in slow growing ones. When the size of the radial number of cambium cells has been established the number of cells is the same during the time of wood and phloem production. When the latewood starts to be formed the rate of cambium cell production decreases and the radial number of cambial cells gets reduced th the dormant condition (Bannan, 1955).

Production of phloem cells is about one-tenth of xylem cells in fast growing conifers, but in both fast and slow growing trees the annual radial increment of phloem is about the same, so in slow growing trees the ratio approaches 1:1 (Bannan, 1955, Wilson,1964).

The important question is how wood-phloem relation is formed in trees growing in heavily polluted environment. It is commonly agreed that in such conditions wood growth is slowed down but usually it is continued almost up to the death of a tree being a witness of a particular tree history. Therefore, growth rings are used for studies of past climates, developments, /dendroclimatology, dendrochronology, etc./. Phloem cells function for very short time, not more than 2 or 3 months. After this time they are damaged and replaced by new growths so they cannot be development witnesses. But current year status of phloem reflects not only leaves feeding possibilities but also transfer to the roots. If phloem is restricted to 2-3 layers of cells /in radial direction/ root system cannot be supplied adequately as by phloem with 10-15 layers of cells.

Fig. 2 represents growth of *Abies alba* trees in heavily polluted areas /zone IV according to the Botanical Garden of PAS division, see Figs.4 and 5 in this paper/ on good, rich in lime soils. There are diargams of growth of two trees. The one on the right hand side was growing in the center of a one hundred years old forest stand with many dying trees around. The left tree diagram represents a tree growing about 100 meters further on in the same forest stand but at the edge of it , next to the open, large area of 20 years old forest. Therefore, this fir had well developed branches with leaves from the top of the tree to 3.6 meters above the ground. Due to this, side branches of the tree could have much better supply of photosynthates to the root system - the lowest branch was only about 4 meters from the roots in this tree while the former tree had about 16 meters for such transport. The fir growing on the edge of forest stand had also many more leaves and its growth was much better than in case of a second tree which can be seen from the curves representing the wood growth.

The tree growing in the same forest stand , at the edge of the big forest was growing quite well. Its growth was limited to a few layers of wood cells a year during the last decade. The second tree from the center

of the forest stand has been limited in growth for the last 30-35 years. It is especially well seen in the middle of this tree. The lowest and the highest parts of the tree have their growth rings a little bit bigger.
A very common symptom of aboundant formation of adventitious shoots on the side of a tree trunk located as near to the ground as possible in firs, pines and spruces in polluted areas serves as the source of carbohydrates which have a short way of translocation to roots, facilitating sieve tubes formation.

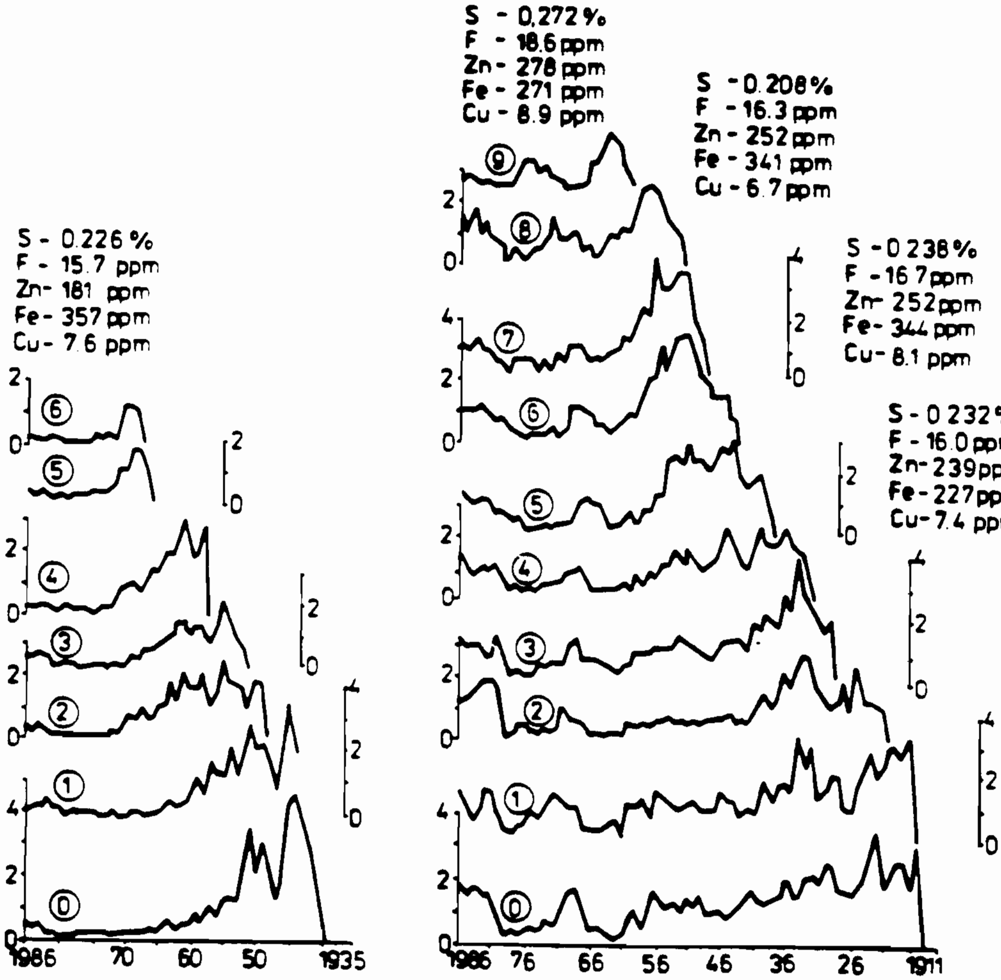

Fig.3. Diagrams representing growth of two pines: the left one - 46 years old and 395 cm high and the right one - 72 years old and 915 cm high. The figures in blocks represent pollutants accumulation in pine needles at the respective heights above the ground. Curves represent width of the growth rings in mm on the respective heights - only the right tree. The left tree was only 395 cm high and the curves are from the following heights: 0 - just above the ground, 1 - 70 cm above the ground, 2 - 120 cm, 3 - 185 cm, 4 - 245 cm, 5 - 310 cm, and 6 - 390 cm above ground level. Both trees were alive and grew slowly in spite of very heavy pollution.

Phloem importance for root supply with carbohydrates explains also why the older and taller trees are more damaged by air pollution than the young ones. In young trees the translocation from roots to leaves and opposite is much shorter than in the old, tall trees.

Fig.3. represents growth of two pines *Pinus silvestris* trees in a very heavily polluted areas /zone IV/. Pine on the left was 395cm high. Up to the height of 2 meters it was well developed with good branches and above this height it was just one stem with few very weak branches due to heavy air pollution. The whole forest stand was about 2 meters high with very few trees growing a little bit higher but all heavily damaged above these 2 meters. All growth were very small and the tree just exists for the last 30 years - growth are a few wood layers a year. But due to branches located close to the ground root system can be supplied and can function.

The right diagram shows a pine tree growing in the pine forest stand, about 10 meters tall at the age of about 80 years. This pine was 915 cm high. Growth rings quite small but the side branches are about 5 meters above the ground and root system can be supplied with carbohydrates. The trees exist in spite of very small growth rings.

Phloem production differs greatly in trees from clean and polluted areas, and from trees which grow vigorously and suppressed. Trees from clean areas grow very well with wide, more 100-150 cells in one radial row of cells in wood. Such trees have quite wide cambial zone /about 10 cells/ and about 7-8-10 cells of phloem cells. Supressed trees have usually narrow wood rings, 10 to 5 cells and also very small cambial zone - 4-5 cells and 2-3 cells of phloem. Not supressed trees have a little bit wider cambial zone - 5-6 cells and about 10 cells in phloem. Tables 1 and 2 represent number of cells in wood and phloem as well as in cambial zones of different trees.

Table 1. Fir *Abies alba* wood and phloem structure in heavily polluted area in relation to the vitality status /number of cells in radial row during winter time/.

Tree characteristics	Height above ground	Wood the last year early	late	Cambial zone	Phloem sieve and parenchyme cells
88 years old tree suppressed - heavy pollution	3	4	1	4	4
	8	3	1	4	3
	19	3	3	4	3
92 years old tree not suppressed heavy pollution	1	4	2	4	8
	15	5	2	5	7
	27	4	2	5	8
86 years old tree heavy pollution not suppressed	2	55	63	6	12
46 yeras old tree very heavy pollution, not suppressed	2	38	71	5	9

Phloem zones are strongly related to wood growth rings but there are differences as well. In a suppressed tree phloem zone is very narrow as a rule but not suppressed tree may have very narrow wood rings in heavily polluted areas and still have phloem zone in good condition. If phloem is functioning well, even in polluted area the tree can exist well and remain in the forest stand.

Such situation can be found in young forest stands with good water and nutrients supply or in trees which have branches from the top to the ground of a tree. Only very heavy pollution which destroys not only tree but also changes soil status /very acid and very alkaline/ can kill every forest or even vegetation in the area. Tree rings studies of a single tree or a few trees cannot and usually do not present the entire forest stand productivity. They may be trees but not the forests.

Table 2. Pine *Pinus silvestris* wood and phloem structure in haevily polluted areas in relation to their vitality status /number of cells in radial row in winter time/

Tree characteristic	Height above ground	Wood the last year early	late	Cambial zone	Phloem sieve, parenchyma cells
23 years old tree in clean area	1	68	58	10	7
	4	81	26	9	8
	9	130	16	7	8
72 years old tree in heavily polluted area - 915 cm height	1	14	8	5	2
	5	26	34	7	2
	9	24	18	6	3
46 years old tree in heavily polluted area 395 cm height	0.7	14	16	4	3
	2.4	9	8	4	3
	3.9	4	6	3	2

4. TREE GROWTH AND POLLUTANTS ACCUMULATION IN LEAVES - WHY A TREE DIES?

Studies of presented above tree growths were collected in two areas in the most polluted forest district Olkusz, which has the highest pollution in Poland with different soils. Very poor sands without any ground waters due to drainage of water by coal mining in the area, as well as very good clay soils rich with lime or limestones. The second area are pine forest stands near Warsaw with very low pollution and soils not damaged by anthropogenic actions. Fig. 4 represents location of sites of trees for growth research.

Keller (1985) presents the opinion that chemical analysis of foliage is of little value for estimating plant responses to air pollution in spite that they indicate the presence of pollutants. However, visible symptoms of injury are also poor indicators of growth reduction since even low SO_2

concentrations of long duration may not produce visible injures, but can decrease growth of trees leading even to their death. Obviously even such low, but prolonged air pollution, has to increase presence of pollutants in foliage and may be an indicator of growth reduction. But we have to know more about relationships between these two factors (pollutants content in foliage and tree growth). The presence of pollutants in foliage may be the only measured indicator of air pollution pressure on forest, since we know that even serious tree leaf injuries caused by a short peak of SO2 exposure damaging foliage may affect tree growth to very inconsiderable extent.

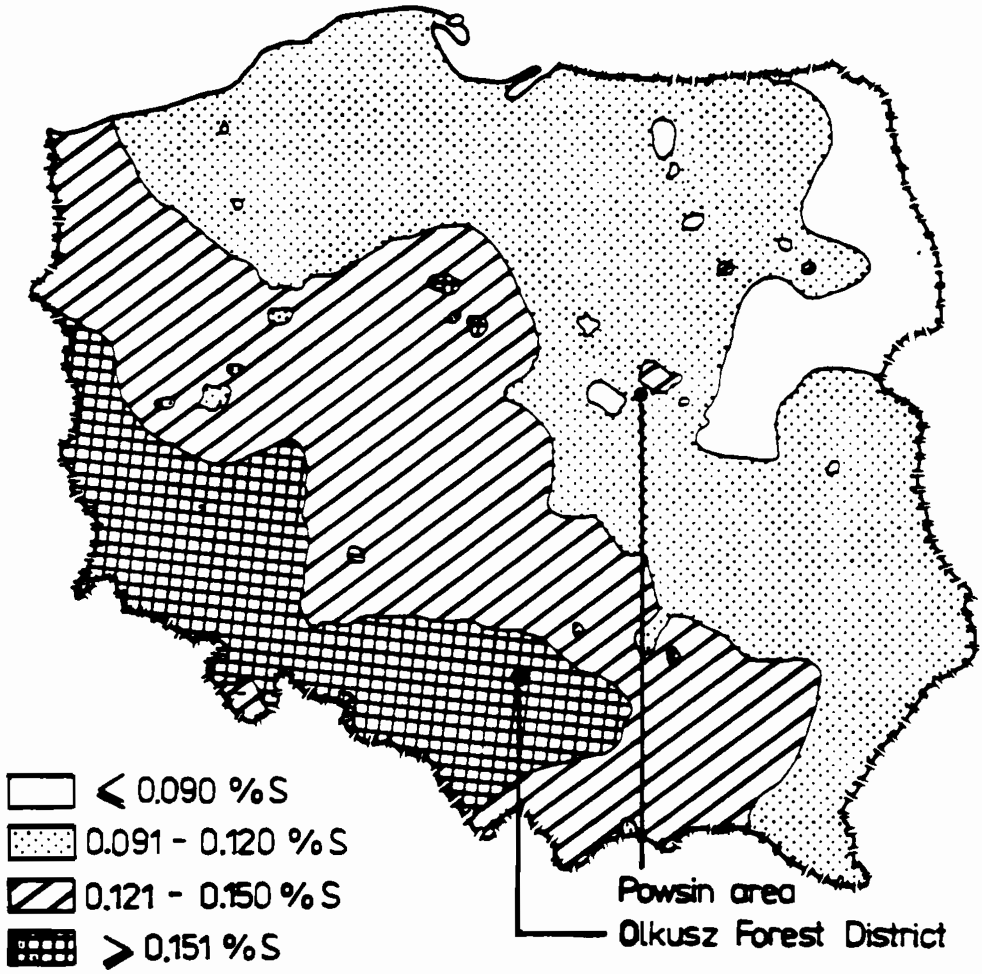

Fig. 4. Four zones distinguished in Poland based on sulphur content in pine needles /see also fig. 5/. The I zone - very clean where sulphur content does not exceed 150% of the normal level in pine needles /< 900 ppm of S/. The II zone - where sulphur content reaches almost 200% of the normal level - it is probably still not toxic level. The III zone - exceeding 200% but below 250% of the normal level which is already toxic to conifers /except Larix spp./, and the IV zone - heavily polluted where sulphur content exceeds 250% - this level is definitely toxic for all conifers (after Holski and Dmuchowski, 1986).

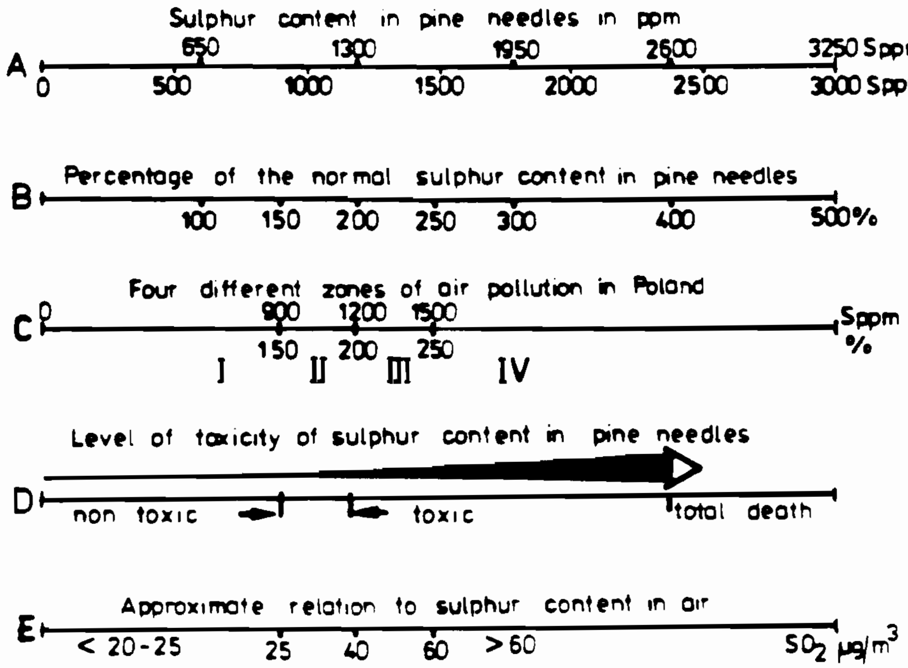

Fig. 5. Relation between sulphur content in pine needles in ppm and as a normal or exceeded levels in percentage compared to four distinguished zones of air pollution in Poland and approximate SO2 content in air in micro gramms per cubic meter as well as toxicity level expected in relation to sulphur content in pine needles.

Fig. 5 represents approximate relation between level of sulphur content in foliage of pine and toxic influence on growth of trees. If only sulphur which is very important element for protein structure is taken into consideration, it may become a limiting factor in growth, while being in deficiency. But as any other element it can be in surplus, since it is almost always present in every industrialized country of Europe. This surplus can be toxic from a certain level of accumulation. It is agreed that level exceeding 200% of a normal content of sulphur in plant starts to be toxic. Our observation confirm this assumption. 200% of sulphur content in pine needles strats to be toxic, but about 400% of the normal content that is about 2500 ppm is the limit of accumulation; normally pines do not accumulate more, since above this level the trees or the parts of trees die, eg. tops of trees. In such cases tops of trees die and forest is lowering in height to 8-10 meters, instead of 15-20 meters or even to 2-4 meters as it is in Olkusz Forest District or in other districts of the IV zone of pollution near the pollution sources.

Trees in heavy polluted areas if not killed through direct strong injuries due to very high concentrations and strong winds can stay for many years. Death of the trees comes even in indirect pollution areas due to steady pollutants accumulation and the normal retardation of growth - leaves, wood-phloem and roots. But the loop of death can work for years, usually 30-50 unless earlier some disease comes or insect population outbreaks or there is severe winter or drought. Accumulation of pollutants, especially sulphur content in relation to percentage of a normal level, can be be a very good indicator of threat. But phloem structure /if very narrow/ indicates the last stage of a tree death.

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3.5 EFFECTS OF AIR POLLUTANTS ON FOREST GROWTH*

J. Pollanschütz
Forest Research Station
Vienna, AUSTRIA

1. CHARACTERISTICS OF GROWTH DEPRESSIONS CAUSED BY AIR POLLUTANTS

It is one of the characteristics of pollution influenced growth behaviour of coniferous trees that they react from the beginning of a moderate to severe impact of air pollutants relevant to forest stands. According to sensitivity, these reactions take place still in the same year or with one year delay showing an evident reduction of radial and diameter increment, especially in the lower and medium stem section. Another characteristic is an evident reduction of variation due to climate of the widths of annual rings from year to year from the beginning of damage. This is shown in the growth ring diagrams B and C in Fig. 1, in comparison with the undamaged reference tree.

The relatively accelerated decrease of annual ring width within one or a few years and the insignificant increment reaction to climatic caused impact can therefore be considered typical for sudden or suddenly increased impact of gaseous pollutants, unless in case of this does not apply for low concentrations. This refers mainly to predominant and dominant trees, trees with a broken crown or severe mechanical root damages may show a similar increment reaction. In codominant and especially in dominated and suppressed trees evident decrease of annual ring widths as well as a reduction of annual variation alone can be due to competition and in this case the reduction cannot be separated from effects caused by air pollution. See growth ring diagram D of a dominated spruce before the damaging impact starts in 1961 in Fig. 1.

For increment studies by means of cores and/or stem analyses it is therefore recommended to select predominant and dominant and, if possible, trees with crowns showing no influence by competion. Contrary to variation of annual ring width in single trees due to the damaging influence of air pollution, variation is considerably increased the

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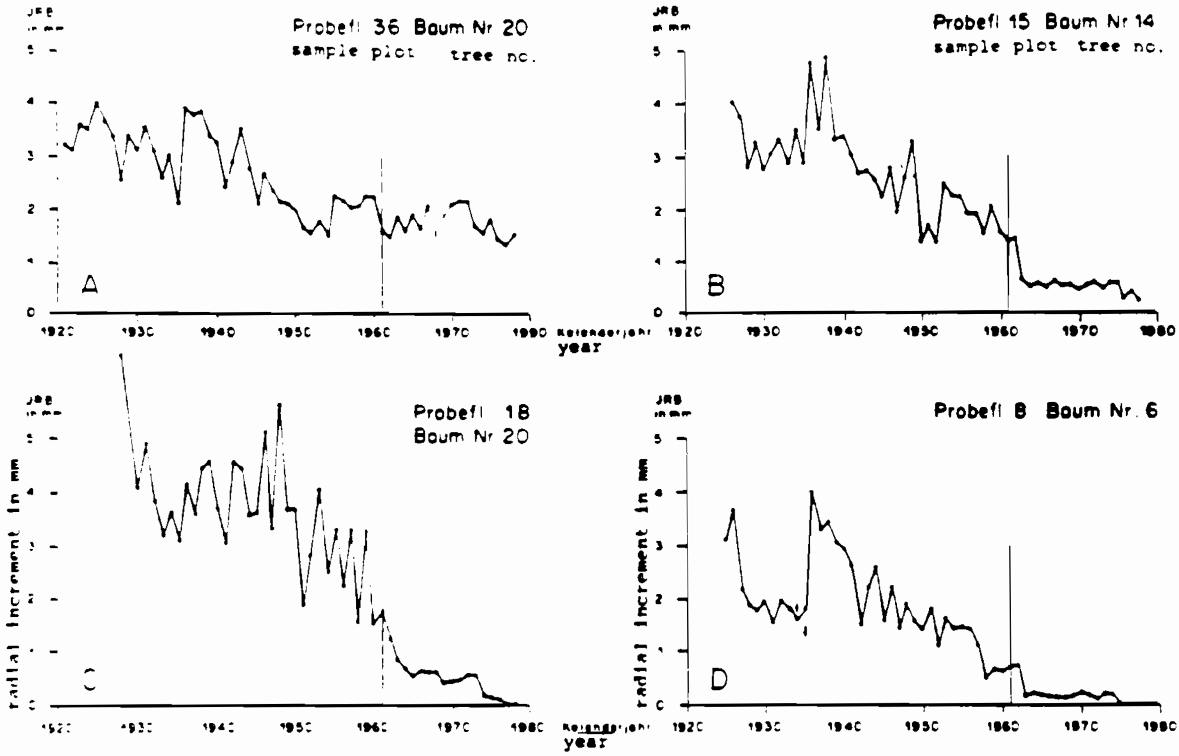

Abb. 1 Immissionsbedingte Radialzuwachsreduktionen (B, C, D) im Vergleich zur "Nullprobe" (A)

Fig. 1: radial increment reduction caused by air pollutants (B, C, D) in comparison with the reference (A).

trees of a stand, according to their genetic predisposition, special site conditions and the degree of exposure resulting from neighbourhood conditions. A comparison of the growth ring developement of the diagrams A, B and C after the beginning of the damaging impact in 1961 in Fig. 1 shows the marked distinction among the trees, which can be recorded not only between sample plots (as is shown in the present case), but also within the sample areas.

For areas and zones respectively subjected to relatively low air pollution, evidence can be provided easily if the research area includes also zones with increased air pollution.

In areas with low impact of air pollutants clear evidence of increment losses can be provided only through critical selection of sample trees and under observation of comparability of the stands.

2. PROBLEMS ARISING FROM COMPARISON WITH "NORMAL" GROWTH TREES

If in a region chemical analyses of air quality and/or needles have proved temporary impact of air pollutants in relatively low concentrations on forest stands, it must be expected that at least sensitive trees have reacted in a reduction of their physiological functions and as a consequence also their increment production. In such cases, only the comparison on increment curves of numerous sample trees from different sites and stands with "standard-increment"-curves - deduced from yield-tables or other models - (see ABETZ, D., 1985) may supply the expected results.

If long range air pullution of non-localizable emittents could have influenced healthy looking or low defoliated trees in their increment behaviour, for which no reference trees are available, only one method remains using theoretical "reference trees".

However in case of heavy impact of air pollutants or significant changes in pollution composition of one or several sources, it will be useful to apply the method of trendextrapolation method, comparising increment curves of non or less influenced trees with the trees to be investigated.

It is a hopeless undertaking to try to prove the negative effects of air pollutants by means of comparative studies in uneven-aged and multi-storied stands due to the extreme increment variation of single trees, whatever the method might be!

Trees with constantly increasing or significant changing increment (see Fig. 2), need not to be taken into accont for comparative increment studies in any case, because it is not possible to distinguish moderate increment relevant influence clearly from normal development.

3. SUMMARY

A evident reduction of diameter increment as well as a distinct diminuation of the climatic caused variation of annual growth are described as typical reactions of coniferous trees to moderate or severe influences of air pollution relevant to forest stands. Problems araising from the choice of adequate stands and trees as a sample for increment research are discussed.

Keywords: Air pollution, growth depressions,
evaluation methods.

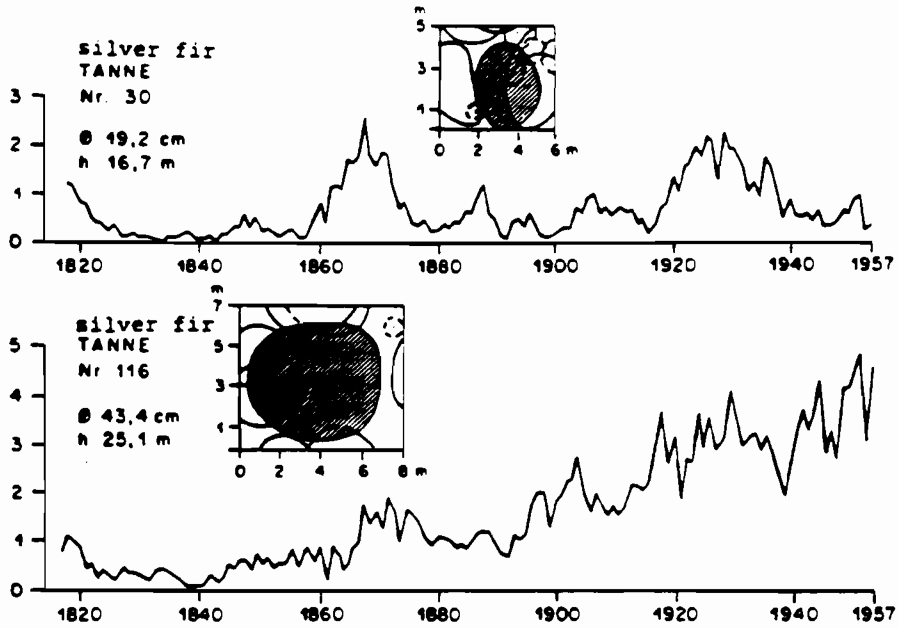

Abb. 2: Jahrringbreiten zweier ausgewählter Tannen mit Ausschnitten aus der Kronenkarte. Plenterwaldversuchsfläche Wolfach 3/II
(aus MITSCHERLICH, G., 1961)
Fig. 2: annual growth of two selected silver firs with crown map sections research area Wolfach 3/II.

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3.6 HARMONIZING THE METHODS FOR ASSESSMENT AND MONITORING OF AIR POLLUTION EFFECTS ON FORESTS IN THE ECE-REGION*

K.F. Panzer
Programme Coordinating Center West
Bundesforschungsanstalt für Forst- und Holzwirtschaft
Hamburg
FEDERAL REPUBLIC OF GERMANY

and

J. Materna
Programme Coordinating Center East
Institute for Forestry and Game Management
Jíloviště - Strnady, CZECHOSLOVAKIA

1. INTRODUCTION

At present, more than 30 states have signed the UN-Convention on Long-Range Transboundary Air Pollution. By signing this convention, signatary states have agreed to reduce SO_2-emissions by 30% until 1992. Under the Convention, delegates of each country meet every year to discuss problems related to air pollution.

This conference, the Execntive Body, decided in 1985 to start an International Cooperative Programme on the Assesment and Monitoring fo Air Pollution Effects on Forests. The prime goals of the programme are :

1. to develop a harmonised method of assessing and monitoring forest damage;
2. to collect data on forest damage in such a way that they are relevant and comparable from one country to the other;
3. to conduct at regular intervals representative forest damage surveys in each country participating in the International Cooperative Programme;
4. to clarify cause-effect relationships as a basis for continued improvement of air quality by pollution abatement.

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An international working group of experts met twice in Freiburg, FRG, and defined the essential criteria for a forest damage assessment procedure, including needle/leaf and soil chemical analysis.

The Federal Republic of Germany, probably the country with the heaviest impact of new, air pollution-realted forest damage, agreed to lead a special working group, in UN-terminolgy called as task force, to promote and realise the goals of the international cooperative programme. ČSSR and FRG offered to establish the two Programme Coordinating Centres, one for eleven eastern countries, the second has been established at the Federal Research Centre for Forestry and Forest Products, Hamburg.

Under the UN-ECE definition the region for which the two centres are responsible comprises all of Europe, the USSR, Turkey in the Southeast, Ireland in the Northwest, but also USA and Canada as well as Austria, Switzerland, Sweden and Finland.

Before presenting the elements and features of the common forest damage assessment methods some comments shall be made on the problems of air pollution impact on forests.

The Cooperative Programme was started as the common decrease of vitality of European forests was evident, new symptoms of injury occured and the known symptoms had developed on sites very far from the centres of air pollution, on sites and in dimmensions previsously unknown.

More theories have been creates to explain these phenomena and very different are the opinions what pollutant or what mechanism of air pollution influence are the cause of changes. But withour doubt is :

- a substancial increase of the extent of damaged forests through classical pollutantswhich is the result of transition from long lasting latent injury to visible symptoms of influence as a result of time or of the influence of other stress factors
- the changes in soil development, the cause of which is the deposition of acid substances have detrimental effect on root system and on mineral nutrition of trees
- the influence of "new" pollutants as ozone has increased

Without respect what pollutant or what process is responsible for the changes in the health state of forests, the main cause is the change in the common character of pollution from a local harmfull factor to a regionally acting ecological factor, which also deeply influences other ecological factors. This change is due to the amount of emissions, which increased in the last decades by 2 - 3 orders, but also due to the broadly used process that should decrease the acting concentrations of pollutants by better dispersion from high stacks. This led to an immediate relief and air quality improvement in the areas concerned but resulted in large area distribution of the noxious fumes and gases /SO_2, NO_x, HCl, HF/ not to forget the number of many not completely identified and listed organic compounds, many of which contribute to the formation of photooxydants.

The effects of this increasing, low level but large-area background air pollution on forests were recognised first by diseased and dying fir, Abies alba, in Southern Germany around 1975. Later on report came in on affected spruce, Picea abies the economically most important species in Central Europe.

Forest have been and still are an essential component of mythology, of man's heritage, they are definitely part of our culture, they are a refuge or resort of recreation for the citizens stressed by the exigencies of modern life. They are ecologically important as pollutant filters and the regulating base for our water resources. These facts and in view o the fact that the ecological conscientiousness and sensitivity of the population are high explains the occasionally hectic, political reactions and public concern in the face of environmentally dangerous accidents in the nuclear and chemical industries during the last year.

2. The "Manual on Methodologies and criteria for harmonised sampling, assessment, monitoring and analysis of the effects of air pollution on forests"

The fact that we are trying to define methods indicates that we face a real problem not solvable by simple human sense and technical means.

In 1985, the two Programme Centres drafted the "Manual" on the basis of the working group recommendation.

The manual was adopted in May 1986 and serves as a guideline and common reference for the execution of forest damage surveys and for reporting the results to the centres for a summary report on the global situation in the ECE-region. The manual recognises three levels of activities, viz.

- large scale-representative surveys of the state o health of forests;
- intensive studies on permanent plots;
- special forest ecosystem analyses.

Priority has been given to level 1. i.e.it was considerednecessary that all participating countries should conduct forest damage surveys at regular intervals and should also adhere to a minimum common standard of survey procedures in order to obtain compatible and comparable data.

The following requirements must be fulfilled :

- only highly qualified and intensively trained personnel shall conduct the survey /most countries hold field training courses in visual assessment every year/;
- the survey must follow a proven statistical design with a systematic layout of sample plots. A 4 x 4 km grid is common in Central Europe, Svandinavian countries use their existing national ferest inventory sample network; it is in fact, a recommendation by ECE to use existing sampling networks for surveying the health status of forests
- the surveys shall be carried out during the vegetation period and shall finish prior to the beginning of autumnal discoloration of leaves.

In the selection of sample trees it is stipulated that only predominant. dominant and codominant trees can be sample trees, because these are most exposed and catch a high load of pollutants, while needle loss in supressed trees may be primarily due to shading.

Some countries use fixed-area circular plots, e.g.Scandinavia or Switzerland; in FRG a 4 point-cluster with 6 nearest-tree-selection is being used.

Sample trees may be visibly marked to assure that the same trees are assessed each year; if this is not acceptable because all trees shall be equally treated in the course of silvicultural operations, then only the plot center is marked invisibly with a piece of iron burried in the ground.

2.1 Classification of defoliation

The loss of needles or leaves is assessed in 5 classes as follows :

class	defoliation	Central Europe defoliation %
0	none	up to 10
1	slight	11 - 25
2	moderate	26 - 60
3	severe	over 60
4	dead	

The Scandinavian countries use 20 % classes, estimating needle/leaf loss in the field in 10 % classes.

It is obvious that different class widths are used within the ECE. However, defoliation in Germany is estimated in 5 % steps the two assessrs and the estimated value entered into the recording form. The allocation to defoliation classes is done on the computer, an average defoliation percent is calculated for each class to follow the development form survey to survey.

As a guideline serves the number of needle years present on the tree : 3 - 4 years on spruce in the lowlands,
5 - 7 years in the mountains
2 - 3 years in pine

2.2 Discoleration

The yellowing or reddening of conifer needles is also a symptom of affected trees. Because of the difficulty to detect this symptom consistently when looking into a bright sky or under limited light conditionswithin a dense stand, reporting of discoloration is optional within the ECE, but obligatory in Germany.

Defoliation and discoloration can be combined in the classification, i.e., a tree having moderate needle loss and moderate discoloration is graded one class lower than for the defoliation loss alone.

A particular difficulty in assessing needle loss is the fact that the assessors should base their work on a tree with "normal foliage". This reference tree is difficult to find in heavily affected forest stands. This dilemma points at the major weakness of the visual assessment, i.e.the subjective influence.

Furthermore, the number of needle years and the type of branching differ between species and geographical regions. Therefore, standard equipment of the assessors are binoculars and a set of tree crown photographs as reference material for defoliation estimation but also for the diagnosis of deseases from biotic agents, insects and fungi /e.g.spruce needle rust-Chrysomyxa abietis, spruce bell moth - Epinatia tedella, beech leaf miner - Rhynchaenus fagi etc./

2.3 Intensive studies on permanent plots

It is obvious that the assessment of damage made as a part of the large-scale, representative survey can only provide an instantaneous picture of the health status of forest at the time of the survey.

It is estimated that at least 10 years of observations and investigations are needed to allow any conclusions on the dynamics of the sanitary evolution of the tree. Hence, long-term investigations on permanent plots are an effective means of gaining more profound knowledge of the cause-effect relationships underlying forest decline. A further advantage is that by concentrating at a single location comprehensive measurements and analyses, valuable data can be gained for explaining causal relationships at reasonable cost. Important parameters to be studied are :

- changes of growth and yield
- deposition of pollutants
- meteorological conditions
- air quality
- soils data
- biotic and abiotic impacts etc.

In selecting study sites, geographical locations, elevation, exposition, site conditions, stand structure, age and species should be representatively covered. Permanent plots should be integrated into the survey network to allow adjustment of large-scale survey results by regression analysis.

The size of the permanent plot should not be smaller than 0,25 ha, management operations are tolerated as long as they do not jeopardize the objectives of the investigation. A comprehensive list is given in the manual on the scope of data to be recorded.

A special feature of the investigations on permanent plots are needle/leaf and soil chemical analysis. Detailed instructions have been defined for sampling and analytical procedures. If tree have to be felled for needle analysis, they should be taken close but outside of the permanent sample plots. Statistically, felling trees for sampling is probably the only way of collecting data objective. However, besides extreme costs, felling removes the object investigation - not an entirely perfect solution to a statistical problem.

Elements are analyzed according to the following three priority levels :

priority 1.: N, S, K, Mg, Ca
2.: P, F, Cl, Na, Zn
3.: Mn, Fe, Cu, Cd, Pb.

So far, no standard reference material for conifers, i.e. spruce needles, is available for intercalibration of the laboratories to be charged with the analyses in the ECE. Preparation of the material is in progress but may take up to the end of 1988 to be available for distribution. Only those laboratories performing analyses in accordance with the required precision standards will be entrusted with analytical work.

Soil chemical analyses

Sampling and analysis of soil serves the following purposes :

- to monitor soil changes attributable to air pollution deppositions on the soil surface;
- to provide information that may assist in understanding the effects of soil changes on the condition of forests /p 71 annex II-8/

Sampling concentrates on the surface humus layers /L, F, H/ to be determined by total weight or weight of layers :

- in the mineral soil, samples are taken at :

  0 - 5 cm
  6 - 20 cm
  21 - 40 cm
  41 - 80 cm depth

The following parameters are determined :

- pH
- exchangeable cations H, K, Ca, Mg, Mn, Fe, Al;
- available nutrients : P, Ca, K, Mg, S
- total content of N, NO_3^-, NH_4^+
- trace elements Zn, Cu, Mo, B
- furthermore possibly As, Cd, Pb etc.

Analysis of the soil solution for :

Na, K, Ca, Mg, Mn, Al, Fe, NH_4^+
SO_4^{--}, NO_3^-, Cl^-, PO_4^{3-}
pH, organic C, N

Sampling to be repeated every 5 years.

It is obvious that this is a complex investigation, requiring decicated fieldworkers, scientists and laboratory workers. The programm is still more comprehensive in the framework of ecosystem analysis.

2.4 Special forest ecosystem analysis

The complexicity of the phenomenon "forest decline" clearly points at the necessity of taking a comprehensive approach in research, understanding the forest ecosystem as an entity and trying to design a complex model of the dynamics of the ecosystem, environmental impacts, internal flows of elements and inputs and outputs of matter. So far we have been collecting pieces of a puzzle, not knowing the design of the mosaic to be assembled.

Special attention should be directed at deposition measurements and the analysis of air quality, monitoring of meteorological data, sampling and analysis of fine roots, production and decay of litter as indicators of the pH status, soil microbiology, notably nitrogen metabolism and of other parameters affecting the forest ecosystem, including impacts on fauna and flora, possible selection of organisms that can serve as bioindicators of environmental changes.

3. The state of forests in the ECE-Region

The following table summarises the area of forests presumably damaged by the effect of air pollution

region	area of high forest /milon ha/	area effected by forest damages
nordic countries		
SF, N, S	52,0	1,0
European community		
12 countries	43,0	4,5
Central Europe		
Austria, Switzerland	4,7	1,2
Eastern Europe		
YU, BG, CS, DDR, PL, H, RO	35,8	2,5 - 4,6
Europe	134,5	9,2 - 11,3
USA, CDN	459,4	unknown
USSR	810,9	unknown

The situation in Central Europe with high population density, concentration of industries and high traffic densities can be described as follows :

In austria over 30 % of conifers and over 40 % of broadleaved trees have higher than normal crown transparency.

In the Federal Republic of Germany 54 % or 4 milion hectares of conifer and 61 % of broadleaved forests show symptoms of damage; mediour to severe effects are observed on 19 % of the forest area.

In Switzerland roughly 50 % of the sample trees exhibit slight to severe defoliation or discoloration.

As a consequence, governments introduced new legislation aiming at a reduction of pollutant emissions.

New regulations are in force concerning the reduction of emissions from industries and from individual cars by subsidizing filters and by tax-credits on catalytic converters and unleaded gasoline.

Research in Central Europe now concentrates on the effects of nitrogen, i.e. as NO_x and particularly ammonia. These compounds have evidently been neglected but they may cause serious imbalances. Nitrate leaching and NH_4 absorption contribute significantly to overall soil acidification.

4. Conclusions

The International Cooperative programme, one of many international efforts aiming at mastering the environmental impacts of antropogenic pollutants on forest ecosystems, is still in its starting phase. It is certainly necessary to start with a geographic survey of the damage situation and to agree on common methods of assessment to obtain a uniform data base before further common measures can be taken.

The "Manual" is not a law, it should be considered as a living document, subject to and deserving further improvements and refinement of methodical approaches.

There is, with a few exceptions, no large scale disappearance of forest - but rather a widespread ecological and physiological instability of forest stands for various reasons.

The fact that air pollution is the major cause of this precarious situation is uncontested. Additional climatic stress may cause large-scale collapse of stands, accelerated by secondary biotic agents such as fungi and insects.

There can be no doubt that forests are the most important component of our environment. Letting them disappear by negligence or inaction would be both, environmentally dangerous and ethically unacceptable. Hence, all efforts must be made to reduce the level of air pollution by reducing emissions from industries, households and automobils. In our drive to reduce emissions we must carefully weigh the risks of nuclear power. Whatever we decide to do, we should always keep in mind that we need an ecological balanced environment, - for our survival and that of future generations.

3.7 THE EFFECTS OF WET DEPOSITED ACIDITY AND COPPER ON THE REPRODUCTIVE BIOLOGY OF *POPULUS TREMULOIDES**

R.M. Cox
Canadian Forestry Service - Maritimes
Fredericton, N.B., CANADA

1. INTRODUCTION

The germination of pollen and subsequent germtube elongation are known to be among the more sensitive botanical indicators of atmospheric pollution (Feder 1968; Ma and Khan 1976; Stanley and Linskins 1974; Feder 1981; Cox 1983a, 1984). Atmospheric pollutants may directly affect reproduction at the time of pollination, either by reducing pollen viability and pollen tube growth or by affecting the chemical environment of the stigmatic surface. These changes may affect stigma receptivity and alter pollen stigma interactions which may reduce gamete competition and thus the quality of the progeny (Mulcahy 1979).

The role of acidity in the toxicity of SO_2 to pollen under high relative humidities has been documented as early as 1931 by Dopp and in *Populus deltoides* by Karnosky and Stairs (1974).

Other studies that have noted the importance of acidity in pollen germination are reviewed by Cox (1983a,b). Masaru *et al*. (1980) were the first to confirm H^+ ion inhibition of pollen tube growth using the pollen of *Camellia* at pH 3.2. This suggested a possible effect of regional acid deposition on plant reproduction. Cox (1983a) demonstrated that of the 12 eastern Canadian forest species tested for pollen sensitivity, most would be inhibited by levels of acidity that occur currently in ambient rainfall and all would be severely inhibited by levels found in fog along the eastern seaboard of northeastern North America (Weathers *et al*. 1986).

The dioecious species *Populus tremuloides* is one that consistently sets fruits from nearly all its pollinated female flowers. These fruits are less prone to carbon resource limitations as they are green and are presumably photosynthetic. These green fruits and flowers can contribute a significant proportion to the carbon needed for their maintenance. These features together with the large number of inflorescences containing many unisexual flowers make this plant very suitable for the study of pollination, seed set, and fruit abortion using excised branches. Dioecious plants like aspen are also uncomplicated by the needs of male fitness which may vastly increase numbers of hermaphrodite flowers of other breeding systems for the sole purpose of producing pollen. This dioecious condition also makes female isolation and controlled pollination easier, without the need for emasculations.

The above observations together with the observations of pollen responses to trace metals (Arvind and Malik 1976; Strickland and Chaney 1979, Masaru *et al*. 1980; Chaney and Strickland 1984) and those reported for combinations of acidity with cadmium (Cox 1986a) prompted the use of this species to demonstrate the potential effects of combined copper and pH in wet deposition on reproductive biology.

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2.0 MATERIALS AND METHODS

2.1 In Vitro Responses

The combined effects of pH and various concentrations of copper on in vitro germination and tube growth of pollen from Populus tremuloides were investigated using a pollen assay similar to that described by Cox (1983a). A factorial design of 50 uL standing drop cultures of the modified Brewbakers solution (Brewbaker and Kwack 1963) at various pH's and copper concentrations (0, 0.05, 0.10, 0.20 and 0.40 mg L^{-1} as chloride) was used in a random block design of 5 replicates. Excised branches of Populus tremuloides were collected from a male clone at Maple Tree Improvement Institute (MTII) Ontario on April 9, 1983 and placed in 0.1 Arnon-Hoaglands solution in the greenhouse. The pollen was collected after anther dehiscence on April 11 and used fresh. The culture medium contained 5% w/v sucrose and was incubated for 4.5 h at 25 ± 2°C after which the pollen was fixed by addition of acetic acid and scored for germination and length of the longest germ tubes (90th percentile).

2.2 In Vivo Responses

Branches of similar size were excised from a single female clone (T166) of Populus tremuloides growing at Maple Tree Improvement Institute on March 4, 1983. The branches were stored outside the greenhouse for 5 days in 0.1 strength Arnon-Hoaglands solution. Five reproductive branches were then brought into a heated pollen free greenhouse at 18.3°C with 17 h day length augmented with fluorescent light and placed in random positions on a bench with their cut ends in 0.1 strength Arnon-Hoaglands solution. Groups of inflorescences (catkins) were then isolated in paper bags on March 12. Fresh pollen was obtained at the time of anther dehiscence from excised branches of three male clones collected from MTII, 5 days previously and isolated in a different greenhouse. This bulk pollen was then mixed and used to pollinate the female catkins the same day.

Pollination. Pollination of each catkin was achieved in this wind pollinated species with the use of a compressed air-operated aerosol nebulizer attached to a small 'L' shaped plexiglass tube fitted with a baffle and air supply. This pollen delivery system was calibrated at 70 psi line pressure to deliver 268 dry undamaged pollen grains $mm^{-2}S^{-1}$, with an error of 8.5%, to a small flat sticky surface (petroleum jelly) held perpendicular to the end of the delivery tube. Each catkin was pollinated separately by partial insertion in the end of the inverted delivery tube for two seconds. After each individual pollination, the catkins were reisolated in the pollination bags.

Rains simulation. After pollination the branches were removed to a pollen-free laboratory where 11 groups of catkins (usually 3) were assigned spray treatments at random. The composition of the simulated acid rain was modified from that of Percy (1986) to reflect closer the precipitation chemistry of central Ontario with initial concentrations of 0.084 ueq Cu L^{-1} and 0.046 ueq Ni L^{-1} added as sulphate and nitrate, respectively. This rain simulant was adjusted to pH 2.6, 3.6, 4.6, with 1:1 molar sulphuric:nitric acid solution. The control was left at pH 5.6 considered to be the pH of distilled water in equilibrium with atmospheric carbon dioxide. These pH treatments were used in an incomplete factorial combination with 0, 0.05, and 0.10 ppm of copper as chloride added to the simulant. The factorial treatments with 0.1 ppm copper with pH 2.6 and 4.6 were omitted from the experiment. This incomplete factorial plus the unsprayed control gave 11 different treatments in each replicate in a

4-block random block design. The pollinations were staggered to allow exactly 1 h before spraying and exactly 7 h between spraying and sampling and fixing of stigmas.

Stigmatic receptivity. Twelve stigma were removed at random from flowers down the length of the terminal catkin of a group to take in account any variation in stigmatic receptivity down the length of the catkin. The individual stigmas were placed separately in small flat-bottomed wells of a plastic tissue culture plate each containing 0.2 mL of 1:1 acetic acid ethanol fixative. After 1 day, 0.1 mL 85% lactic acid was added to each well in the tissue culture plate which was then heated at 60°C for 30 min, sealed, and stored at 5°C before microscopic examination. Prior to microscopic examination of stigma, the tissue culture wells were topped up with 0.2 mL of water and left overnight. Individual stigma were then mounted in 0.1% analine blue in 0.1 M K_2HPO_4, squashed, and placed in a moist chamber overnight at 5°C before examination under an incident-light fluorescence microscope with broad-band blue excitation.Total pollen on the stigmatic surface and under the coverslip was recorded as well as the number that had germinated (tube length longer than the diameter of pollen given).

As ungerminated pollen may be dislodged from the stigmatic surface during fixation, each well in the tissue culture plates was examined with an inverted microscope after a drop of cotton blue in lactophenol was added. Here again total grains were recorded as well as those that had germinated. These two procedures enabled the determination of the total number of grains that had been in contact with individual stigmas and the percentage that germinated to give an accurate account of the receptivity of the stigmas under the various treatments.

Fruit and seed set. The remaining two catkins in each treatment group were undisturbed and left in the pollen-free laboratory until they were no longer receptive, at which point they were placed back at random on the greenhouse bench to set seed until May 3. The catkins were then removed and the second from terminal catkin (terminal catkin was used for stigma receptivity) was scored for fruit abortion by examination of both capsules and peduncle attachment and peduncle scars on the axis of the inflorescence. The capsules were considered aborted when abscission layer had formed at the base of the peduncle and the capsule came away from the axis of the inflorescence with a touch of a finger. All capsules from each catkin were then placed in paper envelopes until scored for seed set.

Twenty capsules were sampled at random from each envelope and soaked in 5% triton X detergent. Each capsule was then dissected to determine the number of full seeds and the number of peglike placenta at the base of each capsule.

3. RESULTS

3.1 In Vitro Pollen Responses

The sensitivity of this pollen to pH was demonstrated by significant ($P<0.05$) reduction of mean length of longest pollen tubes between pH 5.6 and 4.6 while significant inhibition of germination occurred between pH 4.6 and 3.6. Copper, however, was stimulatory at low concentrations (0.05 ppm) for both parameters at pH 5.6 and 4.6, whereas higher concentrations were inhibitory. Analysis of variance demonstrated significant overall effect of pH and copper ($P<0.01$). The relative sensitivity of the two parameters to pH may indicate the slightly more sensitive nature of longest tube growth parameter, however, their sensitivity to copper is

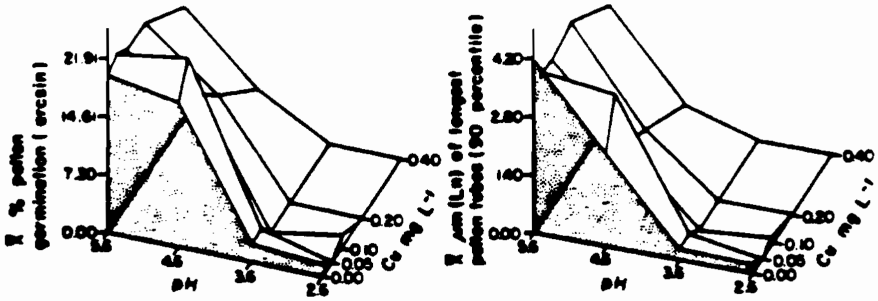

FIGURE 1 In vitro response surfaces of Populus tremuloides pollen to pH and copper content of liquid culture media.

similar (Fig. 1). The germination response surface generated was then subjected to probit analysis and LD_{50} dosages were computed when data permitted (SAS 1979). This data indicated that LD_{50} values for pH increased from 4.29 to 4.56 with addition of 0.20 mg Cu L^{-1} to the solution media demonstrating that copper increased the sensitivity of pollen to pH. An LD_{50} dosage of 0.53 mg L^{-1} was also computed for copper effects and pollen germination at pH 5.6.

3.2 In Vivo Responses

The calibrated pollination procedure produced actual loading of about 125 grains per stigma with a standard error 22% of the mean for the two a two-second exposure used. No significant differences in pollen loading occurred among the four replicates.

The responses of four different components of aspen reproduction to the combined effects of pH and copper content of simulated acid rain after controlled pollination are shown in Table 1.

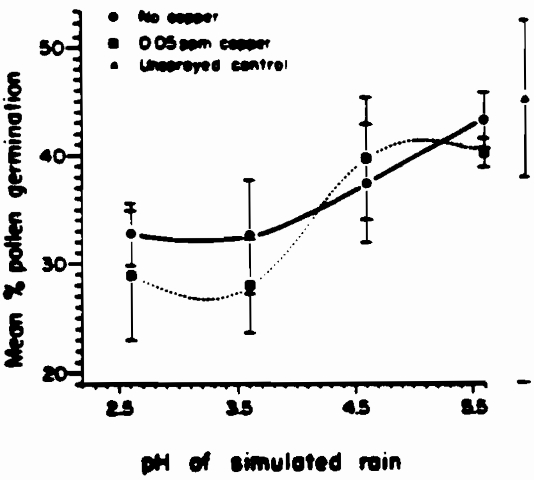

FIGURE 2 The effect on stigma receptivity of acidity and copper additions to simulated rain applied 1 h after controlled pollination in Populus tremuloides. (values are means of 4 reps. ± 1 SE).

TABLE 1. *In vivo* **responses of four components of aspen reproduction to simulated acid precipitation of varying pH and copper concentration.** (values are means of 4 reps. ± 1 SE).

Cu (ppm)	Unsprayed control	pH of simulant 5.6	4.6	3.6	2.6	r
		% fruit abortion (arcsin)				
	1.242 ± 1.21a					
0		11.861 ± 1.9	17.774 ± 1.8	18.132 ± 3.9	12.545 ± 0.9	-0.107
0.05		6.855 ± 2.9	14.969 ± 2.2	16.091 ± 3.4	19.010 ± 5.5	-0.552b
0.10		11.02 ± 1.6		16.341 ± 6.4		-0.297
		Seed/fruit ratio (arcsin)				
	16.582 ± 0.1					
0		15.800 ± 0.6	13.837 ± 0.9	14.971 ± 0.4	15.912 ± 0.6	-0.063
0.05		15.104 ± 0.7	14.281 ± 1.6	15.359 ± 1.4	13.713 ± 0.5*	0.246
0.10		14.837 ± 2.9		12.211 ± 4.9		0.309
		% placenta with seeds (arcsin)				
	62.642 ± 1.4					
0		55.179 ± 2.5	36.859 ± 10.3	53.504 ± 2.3	58.861 ± 2.5	-0.209
0.05		50.535 ± 3.0	52.919 ± 5.3	55.280 ± 6.0	47.720 ± 0.2c	0.107b
0.10		53.343 ± 12.9		40.785 ± 17.4		0.380
		***In vivo* % germination (arcsin)**				
	45.389 ± 7.1					
0		43.189 ± 2.6	37.375 ± 5.4	32.481 ± 5.3	32.668 ± 2.9	0.479
0.05		40.193 ± 1.4	39.666 ± 5.7	27.939 ± 4.3	28.941 ± 5.9	0.511b
0.10		33.801 ± 3.2		30.317 ± 5.1		0.231

a Mean significantly lower than all other treatments ($P<0.05$)
b - $P<0.05$
c Means significantly different from that of the non-copper control ($P<0.05$)

The arcsin transformed *in vivo* germination (%) of pollen that was in contact with the stigma is a good measure of stigmatic receptivity. This measure demonstrated a significant overall reduction in response to pH ($P<0.05$) of about 25% for pH 3.6 with an overall significant correlation ($P<0.01$) (Table 2). This stigmatic receptivity response to individual treatments indicated a higher receptivity in the absence of rain but this failed to reach statistical significance. Significant correlations of stigmatic receptivity with pH were also demonstrated within the 0.05 ppm Cu treatment (Table 1). However the same trend in the absence of Cu just failed statistical significance at 0.05 probability level ($P = 0.054$) due to a slight recovery at pH 2.6 (Fig. 2).

Examination of fruit abortion data showed that the unsprayed control treatment had significantly lower fruit abortion than all other treatments indicating that the action of rain alone for 1 h after pollination may increase fruit abortion. There was an overall significant trend ($P<0.05$) of increased fruit abortion with a decrease in simulant pH (Table 2).

Table 2 'r' values for correlation matrix of responses and treatment variables of combined data

	Fruit abortion % (arcsin)	Seed: fruit ratio (arcsin)	Placenta with seeds % (arcsin)	pH	Cu conc. (ppm)
Seeds:fruit ratio (arcsin)	-0.634*** (n=28)				
Placenta with seeds % (arcsin)	-0.515** (n=28)	0.803*** (n=28)			
pH	-0.325* (n=37)	0.120 (n=26)	-0.007 (n=26)		
Cu concentration (ppm)	-0.069 (n=37)	0.226 (n=26)	-0.067 (n=26)	0.144 (n=40)	
In vivo pollen germination (%) (arcsin)	-0.303+ (n=41)	0.160 (n=28)	-0.036 (n=28)	0.419** (n=39)	-0.010 (n=39)

*** = $P<.001$ ** = $P<.01$ * = $P<.05$
+P = 0.054

However, within the three levels of copper used only the 0.05 ppm Cu treatments demonstrated a significant r value for the relationship between fruit abortion and pH (Table 1). In the absence of Cu, fruit abortion recovered at the lowest pH (2.6) (Fig. 3).

Statistical analysis of the responses seed:fruit ratio and percentage of placenta with full seeds revealed that the pH 2.6 simulant containing 0.05 ppm Cu significantly reduced both these parameters compared with the pH 5.6 no Cu control treatment. Again the unsprayed control treatments for these two seed set parameters were the highest but did not reach statistical significance. The matrix of Pearson correlation coefficients for all parameters and treatment variables (Table 2) shows a highly significant (P<.01) intercorrelation of fruit abortion, percentage placenta with full seeds and seeds per fruit, suggesting that lack of seed set is the cause of fruit abortion. Neither seed set parameter, showed a statistically significant relationship with pH. However, both in vivo pollen germination (stigmatic receptivity) and fruit abortion did demonstrate a statistically significant correlation with pH.

These results plus the relationship between the responses of in vivo pollen germination and fruit abortion (P=0.054) may imply that acidity of rain causes increases in fruit abortion by the inhibition of pollen on the stigmatic surface. This may be caused by increased prezygotic ovule abortion beyond the threshold required to prevent fruit abortion by lack of fertilization. Furthermore, these effects may be enhanced by the presence of low concentrations of copper (0.05 ppm).

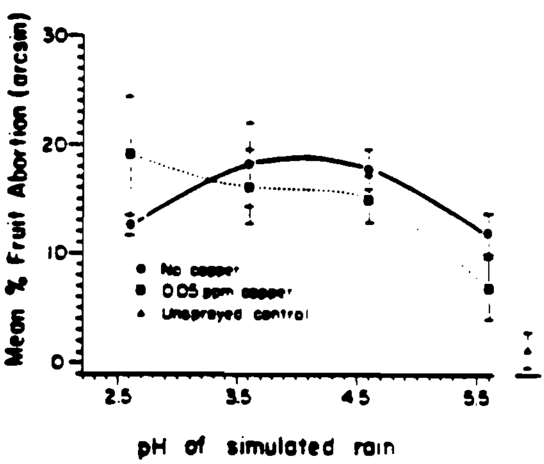

FIGURE 3. The effect on fruit abortion of acidity and copper content of simulated rain applied [illegible] h after controlled pollination in Populus tremuloides. (values are means of 4 reps. ± 1 SE).

4. DISCUSSION

Of the 11 Canadian forest species investigated in vitro for pollen responses to pH and copper (Cox 1986b), P. tremuloides was shown to be among the most sensitive to pH. While being of intermediate sensitivity to copper at pH 5.6 (Cox unpublished) the pollens demonstration of synergism between pH and copper in solution on pollen function may make it especially sensitive to these combinations in wet deposition.

A number of investigations of the effects of air pollution on in vivo pollen germination (stigmatic receptivity) have been reported. DuBay and Murdy (1983) were able to reduce pollen germination on the stigmatic surface of Lepidium virginicum by 50% by fumigation with 0.6 ppm SO_2 while Murdy and Ragsdale (1980) demonstrated similar effects with Geranium carolinianum. In G. carolinianum such reductions in in vivo pollen germination after SO_2 fumigation at high relative humidity was reported by DuBay and Murdy (1983) to have caused reduced seed set. Scholz et al. (1985) was able to inhibit pollen germination on the stigma of excised branches of two Populus species following fumigation with SO_2. There are, however, even fewer reports of the in vivo effects of wet deposited pollutants on plant reproduction. Cox (1984) was able to demonstrate and relate *in vitro* and *in vivo* senstivity of *Oenothera parviflora* pollen to acidity which caused about a 20% inhibition of pollen germination and early tube growth on the stigmatic surface pretreated with acid rain of pH 3.6 and 2.6. In this present study of aspen, rain simulants caused a 20-30% reduction in *in vivo* pollen germination and resulted in a 30% increase in fruit abortion rate.

Overall effects of pH were significant for both *in vivo* pollen germination and fruit abortion. In the presence of 0.05 ppm Cu, stronger responses for both these parameters were found than in the absence of copper. These responses relate directly to the synergistic interaction of pH and Cu found in the *in vitro* investigations of aspen pollen and supports the hypothesis that inhibited pollen germination is the cause of fruit abortion.

The apparent reduction in the rate of inhibition of pollen germination and the recovery in fruit abortion rate with the two lower pH simulants with no copper added may suggest a buffering action of the stigma. This buffering effect may be minimized in the presence of copper beacuse as its toxicity and synergistic interaction with pH which may not be reversible.

The reduction of pollen viability on the stigmatic surface will reduce the number of grains available for fertilization. This is in some respects similar to the effects of varying the pollen loading if precautions are made to standardize pollination. One difference, however, is that non-viable pollen may contribute cell exudates to the stigmatic surface. Variation in pollen loading has been reported to lead to variation in seed number among fruits. This in turn leads to the higher probability of abortion of fruits with low seed number (Murneek 1954; Quinlan and Preston 1968; Sweet 1973; Lee 1980; Bertin 1982; Gross and Werner 1983; Cole and Firmage 1984; McCall and Primack 1985). Furthermore it was suggested (Bertin 1982; Stephenson 1981) that there was a threshold seed number below which it is advantageous, to abort fruits, however the threshold may vary according to the plants resources and the number of developing fruits (Quinlan and Preston 1968). The function of fruit abortion in wind pollinated dioecious perennials that have small green pericarps, such as aspen, is not clear unless there is a disadvantage in wind seed dispersal associated with fruits with low numbers of seeds. Another hypothesis to explain the evolution of fruit abortion in this species is that small seed numbers result from few viable pollen grains and low gametic competition and therefore the seeds are likely to be of reduced quality (Stephenson 1981; Lee 1984). However in wind pollinated plants the degree of gamete competition is dependent on the number of grains that first arrive together on the receptive stigma. There appears to be strong correlative evidence to suggest that increased fruit abortion was caused by lack of fertilization brought about by the inhibition of pollen on the stigma by acidity and copper content of simulated rain. However, the possible direct effect of acidity and trace elements in inducing the processes leading to abscission of the fruit cannot be overlooked as mechanical damage to fruits can also cause their abortion (Stephenson 1981).

5. ACKNOWLEDGEMENTS

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3.8 PHYSIOLOGICAL AND DENDROCHRONOLOGICAL INDICATIONS OF FOREST DECLINE AND THEIR APPLICATION FOR MONITORING*

L. Kairiukstis

Environment Program
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, AUSTRIA

and

J. Grigaliunas, L. Skuodiene and V. Stravinskiene

Lithuanian Scientific Research
Institute of Forestry
Girionys, Kaunas,
Lithuanian SSR, USSR

Abstract

This paper is concerned with the feasibility to apply an integrated approach which includes physiological, dendrochronological and forestry methods for early indication of forest decline attributed to air pollution. It is determined that the physiological state of trees under a situation of stress is established according to the function of potassium ions (K^+) and potassium residue (K_2O) in annual rings, which in turn are strongly correlated with ring width indices. The express-method elaborated can be used for early indication of forest decline. The tree-rings and high increment chronologies established provide explicit retrospective and prognostic information of forest decline under the background impact of climatic factors. Examples of the application in practice of such methods in the Lithuanian SSR are also given.

1. INTRODUCTION

The consequences of air pollution caused by industrial emissions are clearly visible. In many regions, in particular in developed countries, forests suffer from air pollution (Nilsson, 1987). Due to pollution, the productivity of the forest and its ecological sustainability is diminishing. At higher concentrations of pollutions, not only single stands or more sensitive wood species, but also entire forests in large regions are dying out (Materna, 1987). The situation with respect to air pollution is most alarming, and if permitted to continue, could result in untold damage to the forest ecosystem as a whole.

The Manifest of the *IXth World Forest Congress* (Mexico, 1985), the Declaration of the *XVIII IUFRO World Congress* (Ljubljana, Yugoslavia, 1986) and also the Report of the International Conference on *Acidification and its Policy Implications*, organized

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*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

by the Government of the Netherlands in cooperation with UN-ECE (Amsterdam, 1986), made an unanimous appeal to nations and governments for international cooperation to combat air pollution and to protect the environment and forest as a very important natural renewable resource.

At the same time, there is inadequate knowledge of physiological processes in trees as caused by air pollution and other processes. With the aid of the present visual methods, forest damage is noted too late when the process is inveterate. Therefore, for monitoring of forest decline, appropriate early indication methods are needed. Methods of early assessment which are capable of predicting the dynamics of forest growth attributed to air pollution should warn us about the adverse response of stands to environment contamination in advance. Early indications of damages and prognoses of possible consequences should be made available to assist policy makers in further shaping abatement policies.

2. OBJECTIVE, METHODOLOGY, ANALYSIS

Having objectives to estimate as early as possible forest damage attributed to air pollution, we investigated the following tasks:

- The assessment of the physiological state of trees in "stress" situations due to atmospheric pollution as well as in "stress" situations due to mutual interaction among trees in the process of ecosystem formation. It was assumed that the "stress" situation occurs instantaneously (t_1) and may be detected by physiological, biochemical and energetical changes in cells. The process of adaptation to stressors can take a long time (t_3) and lead to different consequences. It determines the intensity of tree differentiation in growth development and even causes death when absolute discordance of metabolic reactions occurs. Also, it was assumed that in both of the above situations certain typical deflection in cell metabolism under stress reveals considerable changes in structural composition of albumin and phyto-hormones and also that this process can be related with the function of potassium ions (K^+) which is comparatively easy to detect.

- Dendrochronological and chemo-ingrediental indications of forest decline due to atmospheric pollutions. It was assumed that changes in biochemical and physiological state of trees due to acting stressors (pollutants, etc.) can be retrospectively detected over a long time-period through changes in tree rings both a) physically by measuring the tree-ring width and density and b) by estimating the potassium residue (K_2O), in the annual ring. Yearly occuring climatic fluctuations in this case which impact tree growth must be taken into consideration and filtered by dendrochronological methods.

- Finally, we studied the feasibility to connect early indications of stress reactions and adaptation with the biometrical and morphological parameters such as current height increment of trees aiming to apply the tree height increment to monitor forest decline. This was made because, first, the height increment in comparison with radial increment, at least for young and middle-aged trees, is a more sensitive index for assessment of forest damage; second, the natural variation of the height increment under the same conditions of growth is less significant than that in the radial increment. Finally, the height increment is the most reliable forestry index and is easy to measure without professional experience. Also, a medium time-scale (t_2) is used to detect tree height increment changes, and are still enough for a policy operation: to take counter measures (to combat pollution, etc.).

The main scheme of the components for assessment of stress reaction attributed to air pollution and ecoclimatic background fluctuations is given in Figure 1.

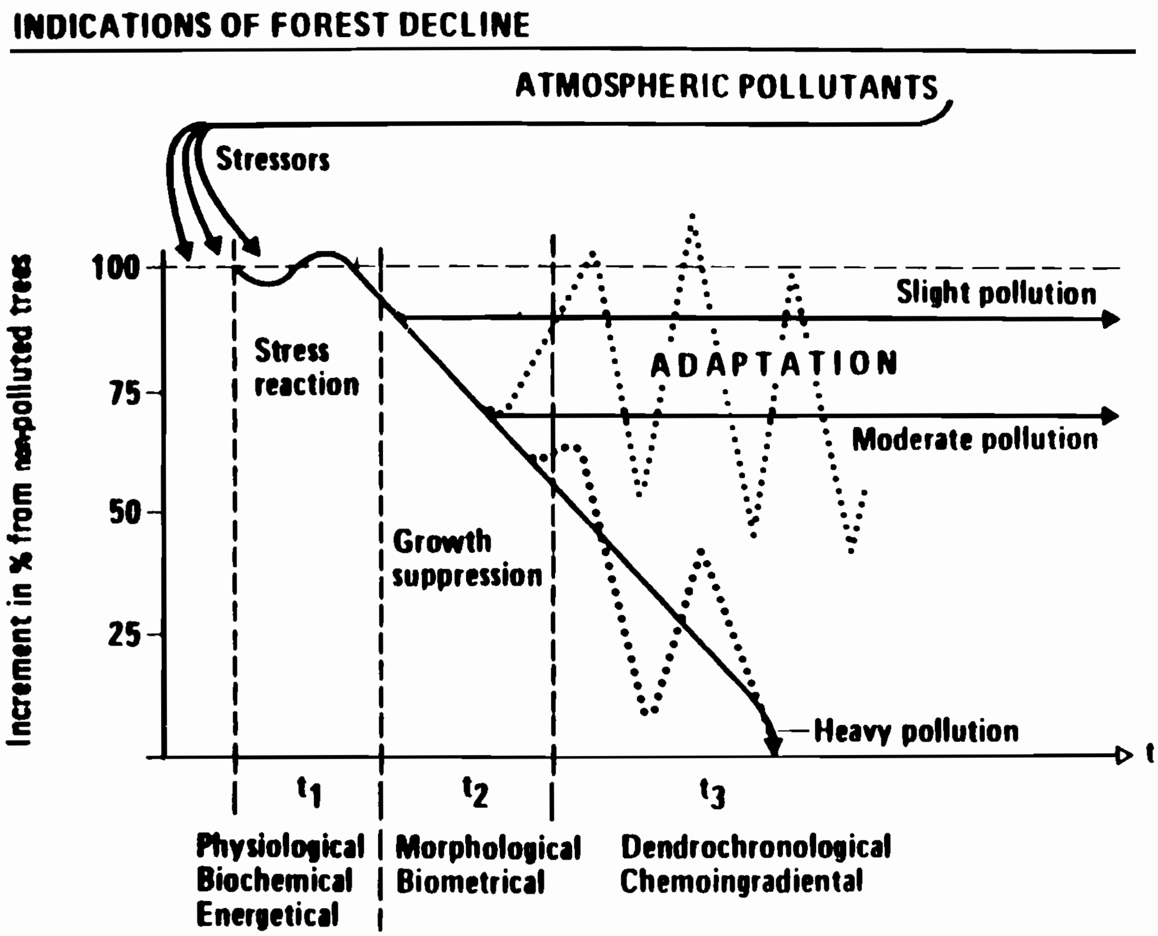

Figure 1. Main scheme of physiologico-biochemical, forestry-biometrical and dendrochronological-chemico-ingrediental assessement of stress reaction, growth suppression and adaptation of trees attributed to air pollution and ecoclimatic background fluctuations.

2.1 Evaluation of the Physiological State of Trees in the Initial Stage of Damage

The transition of substances in plants is regulated with the aid of cell membranes. They perform this function by passive and active transition of substances. Active transition of substances is a more intricate process since it requires a biological energy source within the cells. The source of energy which catalyzes the substance transition against the concentration gradient is a hydrolysis of the molecules of adenosinetriphosphate (ATP). However, for a continuous synthesis of ATP molecules, K^+ ions are needed. According to the data gained in laboratory experience, the cells of plants lose potassium when toxic substances are added in the nutritional environment. This holds true for the conditions of air pollution by chemical substances as well (Udovenko, 1976, 1979; Kairiukstis and Skuodiene, 1984). With an increase in K^+ ions permeability through membranes of cells, the interrelationship between the biological processes requiring intensive substance exchange is noted during the growth of pollen tubes in the early phases of seed germination (Robinson and Jaffe, 1973; Weisenseel and Jaffe, 1976). Owing to potassium losses the energetic potential of substance transmission decreases. Consequently, the organism is provided with less micro and macro-elements. Such a disorder of the energetic balance of cells results in the delay of photosynthesis, breathing, albumin exchange and other functions of immense importance for the production process.

Thus, the suggested method for early assessment of forest decline is based on the physiological state of trees determined by measurement of the quantity of K^+ ions permeated via cell membranes under the impact of industrial emission.

The physiological function of K^+ ions penetrating via cell membranes was determined with the help of the "B-74" ionometer, applying highly sensitive electrodes of "Kritur" type. The quantity of K^+ was calculated according to the standard curves for KCl, the concentration of which comprises from 10^{-1} M to 10^{-6} M, i.e., from 7.455g to 0.0000745g. The optimum magnitude, the volume of the ionized water and duration of measurements were determined experimentally taking into account electrode sensitivity (from 10^{-1}M to 10^{-6}M).

The potassium residue in the radial rings of wood was determined by the flamy-photometric method, based on the dependence of the intensity of element radiation on its content in the sample. For this purpose, the flame photometer FLAPHO 4 was applied. Radial core rings (weighing 50mg) were analyzed. Broadleaved and conifer species such as *Populus tremula L.*, *Quercus robur L.*, *Betula verrucosa L.*, *Picea abies Karst.*, *Pinus silvestris L.*, affected by industrial emission were investigated. The trees were from 50 to 70 years of age. The distance of trees from the source of contamination (1-12km) was taken into consideration.* The trees of the same species growing under normal conditions of background air pollution (control stands) were also considered.

2.2 Dynamics of Radial Tree Increment

Since 1979, the dendrochronological investigations on changes in the radial increment of trees in stands attributed to atmospheric pollution have been carried out. The objective was to elucidate the feasibility of estimating the damage caused by emission of a factory of nitric fertilizers. *Pinus silvestris*, *Picea abies*, *Quercus robur*, *Betula verrucosa*, *Fraxinus excelsior*, *Populus nigra*, *P. tremula*, *P. alba*, *Alnus glutinosa*, *Alnus incana of Vaccinium myrtillus and V. myrtillus/Oxalis* forest types were investigated. The trees of the prevailing classes (according to the classification by L. Kairiukstis (1969)) were selected in 60 experimental plots

*The source of contamination selected was a factory of nitric fertilizers, the emissions of which mainly consist of: sulphurous anhydride, nitric oxides, fluorine combinations, ammonium as well as formaldehide, methanol, carbomide dust, nitrophosphate and amonium nitrate.

allocated in pure or mixed (up to 20% of other species) one-storied stands, the relative density of which was 0.7–0.9. These stands grow in the zone of intensive air pollution (up to 5km from the factory) and less intensive air pollution (from 6.5 to 9.0km from the factory). In each experimental plot, core samples were taken by Pressler perforator in 15-20 damaged trees at breast-height in two directions: North and South. Analogical stands growing outside the contaminated zone as well as standard dendrochronological series of the annual rings (master-chronologies) for most of the above-mentioned species were selected for control purposes. They gave information on the base line dynamics of the radial increment outside the zone of impact of contamination caused by industrial emission. The core samples were analyzed with the aid of a modified (accuracy ± 0.1mm) "ADDO-x" device by Ecklund. The data of measurements were calculated by computer according to standard programs.

The data of the local meteorological stations were applied for analyzing the results. The mean climatic indices calculated for the whole territory of Lithuania in the period 1893-1985 enabled the general climatic background to be evaluated.

The growth of the control stands (base line) in favorable or unfavorable climatic periods was compared to that of damaged stands. The analysis of the meteorological data in these periods gave us a possibility to determine damage due to air pollution under certain climatic conditions.

2.2 Evaluation of Tree Height Increment

The conditions of stand growth including climatic fluctuations and those occurring due to anthropogenetic influences such as atmospheric pollutants, etc., together affect the radial and tree height increment. A more rapid and susceptible response of height increment to the changed environment is noted because the natural variation of the height increment, under the same conditions of growth, is less significant than that in the radial increment. This suggests that the height increment is a more effective index to assess environmental change. It is expedient to apply the peculiarities of its dynamics to determine suppression due to which this increment decreases. The loss of the increment due to changes in environment may be ascertained by comparing the height increment of stand investigated and the established base line (standard) increment of undamaged stands under analogical conditions.

Let us consider the establishment of a base line of height increment for the particular stands. For the construction of the height increment base line, the assessment method of its dynamics has been carried out. For this purpose, a precise measurement data of the height increment is obtained from tree species with distinctly pronounced verticels. The conifer species such as *Pinus silvestris* and *Picea abies* is most appropriate for this purpose.

The initial information was obtain in the Lithuanian SSR from 43 experimental plots which were allotted in natural and artificial stands unaffected by industrial emission. Silvicultural measures are insignificant in these stands. In each experimental plot, the best developed specimens were selected. With the aid of a telescope graded stem, the height of the verticels was measured accurately up to 60 years of age (starting from the ground surface). At the height of 1.3m of each tree age was determined by boring and up to this height the number of years according to the verticels found. Tree age enabled us to establish calendar years of its planting or the start of its growth from natural regeneration.

Further, the annual height increment (Z_h) and coefficient k_h of each tree were calculated by computer. The coefficient

$$k_h = h_{Z_{h\max}} / A_{Z_{h\max}} ,$$

where $h_{Z_{h\max}}$ is the height at which the height increment is maximal, and $A_{Z_{h\max}}$ is the age at which the height increment is maximal. As can be seen from Table 1, k_h determined the intensity of the height increment up to even 60 years of age.

Table 1: Correlation between height increment of the best developed trees and coefficient k_n for the scotch pine of *Vaccinium myrtillus* forest type.

Age	Interval of k_h	Correlation coefficient r	r^2	$\pm m_r$	$\frac{r}{m_r}$	N	h	σ_h
10	0.21–0.62	0.927	0.8585	0.0098	94.66	209	3.93	1.18
20	0.21–0.62	0.934	0.8714	0.0089	104.93	209	9.27	3.33
30	0.21–0.50	0.806	0.6493	0.0352	22.86	99	12.10	3.00
40	0.21–0.50	0.711	0.5060	0.582	12.22	72	15.09	2.84
50	0.21–0.50	0.603	0.3853	0.0948	6.55	42	17.08	2.27
60	0.21–0.31	0.456	0.2078	0.0264	1.73	9	18.10	0.85

It is seen that the curves of height increment having different k_h do not intersect (Figure 2). Thus coefficient k_h by grouping Z_h can replace the scale of site quality. Coefficient k_h can be readily measured in trees or calculated by regression. This is its superiority over other methods.

The height of trees at different ages (h_A) was smoothed with the help of the formula

$$h_A = 10 \cdot k_h \cdot h_B \cdot t_h[aA] \cdot [1.3 - 1.3/(1+A)^b] \ ,$$

where

h_B = the height of a tree at the time when the increment was last measured (basal height);

t_h = the hyperbolic tangent;

A = age;

a, b = parameters of the equation.

The first derivative of formula h_A enables the smoothed height increment to be calculated.

The height increment depends on stand structure, age, the intensity of silvicultural measures, site conditions, climatic factors, and environmental contamination. As mentioned earlier, the peculiarities of stand structure and site conditions are estimated by the value k_h. The impact of silvicultural measures are eliminated when using well-developed trees.

With increasing age, the height increment gradually increases, attains a maximum then decreases. The variation in the decrease phase is noted. Hence, age must be taken into account when estimating the height increment by absolute values.

The variation in height increment due to the dynamics of the climatic fluctuations must also be considered. To reach this objective within the calendar years, Z_h of trees was identified and compared with the approximated indices of the radial increment (Z_r) of trees growing in the same conditions. It was noted that Z_h, having

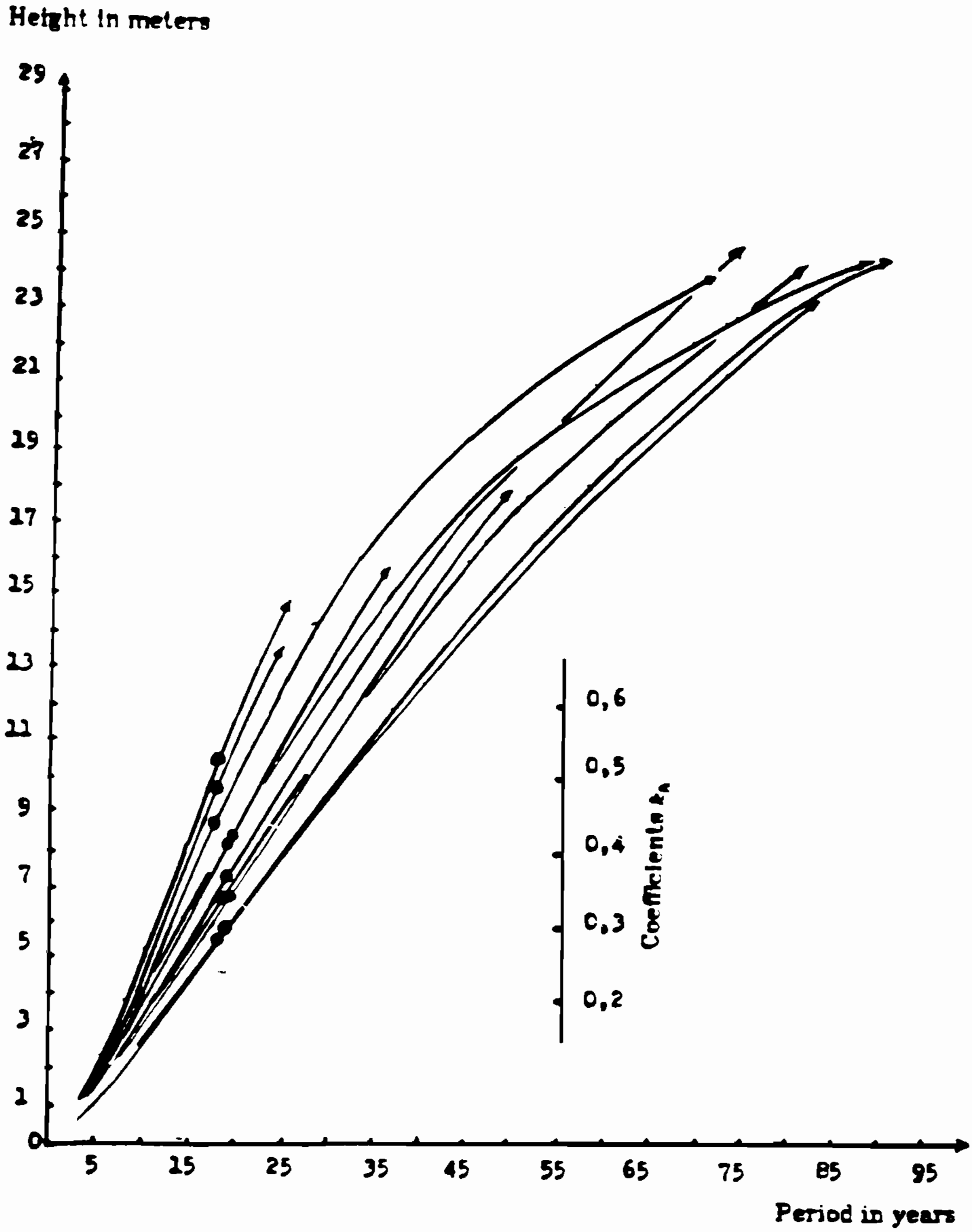

Figure 2. Distribution of curves of the mean height of maximally-growing trees in different experimental plots of scotch pine stands of *Vaccinium myrtillus* forest type depending on k_h.

attained the maximum decreased rather sharply although the indices Z_r increased (Figure 3). In spite of the fluctuation of indices Z_r, the decreasing phase in Z_h (shaded area in Figure 3) always existed. It was proved by analyzing data in all experimental plots. Following the decreasing phase, Z_h sometimes increase vigorously and frequently contradict the phase of indices Z_r. This suggests that for the evaluation of environmental changes in middle-aged and premature forests, beginning with 20–25 year old trees, it is better to apply the values of the variation in the height increment. At that time the effect of biological factors on the height increment diminishes and trees become more sensitive to environmental change.

Following the early variation in Z_h due to biological and phytosociological factors during the cenoses creation, a more significant influence of climatic factors on growth is observed. The dynamics of the height increment and that of indices Z_r become more synchronous. This allows us to assess change in Z_h under the influence of climatic factors and for the required age to determine the actual baseline stand increment which can be used as a comparison with the increment of the stand under investigation.

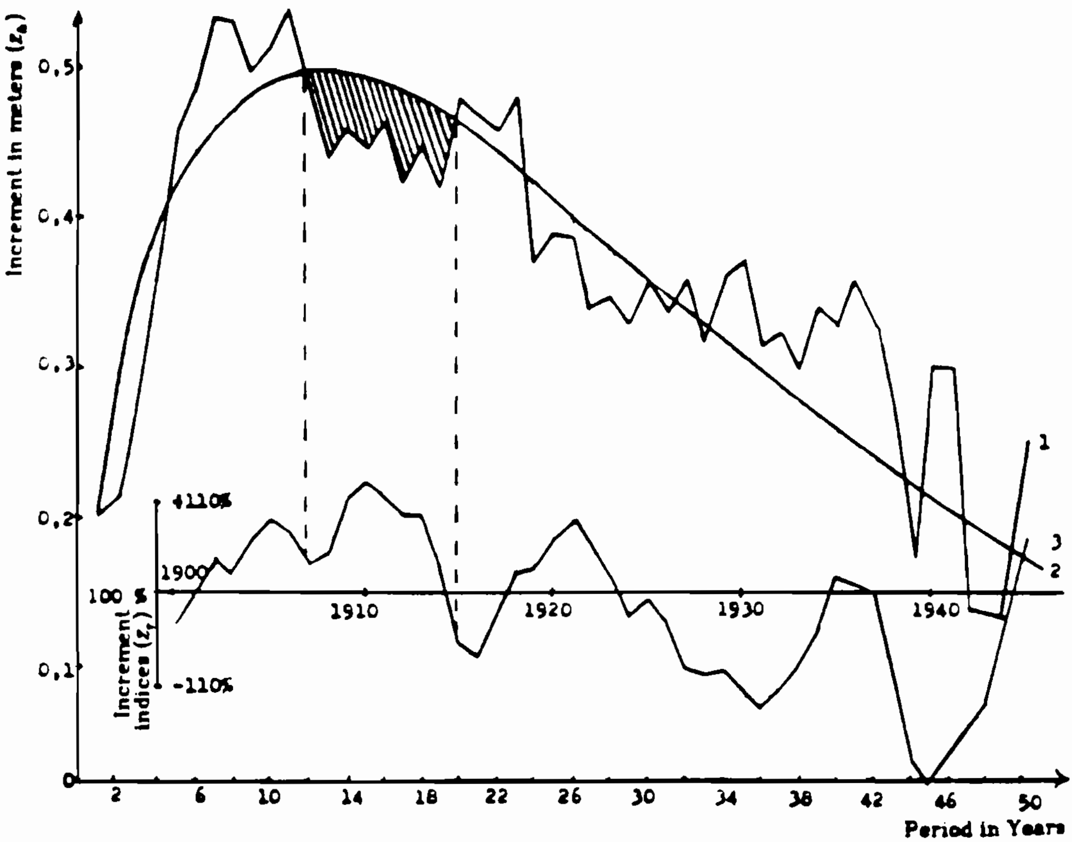

Figure 3. Correlation between empirical (1) and smoothed (2) height increment and between approximated indices (3) of the radial increment on dry sites of scotch pine stands in Lithuania. Shaded area always exists and indicates a decrease in height increment independent of the phase and magnitude of the radial increment indices.

3. RESULTS AND DISCUSSION

3.1 Evaluation of the Physiological State of Trees According to the Penetration of K^+ ions via Cell Membranes

It is determined that ion penetration via cell membranes changes considerably under the impact of industrial emission. The concentration of K^+ ions permeating via cell membranes depends on the species and tree distribution from the source of emission, in other words, from the concentration of pollutants.

It is found that in the heavy polluted zone situation up to 3km from the source of emission, the increase in K^+ penetrated ranges on average of 151.5–187.5% for the broadleaved species (*Q. robur, B. verrucosa, P. tremula*) whereas that for conifers (*P. silvestris, P. abies*), 220.8–225.5% (Figure 4). With increasing distances from the contamination source, the permeability of cell membranes of broadleaved species decreases rather uniformly. At a distance of 6km, cell membrane permeability exceeds the control stands by 106–117%. Although for conifers the loss of K^+ ions tends to decrease, further from the source of emission the loss of K^+ ions compared with the control stands, remains rather significant in the whole 6km zone (142–153%).

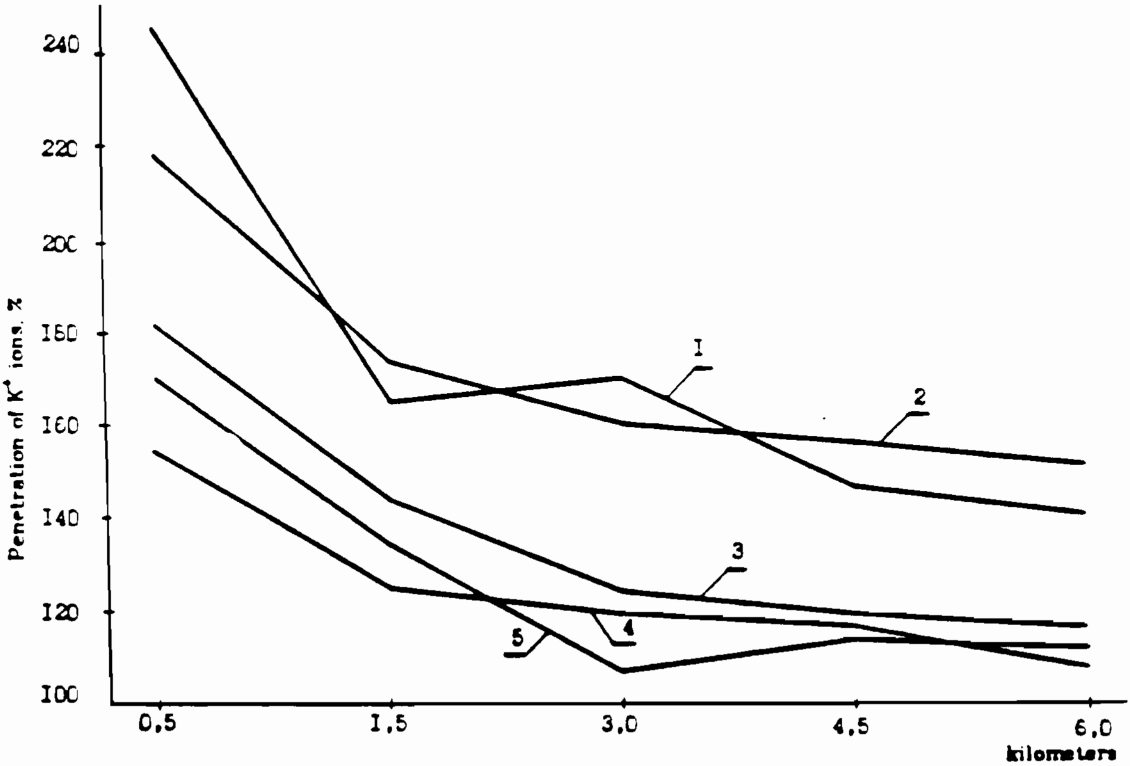

Figure 4. Permeation of K^+ ions via cell membranes depending on the distance from the source of air pollution:
1 = *P. silvestris*; 2 = *P. abies*; 3 = *Q. robur*; 4 = *P. tremula*;
5 = *B. verrucosa*; (100% is accepted as normal for unaffected trees, (i.e., control stands).

Judging by the level and character of K^+ ion penetration, the energetic potential of substance transition (which results in the metabolism of cells for conifers) in the given conditions is subject to significantly greater disorder. Previously obtained data

(Kairiukstis and Skuodiene, 1984, 1986) indicated that in analogical conditions for conifers, particularly for *P. silvestris*, albumin exchange and conversion of nutritious substances decreased considerably. The structure of chlorophyl changes as well. Hence, the trees lose reparational and adaptation ability and their resistance to frost decreases. Under unfavorable climatic conditions which are also fluctuating in time, the impact of chemical air pollution increases. It causes accelerated fall-off of the conifers from the total structure of the forest cenosis.

3.2 The Characteristics of Potassium Residues in Tree Rings

It was elucidated that under the impact of industrial emission, K^+ ion supply was disturbed. Hence, disorder of the energetic potential of transition of substances necessary for the normal growth of trees was observed. This suggests that an interrelationship exists between the potassium residue in wood (tree ring), the radial increment, climatic changes, and the background of industrial contamination. An attempt was made to detect this interrelationship retrospectively.

A comparison of the potassium residue and the radial increment (tree-ring width) of *Pinus silvestris* in the background of dendroclimatic changes was made for the period 1930–1985. It was found that in the period 1930–1967, i.e., before the appearance of industrial emissions in the area investigated, the dynamics and the potassium residue were in conformity with the fluctuations of the radial increment. For instance, maximum content of potassium in wood corresponded to the increase in the radial increment in 1935, 1950, and 1965 (Figure 5). In the course of the whole period till the start of the contamination there was linear dependence of the data of the potassium residue and radial increment on the dendroclimatic curve expressed by the approximated indices of the radial increment.

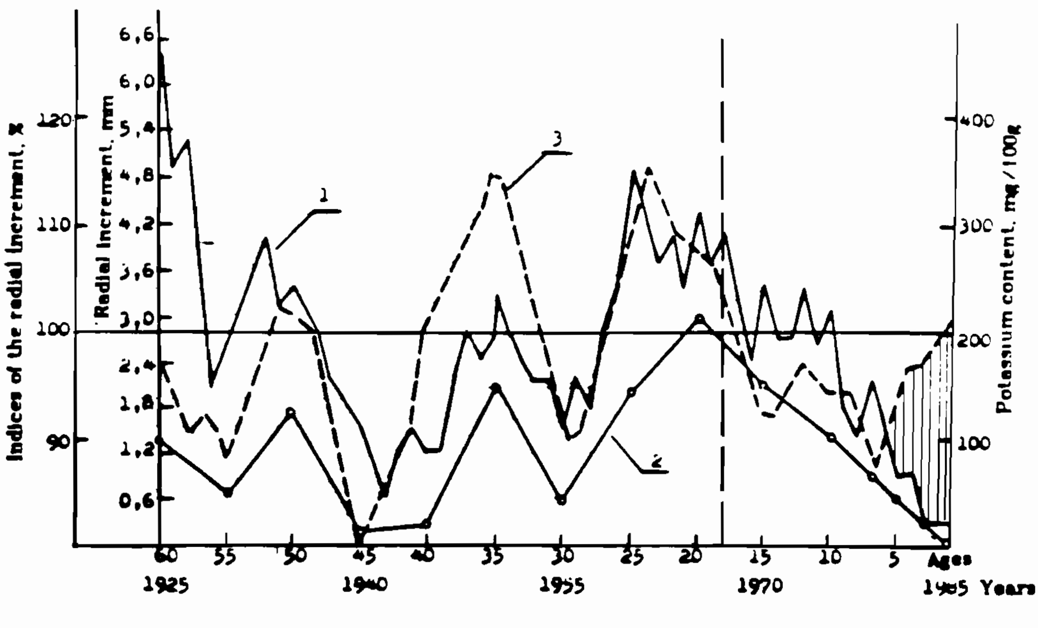

Figure 5. Characteristics of the potassium residue in tree rings in the background of climatic and air pollution changes: 1 = radial increment in mm; 2 = potassium content, mg/100g; 3 = indices of the radial increment, %.

During the period 1967–1985, a new tendency appeared in the correlation between the parameters investigated. Significant rhythmic fluctuations of the radial increment (from 2.43 to 3.04 mm/year) were noted in the course of the first eight years (1969–1977). However, the rest of the the seven-year period was characterized by a considerable fall in increment. Due to industrial emissions, the quantity of potassium residue in tree-rings diminished distinctly as a result of the decreasing potential of substance transition. In the given period the decline of potassium residue and radial increment decrease were noted to have the same tendency but the dendrochronological indices giving base line growth differed to the greatest extent, particularly for the last eight years (the shaded area in Figure 5).

As a result of the foregoing considerations, we can assume that the penetration of K^+ ions via cell membranes and the potassium residue in tree rings may be applied for an early evaluation of forest decline attributed to air pollution.

3.3 Evaluation of the Dynamics of Tree Radial Increment Decrease Attributed to Air Pollution

Tree ring studies (Vins, 1962; Schweingruber, 1986; Cook, 1985; and Kairiukstis and Dubinskaite, 1987; etc.) have proved that dendrochronological methods can be applied for the assessment of forest decline attributed to air pollution. Data collected in the Lithuanian SSR for different species of wood and soil sites indicate that before one or other particular region was polluted (local pollutant sources occurs), the dynamics of the radial increment in conifer stands has a certain fluctuation similar to the 11 and 22-year cycles. The maxima of the increment coincide in periods of significant rise in air temperature whereas the minima coincide in those of temperature fall in the beginning of vegetation. For instance, during the periods 1924–1926, 1936–1937, 1947–1949, air temperature in May was from 10 to 15%, from 10 to 26% and from 18 to 20% higher, respectively, than the mean perennial rate. This resulted in a certain increase of radial increment during these years. A considerable fall in temperature in the beginning of vegetation in the periods 1918–1919, 1928–1929, and 1940–1943 was damaging to the increment of stands investigated.

Following the appearance of anthropogenic pollutants, for example in a region in which the source of pollution was built up in 1967, instead of the last maximum of tree growth according to natural climatic fluctuations in the period of 1973–1975, the minima started. This appeared due to the constant adverse influence of industrial emissions (Figures 6 and 7). In particular, a significant negative impact of industrial emission on conifers was noted during the period 1976–1979. At that time, the radial increment of *P. abies* in the intensive pollution zone decreased from 40 to 60% while that of *P. silvestris* from 30 to 50%. The period 1980–1981 showed a coincidence at the start of the decrease of considerable suppression to which the control stands were subject in the period 1977–1979 due to a sharp rise of solar activity. An increase in the radial increment and improvement of the total state of the damaged stands might be expected. The period 1980–1981 favored growth and the radial increment of the control stands increased by 20% more than the perennial rate. However, the increment of the damaged stands did not attain the previous amount. Under the favorable climatic conditions in 1982, the radial increment of the control stands decreased further. In the period 1983–1984, a maximum annual radial increment of control stands was observed. Despite this, the increment of the damaged stands did not attain the previous level (Figures 5 and 6).

The growth of early, late and annual tree rings (expressed in indices) indicate a conditional stabilization of the radial increment in recent years compared with least values during the period 1978–1982. For a more illustrative comparison of the data a decrease in the radial increment of stands for all species investigated (for conifers at different ages) was established in percent of the control stands.

In 1983 the increment of spruce stands growing in an intensively air polluted zone (at a distance of 5km from the local pollutant source), comprised from 50 to 70% of the annual radial increment, depending on stand age. The same increment values were

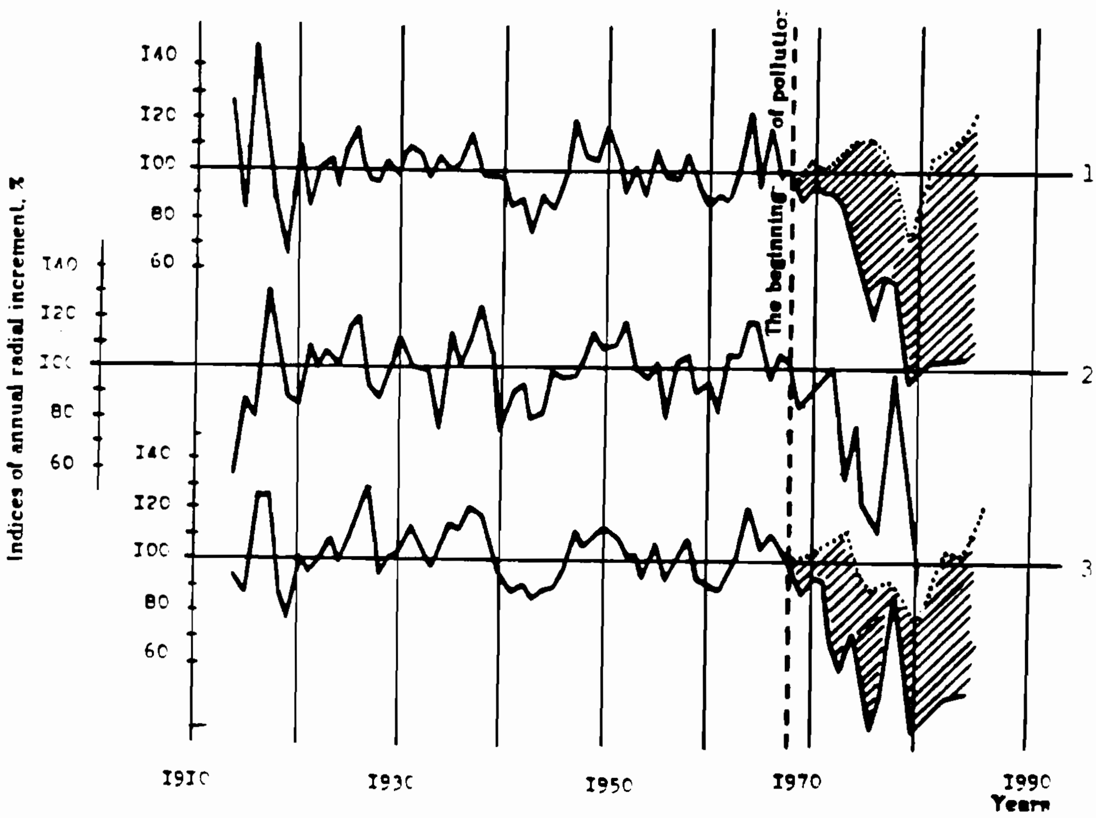

Figure 6. Dynamics of the indices of annual radial increment for *Picea abies* in the intensive air pollution zone:
1 = early wood; 2 = late wood; 3 = annual rings;
/// = loss of radial increment when compared with comparatively unpolluted region (control stands)

obtained during the period 1984–1986. Over a period of 19 years of the activity of the pollutant source (factory), the mean cyclic radial increment of spruce stands aged from 20 to 40 years constituted only 67% of the control stands whereas that of stands aged from 41 to 60 years and from 61 to 80 years, constituted 76 and 86%, respectively. In 1983, the radial increment of pine stands comprised from 55 to 58% of the control stands and in the period 1984–1986 it constituted from 59 to 80% of the control stands. Over a period of 19 years of the activity of the pollutant source, the mean increment according to the age groups of pine stands constituted 72, 79 and 88%.

Broadleaved species are more resistant to air pollution than conifers. In two five-year periods (1968–1977) from the outset of the factory's activities in the intensively-contaminated zone, *Quercus robur*, *Fraxinus excelsior*, *Betula verrucosa*, *P. tremula*, *P. nigra*, *A. glutinosa*, and *A. incana* grew as before. During the period 1978–1982 the increment of the broadleaved trees from 20 to 40 years of age comprised: for *Q. robur* and *F. excelsior* = 75%; for *P. tremula* = 71%; for *B.*

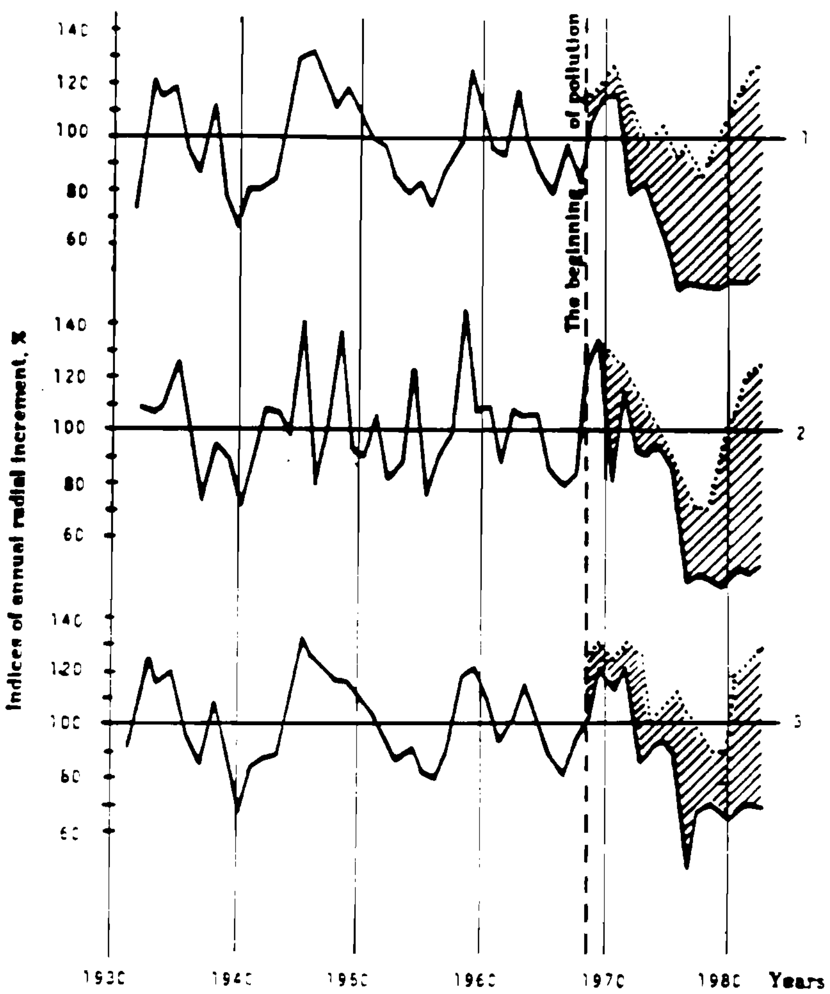

Figure 7. Variation in early (1), late (2), and annual (3) ring width of *Pinus silvestris* in a considerably polluted region.
/// = loss of radial increment when compared with comparatively unpolluted (.....) regions.

verrucosa and *A. glutinosa* = 76% and for A. incana = 79% of the control stands. The increment of the *Populus nigra* hardly changed. During the period 1983–1986 the decrease in increment of broadleaved species stablized relatively to the level of that of the period 1978–1982. Since 1968 in the zone from 6.5 to 9.0 km from the source of air pollution, the increment of *Q. robur* and *A. glutinosa* has been increasing slightly, that of *P. tremula* and *B. verrucosa* has been decreasing insignificantly, while that of *Populus nigra*, *A. glutinosa* and *A. incana* has not shown any essential change in comparison with the control stands. In the average air pollution zone, such a tendency is characteristic of the whole period of a factory's active life as a source of pollution.

Using the cyclical fluctuations of tree ring chronologies, dendrochronological prognoses of tree ring indices were established (Kairiukstis and Dubinskaite, 1986). Taking into account the dynamics of the annual radial increment of trees by the year 2020, it is reasonable to suppose that the dynamics of forest decline due to industrial emissions will be conditioned by the climatic background in the case that the

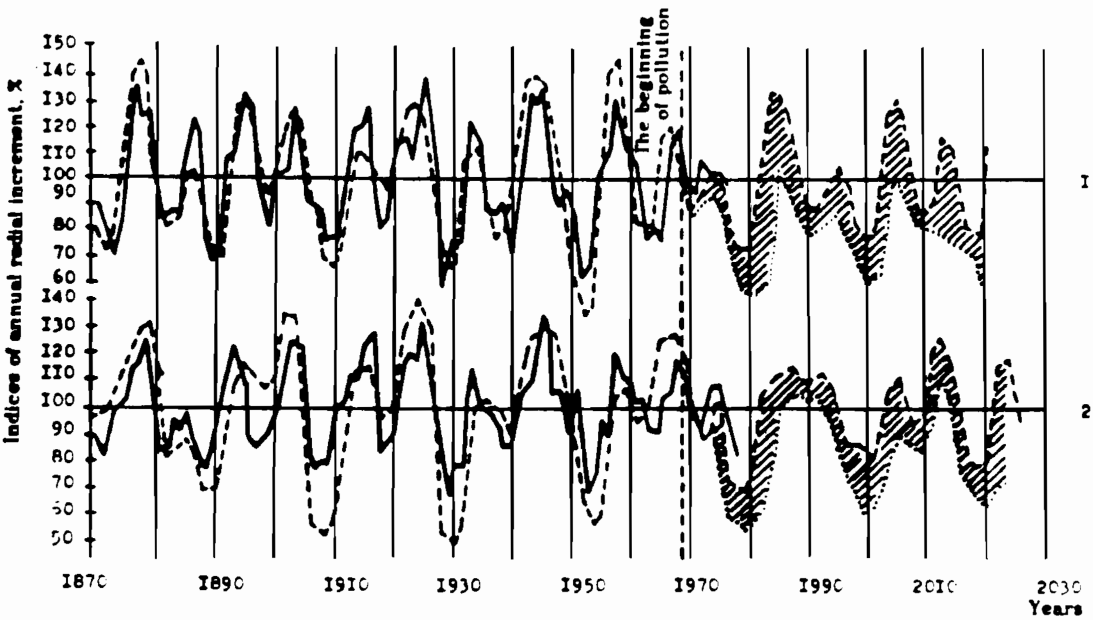

Figure 8 Dynamics of the indices of actual radial increment in pine stands (——) and values of approximating function y(t), (- -).

Damage prognosis in the case when emissions of pollutants remains the same:

1 - pine stands of *Carex/Sphagnum* forest type

2 - pine stands of *Vaccinium myrtillus/Sphagnum type*.

contamination level of the environment remains stable. Consequently, during predicted unfavorable climatic periods (1988–1991, 1999–2001, 2010–2011, 2019–2020) for tree growth the loss of the radial increment will increase. During favorable climatic periods, enhancing the increment of the control, the level of the loss of the radial increment in damaged stands should stabilize and decrease, compared with that during unfavorable periods (Figure 8). With a constant increase in air pollution, the unfavorable climatic background will considerably inhibit the increment and the forest will die.

3.4 Baseline of Tree Height Increments and its Application for the Assessment of Forest Damage

With the aid of the computer, the height increments are divided into groups of age and k_h and into amplitudes and groups of approximated dendrochronological indices of the radial increment of the corresponding site (dry or moist). On the basis of the data obtained, the mean base line height increments are calculated. An extract of the base line increments is shown in Table 2.

The data in Table 2 enables the loss of the height increment by suppression under the impact of environment contamination to be established. For this purpose, the height increment of stands investigated must be compared with the base line height increments established using the above method and presented within the described parameters. The differences obtained indicate abnormal stand growth. Of course, one must be aware of the dynamics of indices Z_r for the period investigated (covering this particular year). Therefore the dendroscale of indices Z_r must be constantly

Table 2: An example of the base line height increments of the best developed trees in *Pinus silvestris* stands of *Vaccinium myrtillus* forest types.

Age		Dendroscale indices (radial increment), %								
A	k_h	−16	−12	−8	−4	0	4	8	12	16
		Height increments, m								
30	0.2	0.30	0.31	0.32	0.34	0.35	0.36	0.37	0.38	0.39
	0.3	0.33	0.34	0.36	0.37	0.37	0.38	0.39	0.40	0.41
	0.4	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44
36	0.2	0.26	0.29	0.31	0.33	0.34	0.35	0.35	0.37	0.38
	0.3	0.28	0.31	0.33	0.35	0.36	0.37	0.38	0.39	0.40
	0.4	0.30	0.33	0.35	0.37	0.38	0.39	0.40	0.41	0.42

supplemented or extrapolated according to the models (Kairiukstis and Dubinskaite, 1986).

The height increments vary in the stands. To establish a more objective evaluation of the loss of height increment due to suppression Z_h, it is necessary to measure increments of several trees precisely by telerelascope or graduated stem. The measured number (n) of trees will depend on changeability (σ) in Z_h; it is possible to determine this according to the standard formula:

$$n = \sigma \frac{2}{Z_h} \cdot t^2 / m^2 g_{z_h} \ ;$$

where t = 1 if probability P = 0.683; t = 1.96 if P = 0.95.

4. CONCLUSIONS

1. As a result of these studies, an express-method of early assessment of forest decline was elaborated. The method is based on K^+ ion permeability via cell membranes and enables one to:
   - establish rapidly and precisely the initial phase of changes in the energetics of cells and in the whole tree under the impact of unfavorable (stress) factors in the environment (air pollution, etc.);
   - assess the the physiological state of trees before the reflection of the consequences of unfavorable impact of the environment on the increment.
2. It was determined that the potassium residue (K_2O) in the radial increment highly correlated with dendrochronological indices of ring width and may be applied to evaluate forest decline attributed to air pollution in the background of climatic and ecological changes.

3. The comparison of the radial increment of trees damaged by air pollution and increment indices taken from undamaged stands or from existing dendrochronological series in the region investigated enabled the start and magnitude of damage to be ascertained and the loss of productivity calculated. The application of dendrochronological series also enabled us to elucidate separately the dynamics of the radial increment decline attributed to air pollution and forest increment dynamics caused by natural ecoclimatic background fluctuations. Dendrochronology also enables us to retrospectively reconstruct long-term pollution impacts on the forest and also to derive a prognosis for the loss of forest productivity if pollution sources in the future remain the same.
4. The analysis of the height increment (Z_h) dynamics of the best developed trees allowed the dendroscales of the height increment dynamics of undamaged stands to be constructed. Following the calibration with dendroscales of the radial increment indices, it is feasible to apply data (Z_h) of these dendroscales to estimate the loss of the height increment attributed to air pollution. To evaluate the suppression Z_h in practice, it is necessary to measure the length of the top shoots (annual increments) of the required number of trees and to establish the age of each tree and coefficient k_h. The application of this method has proven itself in the Lithuanian SSR for damage assessment in conifer forest from 20 to 60 years.

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3.9 TREE-RING ANALYSIS IN THE SWISS FOREST DECLINE STUDY OF 1984*

O.U. Bräker and S. Z'Graggen
Tree-Ring Analysis Research Group
Swiss Federal Institute of Forestry
Research
CH-8903 Birmensdorf, SWITZERLAND

Abstract:

To inventory Swiss forest damage, sample plots of 371 clusters were evaluated in 1984. On each plot one core was taken from one conifer species. The measurements of the ring growth of these cores show in general reductions with increasing needle loss. The decline shifts for spruce are not significant until needle loss reaches 30 % while fir already shows significant shifts in the 15 % class. The shifts have persisted to the present and start in the years 1948, 1956, 1962, 1968; some were triggered by climatic extremes.

1. Introduction:

To evaluate the state of health of the Swiss forests, a terrestrial inventory was made in summer/fall of 1984 by the Swiss Federal Institute of Forestry Research. The aim was to judge canopy condition for the most important tree species on clustered sample plots in a grid system of 4 x 4 km (SCHMID-HAAS, 1985). To save time the inventory was restricted to the public forests and to sites easily accessible by road (48 % of the Swiss forest area). Among various measurements and observations on the trees by forest mensuration techniques, tree cores were taken from one conifer species as a reference on each plot for further evaluation.

2. Tree-core analysis:

The cores were analysed in two different ways:

- by measuring the ring widths on a messuring device (hardware ANIOL coupled to personal computer NCR DM 5, softwsre CATRAS by ANIOL) and
- by the determinstion of abrupt growth changes (SCHWEINGRUBER, 1986).

Of 1575 cores, 1500 (95 %) could be used for interpretation. The species distribution is shown in Fig. 1.

*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

Fig. 1: Species distribution of tree-cores

Spruce	Picea abies	953 cores	63.5 %
Fir	Abies alba	328	21.9
Pine	Pinus silvestris	92	6.1
Larch	Larix decidua	89	5.9
Stone pine	Pinus cembra	30	2.0
Douglas fir	Pseudotsuga menziesii	6	0.4
E. white pine	Pinus strobus	2	0.1
Total		1500	99.9

3. Aims of first investigations:

The main question of growth analysis concentrates on the state of health of the Swiss forest area. Is there any relationship between needle loss and growth ? Are damaged trees growing differently from healthy ones and if so, since when ? In this first presentation, only preliminary results for spruce and fir are presented. The corresponding numbers of related sample plots are given in Fig. 2.

Fig. 2: Species distribution of clusters and sample size

Total Inventory 1984		371 clusters	100.0%	26927 trees
				1000 %0
Spruce	Picea abies	284	76.6	35
Fir	Abies alba	150	40.4	12
Pine	Pinus silvestris	58	15.6	2
Larch	Larix decidua	53	14.3	2
4 species in common		328	88.4	54

4. Relationship between needle loss and growth:

A preliminary study of spruce in the Swiss Central Plateau showed no significant growth differences between needle-loss class 0 (healthy,0-10%) and class 1 (slightly damaged,15-25%). Therefore the total material was differentiated into 5 % needle-loss classes. Furthermore, the total material consisting of canopy social classes 1-4 (dominant, codominant, dominated, suppressed) was reduced to the first two classes. An additional restriction was made by differentiating age classes (SCHOEPFER UND HRADETZKY, 1986), since age class markedly influences growth patterns and needle loss (Fig. 3).

Fig. 3: Growth and needle loss in relation to age classes only social classes 1+2 (dominant and codominant)

age class		<=60	61-80	81-100	101-120	>120	all
Spruce	RW mm	260	211	201	184	150	
	RWE mm	17	11	11	9	5	
	N	96	97	107	99	269	668
	N%	10	10	11	10	28	70%
	NL %	5.6	9.0	10.2	11.3	14.4	
	NLE %	0.8	0.9	0.8	1.0	0.7	
	N%		————	31 %	———		
Fir	RW	300	200	190	129	123	
	RWE	32	19	18	27	12	
	N	35	59	53	23	67	237
	N%	11	18	16	7	20	72%
	NL	4.1	10.9	8.0	14.3	17.5	
	NLE	0.9	1.3	1.2	2.0	1.5	
	N%		————	41 %	———		
Pine	RW	201	97	82	78	41	
	RWE	37	16	17	11	5	
	N	5	12	15	19	25	76
	N%	5	13	16	21	27	83%
	N%		————	50 %	———		
Larch	RW	143	114	69	97	73	
	RWE	58	17	15	23	7	
	N	2	5	11	10	39	67
	N%	2	6	12	11	44	75%
	N%		————	29 %	———		

RW = average ring width of 1983
RWE= standard error of the mean
N = number of observations/cores
N% = percentage of all cores/species
NL = average needle loss 1984
NLE= standard error of the mean
—— = summary percentage of age classes 61-120 years

As the number of observations show, the sample size decreases rapidly with these restrictions. Therefore, for further evaluation of the growth patterns, the age classes 61-120 were chosen as a compromise.

The distribution of needle loss within these reductions of sample sizes is illustrated in Fig. 4. Comparisons with damage percentages of the total inventory 1984 show little deviation of the data subset used.

Fig. 4 Distribution of needle loss and number of cores

species	0-10 %	15-25 %	30-60 %	65-100%	
Spruce	608	260	82	3	953
%	64	27	9	0	100
subset	214	77	17	-	308*
%	69	25	6	-	100
inventory	65	28	6	1	100
Fir	203	93	29	3	328
%	62	28	9	1	100
subset	99	39	11	-	149*
%	66	26	8	-	100
inventory	61	28	9	2	100
1985 inventory all conifers	63	28	8	1	100

* sample size age classes 60-120

5. Growth-ring patterns, long-term trends:

From single core data, average time series were calculated for each 5 % needle loss class from 0 % - 25 %, and for 30-60 %. These average growth curves contain only cores with age classes 61-120 years (for the year 1983) and belong to social class 1 and 2. In addition, the standard error of the mean for each yearly average was also caculated at the level of two sigma.

Since the restricted data set still contains fairly heterogeneous material in each average (various sites, various regional distribution), growth levels between the needle-loss classes also differ for periods considered mostly undisturbed (before 1940). Therefore a homogenising procedure was applied, shifting the average curves to a common mean in the calibration period 1920-1950. The starting year was set to ensure an adequate number of observations. Fig. 5 and 6 show the corresponding normalised average curves.

Although we find decline shifts in the periods after 1944, 1948, 1962 or 1974/76 for spruce, only the needle-loss curve 30-60 % shows significant decline from the 0 % class in the period 1970-today. For fir, the corresponding shifts start in 1948, 1956, 1962 or 1968 (ECKSTEIN et al., 1983; BAUCH et al., 1986) and are already significant for the 15 % class up through all classes to 30-60 % (see Fig. 6).

6. Growth-ring patterns, short-term trends (1970 ff):

Since, among other authors, KONTIC et al. (1986) describe remarkable proportions of recovering trees in most recent times, the following list (Fig. 7) qualifies corresponding growth levels.

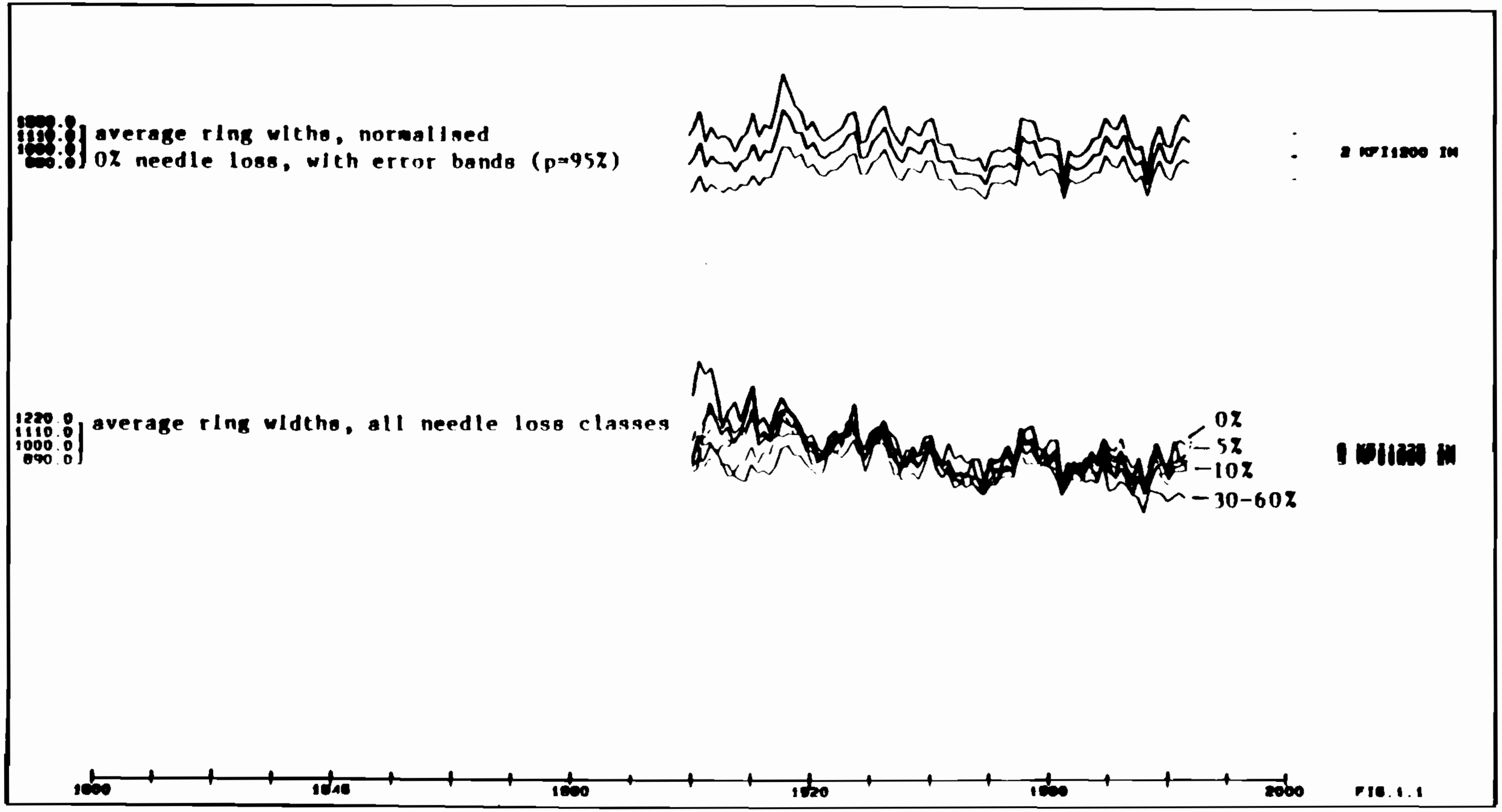

Fig. 5: Average ring width series for spruce, needle losses 0%, 5%, 10%, 15%, 20%, 25%, 30-60%.

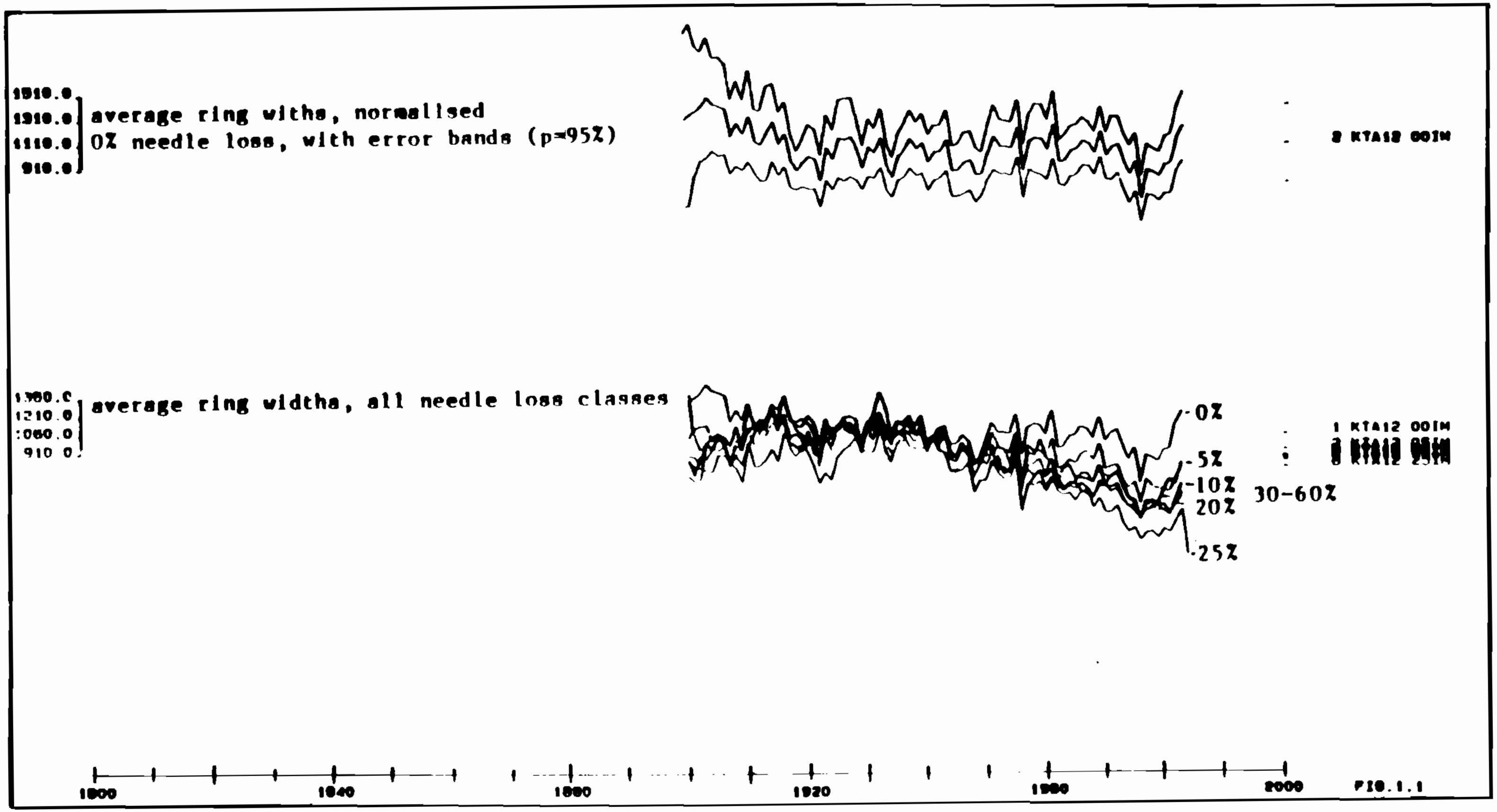

Fig. 6: Average ring width series for fir, needle losses 0%, 5%, 10%, 15%, 20%, 25%, 30-60%.

Fig. 7 Short term trends 1970 - 1983

needle loss	Spruce / Fir
0 %	recovering since 1976, level of late 60's or early 70's or better
5 %	same as 0 %
10 %	recovering, but equal or slightly below early 70's (i.e.fir equals 1974)
15 %	same as 10%
20 %	same as 10 %, apruce equal, fir slighly below
25 %	same as 10 %, spruce sligthly better, fir equal
30-60 %	same as 10 %, spruce below, fir better

7. Abrupt growth changes:

The method determines visuslly clear abrupt growth changes lasting at least 4 years by fixing the starting and ending years. Once disturbed, the growth pattern at the inner end of core, taken as "normal", is never restored, but comprises only depression and/or release phases. For all the cores of a species, these status conditions were summarized by year-by-year frequency counts . A more sophisticated method even considers reduction / release classes of different strengths (according to the estimated % of change in relation to the previous period). The conspicuous annual peaks in the frequency counts are shown in Fig. 8. Most of the years of depression are correlated with climatic stress conditions. But for later interpretation of this averaged yearly information, regional differences in climatical response has to be considered.

Fig. 8 Abrupt growth changes starts

Spruce		Fir	
Depressions	Releases	Depressions	Releases
1920/1922		1921/1922	
1933		1933	
1935	1939		
1944/45/1948	1949-1951	1944/1948	1951
	1955	1956	1961
1962	1963/1966/1969	1962/63	1966
1970/1974		1968/1971	1972
1976	1977	1973/74/1976	1977
	1981	1980	1982

The percentage of cores (all cores for spruce and fir) in depression or release status is shown in Fig. 9 and 10. Since towards the most recent time, more and more cores can have other than normal status, the percentage tends to increase towards the present. Various major oscillations, especially in the depression time range reveal increases in depressions in the periods 1922 ff, 1943-48, 1962 ff, 1974/76 for spruce and 1922 ff, 1944 - 1949 and towards 1976 for fir. Release has more a steady trend, although some jumps in increase are observed in 1951, 1955, 1981 for spruce and at the end of the 40's, 70's and in 1982 for fir.

Since abrupt growth changes do not reflect any steady changes or trends, these data show only the high frequency time domain signal. In 1983 the spruce shows 41 % in normal status, 15 % in depression, and 44 % in release. Corresponding values for fir are 24 % normal, 33 % in depression, and 43 % in release. Firs seem actually to suffer much more than spruce, although the release tendency looks simillar.

The relative number of abrupt growth changes allows calculation of proxy growth patterns in time. But for these curves, the same restrictions are valid as above: only the high frequency information is correct and supports the findings in the measured growth curves. The absolute growth levels should not be compared within nor between the curves.

8. Further research:

Detailed studies on homogeneous material from one or several comparable sites has already been done and has shown significant differences in growth patterns with declines starting already in the 20's, 40's or 50's (SCHNEIDER,O., 1985; HARTMANN,PH., 1986; DUC,PH., personal communication). Most often, climaticly extreme years act as a trigger for decline phases. These declines have persisted to the present and are mostly associated with a high present level of needle loss (medium damage or more). With respect to these findings, further investigations should be based on a larger or more homogeneous data set to ensure valid interpretation.

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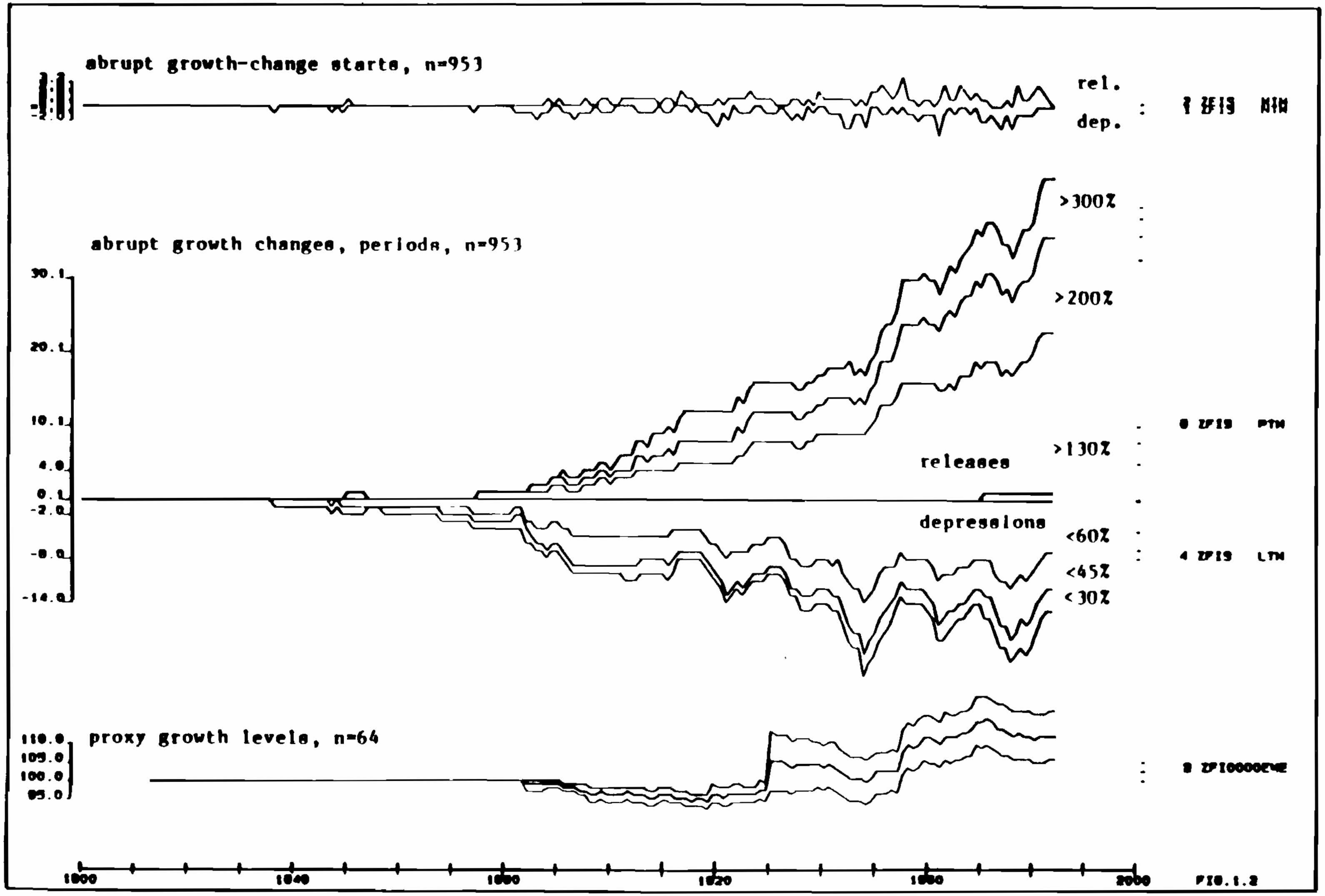

Fig. 9: Abrupt growth changes of spruce, starting years, periods (frequencies) and proxy growth.

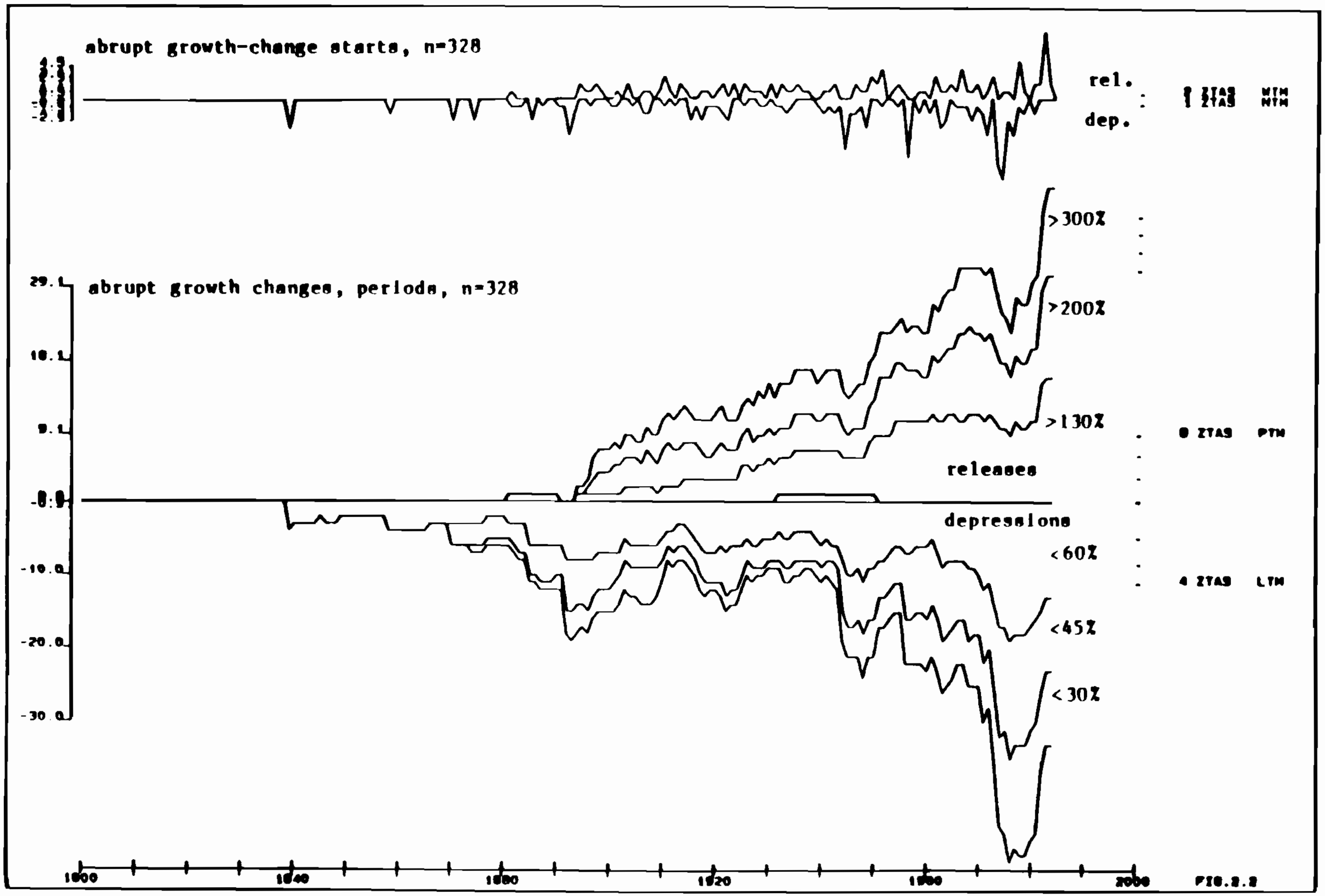

Fig. 10: Abrupt growth changes of fir, starting years, periods (frequencies).

3.10 COMPARATIVE STUDIES ON THE ANNUAL RING PATTERN AND CROWN CONDITION OF CONIFERS (THE VALAIS, SWITZERLAND)*

R. Kontic and A. Winkler-Seifert
Institute of Botany
University of Basel
CH-4000 Basel, SWITZERLAND

ABSTRACT

Three methods of forest damage assessment (annual ring analysis, terrestrial crown assessment, and interpretation of infra-red aerial photographs) are compared. Used alone, the two methods of crown assessment provide only partial findings. Annual ring analysis supplies much information - on the history of forest damage, conditions of site and climate, and the current trend shown by the state of health of the trees - which is indispensible for the interpretation of the crown assessments. It's very much advisable to combine the three methods.

1. INTRODUCTION

In 1983, annual ring analysis were conducted on pines (Pinus silvestris L.) from neighbouring stands (Unterer Pfynwald, Rottensand) with pollution damage but with different site conditions. For purposes of comparison, crown assessments were carried out in 1977 and 1983/84 by means of terrestrial surveys and infra-red aerial photography.

Many of the pines exhibited abrubt growth reductions, in some cases persiting for decades. From 1977 onwards a large proportion of the trees began to recover, obviously because, on the one hand, emissions in the area were considerably reduced, and on the other, weather conditions were particularly favourable. The severe injury at Rottensand, which caused extreme growth reductions, lasting from five to fifteen years (from 1966), in almost all the pines was presumably due to the sinking of the ground water level, while recovery may have been triggered by its rising once more (from 1975).

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2. METHODS

2.1. Annual ring analysis

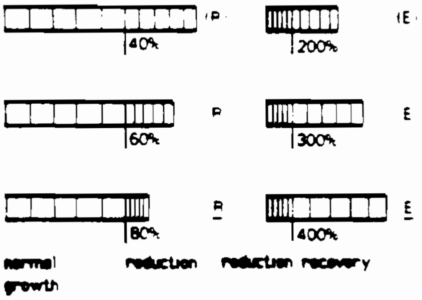

FIGURE 1 System of damage classification used in annual ring analysis. (Schematic diagramm for the quantification of abrupt reduction and recovery evident in tree-ring sequences).

Comment. Changes are calculated as a percentage of the widths of a comparable number of rings before and after the change. The symbols (R), R, and R, and (E), E, and E, represent the degree of reduction or recovery respectively. Trees without reductions or with continuous decrease are classified as healthy ('G').

2.2. Crown assessments

TABLE 1 Systems of damage classification used in terrestrial crown assessment and aerial photographic survey.

Terr. crown assessment	Aerial photography
0 = dense	0 = healthy
1 = transparent	1 = slightly damaged
2 = sparse	2 = moderately damaged
3 = very sparse	3 = severely damaged
4 = bare	4 = dead

Comment. Both methods of crown assessment are based on scales with 5 classes each. Actual assessment, however, is made from different view-points and with different criteria. While terrestrial surveys assess the needle loss, infra-red photography registers changes in the colouring and texture of the tree crowns.

3. SOME RESULTS OF THE COMPARISON OF THE METHODS

3.1. Actual relationship (cf. figure 2)

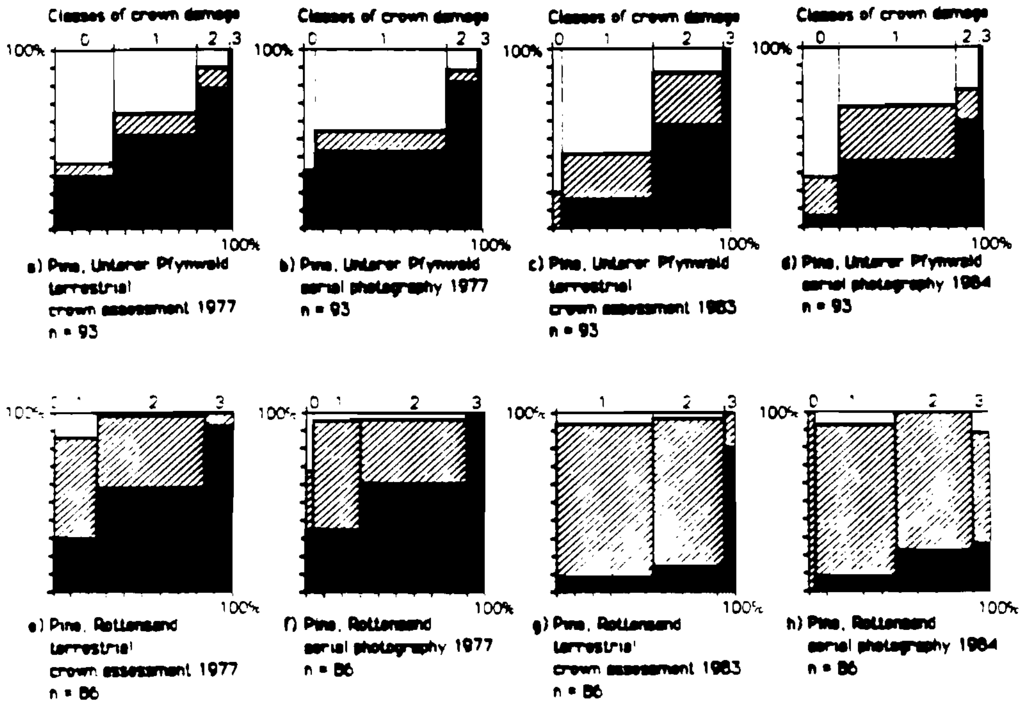

FIGURE 2 Percentages of annual ring sequence classes in pines with differing crown appearance (Unterer Pfynwald and Rottensand).
Annual ring sequence classes: 'G' = white
'E' = hatched
'R' = black
Classes of crown damage: percentages are represented by the width of the corresponding columns
Study material was taken from sites with comparable conditions; both at Unterer Pfynwald (a–d) and Rottensand (e–h) the same trees were sampled.

At Rottensand, where pines grow at the limit of their survival conditions (forest steppe), the mean density of needles was lower in 1983/84 than at Unterer Pfynwald, where growth reduction was much greater.

A tree with a fairly sparse crown growing on a poor site may grow only slowly, but it grows regularly, so that it cannot be regarded as damaged. On the other hand, a tree with a dense crown growing on an optimum site may already exhibit great reduction in wood formation.

On the other hand, it is obvious that very localised conditions, genetic factors, and other, not immediately identifiable influences play an important role in the natural and actual crown condition. Trees with a wide range of needle density and with or without growth reduction may occur within a very small area. Thus, even in the best of cases, it is only possible to detect more or less clear trends reflecting a relationship between crown condition and annual ring pattern; only on average, not in every case, do pines with severe damage exhibit a lower needle density than those with no or only slight growth reduction.

Comparison of crown appearance and annual ring pattern, becomes almost impossible when, as in the case of Rottensand, many (1977, cf. figure 2 e, f) or almost all (1983/84, cf. figure 2 g, h) of the trees, are undergoing a phase of recovery. Nevertheless, the investigation of such trees gave additional indications as to the chronological relationship between annual ring pattern and crown condition (cf. figure 3).

3.2. Chronological relationship (cf. figure 3)

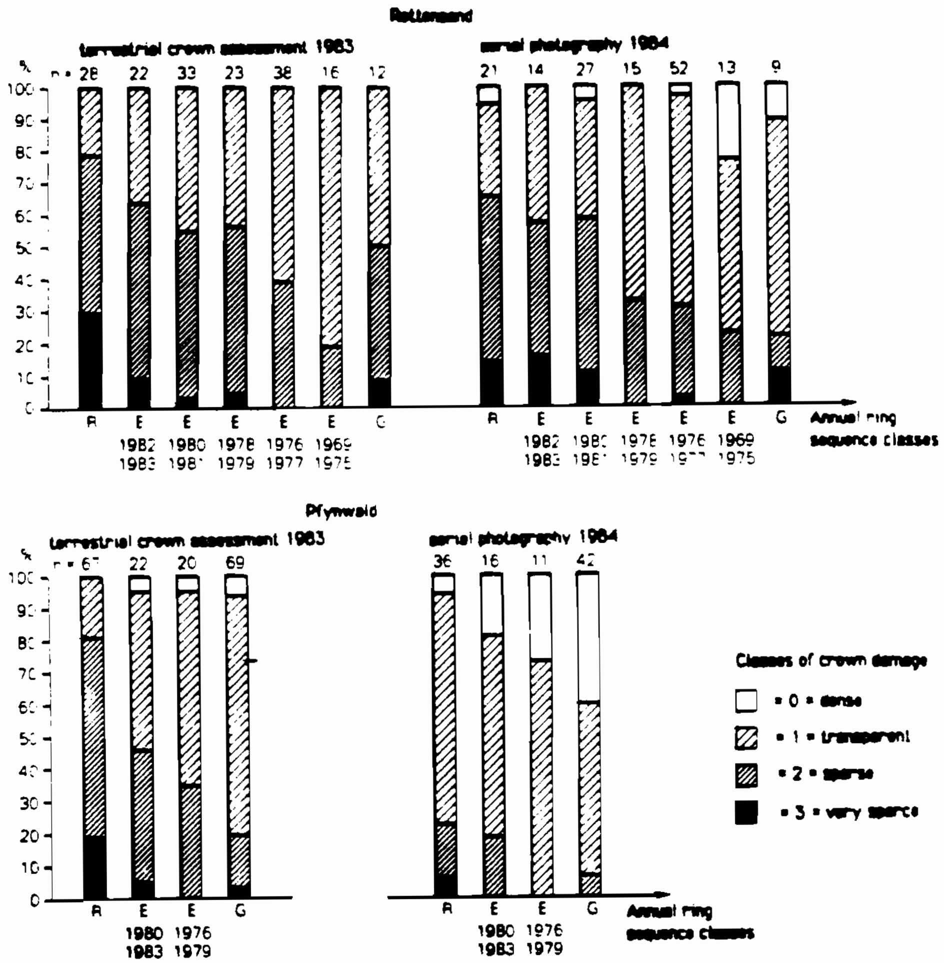

FIGURE 3 Distribution of classes of damage in pines showing long-term or recent recovery ('E'), according to terrestrial crown assessment and aerial photography (Unterer Phynwald and Rottensand). The dates beneath the columns show the onset of recovery phases. For purposes of comparison, the diagramms for pines with and without growth reduction ('R' or 'G') ar included.

In phases of recovery, crown development lags behind that of the annual rings. The diagram illustrates how pines exhibiting recent recovery in the annual ring pattern may still display a general crown appearance similar to that of damaged trees. From the time at which recovery becomes evident in the stem it may take as long as ten years before the crowns of previously damaged pines exhibit a needle density comparable to that of trees without growth reduction.

Firs (Abies alba Miller) and spruces (Picea abies (L.) Karst.) growing in the Valais behave similarly.

Furthermore, in 1977, damaged pines which entered a recovery phase one, two or several years later appeared, on average, just as injured as those which never recovered. Crown condition thus provided no definite criterium for future development.

The study material used did not allow conclusions as to where damage was first manifested in each case, since even the most recent damage occurred long ago.

4. CONCLUSIONS

Positive environmental influences, and propably also negative ones, are manifested in the stem some years before they become evident in the crown. In evaluations on the basis of crown condition alone, trees in good condition, with growth reduction, or with recovery may be confused with each other. Trees which still appear very unhealthy may already have resumed normal growth in the stem, while healthy-looking trees may be unable to benefit from their large mass of needles, and exhibit severe growth reductions. A given density of needles is of varying significance for the condition of the tree, depending on disposition and site conditions. Growth within the stem, however, reflects the physiological importance of the crown density and the "inner reserves" of the individual tree; in other words, annual ring analysis can be used to relativise the results of crown assessments. Studies on firs and spruces in the Valais have produced similar findings. We recommend to combine the three methods.

Furthermore, the differencies between the two methods of crown assessment as well as their subjectivity lead to wide deviations in single tree assessment. Consequently, periodic surveys only allow conclusions on the general trend in the condition of a large number of trees, and even this findings are only valid if the deviations average out, i.e., are not due to systematic errors. Uninterrupted observation during several years is indispensable for reliable single tree assessment.

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COMPARATIVE STUDIES ON THE ANNUAL RING PATTERN AND CROWN CONDITION OF CONIFERS: THE SITUATION IN SWITZERLAND AND SOUTHERN GERMANY. GENERAL CONCLUSIONS

Raymond Kontic
Institute of Botany, University of Basel, 4000 Basel, Switzerland

1. THE SITUATION

In order to assess the physical condition and development of trees or forests, we judge the quality of the crowns on the one hand and the growth of the tree-rings on the other hand. Yet in many cases the forest damage results diagnosed with the help of crown assessment differ quite considerably from the results of the tree-ring analysis of the same trees (12, 17, 22, 25, 27, 28). This remark applies to conifers in particular, as not much research in this respect has been done on deciduous trees.

The average needle density, that is what can be called "normal" for a tree depends on its habitats. It is, for instance, sparser on slopes facing south than on slopes facing north (6, 7, 17). But even within the same habitat it was nearly impossible to distinguish trees with or without growth reduction (or regeneration) with the help of crown assessment alone (18, 19). Individual differences obviously play a role, too.

As a result of our investigation (18, 19) we were able to explain, partly at least, these discrepancies: damage and regeneration are not necessarily reflected in the stem and in the crown; or they may be discovered earlier by the one method than by the other. We were able to prove, for instance, that the stems of trees had recovered years before their crowns. Even trees with an extremely low needle density may be in a phase of growth regeneration.

Many authors think that damages may be discovered earlier by tree-ring analysis than by crown assessment (2, 3, 4, 13, 29). But in the case of spruces a big rate of foliage-loss was found without any growth reduction visible in the stems (9, 17, 24, 26). Thus the one or the other method may be more adequate for the early diagnosis of the physical condition of trees (18, 19).

All these problems are problems of single tree assessment, which is the basis of every damage assessment. If the average assessment of all trees shows a clear tendency, that is if most of the trees with dense crowns develop normally, and if trees with a sparse crown are those who suffer from growth reduction, then the question of the individual differences might be neglected for a nation-wide damage inventory.

But this is not always the case. In nearly every tree-ring analysis that was made in Switzerland (1, 5, 11, 14, 16, 17, 18, 19, 20, 21, 30, 31, 32), more and more trees were found with a more or less considerable growth regeneration in the period after 1976. The same phenomenon was found in Bavaria and in Baden-Württemberg by many authors (9, 12, 15, 23). During this workshop, by the way, this result was confirmed by observations in the Vosges Mountains (Fir, East France, Prof. Muller).

These results all indicate a general improvement of the physical conditions of trees. Analysises of crown condition that were made in the same area, over the same period of time, however, indicated in Switzerland as well as in the Federal Republic of Germany a drastic deterioration of the trees' physical condition in general (8, 10).

People will ask: What's happening in our forests? What can we rely on? Which method is more reliable for the assessment of damage or health?

Do we obtain differing results because the regeneration of crowns does, naturally, lag behind the tree-ring growth? What means growth regeneration? Does it really mean that the trees recover, perhaps because the immission of sulphur dioxide has gone down since 1977? Or are the regenerations of a rather pathological nature? A consequence of the fertilizing effect of nitrogen oxide immissions? Or are the synergetic effects of nitrogen oxide and sulphur dioxide less dangerous nowadays?

2. THE CONCLUSIONS

In the present situation we can't help asking: What is a healthy tree? For the time being and because of the discrepancy of results, we can't say anything definite about the course of development of the forest decline.

Considering all this I recommend the combined application of as many methods of forest damage assessment as possible. And at the same time we should, in scientific talk, avoid such notions as "health, damage, regeneration" as long as we can't define them clearly. Classifications such as "healthy, ailing, sick, dying" or "slightly, moderately, severely damaged" should be replaced by less insidious terms, such as foliage rate or percentage or growth decrease and increase.

These uncertainties would be far less serious, if there wasn't this political dynamite in them. Year after year the press pounce on the latest forest assessment data as if it were the latest football results. I dont want to imply that these data are less important than football results, but the speculations that arise around them are of a much greater political impact.

Those people who are very reluctant to accept all kinds of environmental measures as well as the most convinced environmentalists, scientists included, use these statistics to put on political pressure to prevent or to enforce environmental measures. And this is exactly what these data are not to be used for, because their interpretation is neither plain nor unambiguous.

If we demand environmental measures today, because the physical condition of our forests is more or less deteriorating, what do we demand tomorrow, when they recover, perhaps only for a short period?

Most of the scientific discussion today takes place on the same level as the talk of those who are against environmental measures. This is something we must not permit, because like this we accept their demands for more and more proofs. In order to call for environmental measures we need not prove that our forests are dying from immissions. We don't lose any of our scientific respectability if we make clear that, for the time being, we are not able to say how the situation of our forests will develop. But if we let ourselves in for this insignificant controversy: "Are the forests dying or aren't they" or "How fast are they dying" then we lose our time, our energy, and our reputation.

If we make damage assessments, and we must make them, the first thing we must make clear are the limitations of these methods and the aim of such an inventory.

In the Swiss Forest Damage Assessment 1986 (8) you can read: "The principal aim of this report is to provide the political authorities with the necessary basis for decisions to be taken against the forest decline" (translation). At the moment, this is as impossible as it is unnecessary. Perhaps we'll know more about the reasons and the dynamics of the forest decline in about twenty years. Maybe we have enough time to learn and understand it. But we don't have any time left to demand environmental measures, and we cannot and must not demand them on the basis of our forest damage inventories.

Therefore it is our first task to aim the discussion at the more vital problems: The essential thing for the demand of environmental measures is the fact that there are pollutants which get into the air where they don't belong per definition. This idea alone, that pollutants, no matter how much diluted, may harm the whole environment, not only the forests, must be reason enough to do every possible thing to prevent these immissions or to reduce them as much as ever possible. This demand would be well founded and enforceable, even if our forests were thoroughly healthy.

In many states the law expects the accusers, that is the environmentalists, to prove their case. It is our second task to have these laws changed.

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3.11 DISTURBANCES OF FOREST FUNCTION UNDER THE STRESS OF AIR POLLUTION*

W. Grodziński
Department of Ecosystem Studies
Jagiellonian University
Kraków, POLAND

ABSTRACT

A team project was developed to study the function of large forest ecosystems under the stress of air pollution in southern Poland, and to propose general methods of forest management in industrial regions. The study are includes a complex of lowland pine and deciduous forests (Niepolomice Forest – 11.000 ha) situated 20–40 km east of Kraków. For the last 30 years the forest has been exposed to long-term, moderate-level air pollution, chiefly SO_2, heavy metals and fluorine, emitted by the coal combustion industry in the region. The woodland habitat was already heavily contaminated by sulfur and trace metals, and was also acidified.

The forest was studied as an input-output system: the input was measured as wet and dry atmospheric deposition, whereas the output was measured through the entire woodland watershed. Primary and secondary production and decomposition were evaluated in detail. Different behavior of energy, nutrients (N, P, K, Ca and S) and pollutants (S, Cd, Pb, Zn, Ni, Cr and Cu) was observed and described. The field studies and a simulation model revealed a reduction of the potential photosynthetic activity of pine needles by 13–18%, and of the timber increment by at least 20%, and also an inhibition of litter decomposition by about 20–25% due to the possible inhibition of microbial activity. Consequently, the main disturbances of forest ecosystems in industrial regions concern such basic functions as: cycling of nutrients, primary production, and changes in top soil.

The following practical recommendations were established and are currently in use:

1. to gradually rebuild the pollution-sensitive pine into a more resistant mixed forest;
2. to fertilize the pine carefully from the air;
3. to raise the water-table by ameliorations in order to provide more available nutrients for the roots; and
4. to optimize wildlife management, and to reduce tourist pressure.

A book originating from the project was recently published: *Forest Ecosystems in Industrial Regions*. W. Grodziński, J. Weiner and P.F. Maycock (Eds.), Springer Verlag, Berlin; XVII+227 pp., 116 Figures, 98 Tables.

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3.12 PLANT SUCCESSION IN A MAN-MADE NORWAY SPRUCE ECOSYSTEM ON A CLEAR-CUT AREA AS RELATED TO SOIL PROCESSES AND NUTRIENT BALANCE*

F. Vasicek and E. Klimo
Institute of Forest Ecology
University of Agriculture
Brno, CZECHOSLOVAKIA

ABSTRACT

Studies were made of changes in herb and juvenile woody vegetation under a mature Norway spruce stand and on a clear-cut area. Effects of logging and reforestation practices on the structure of surface humus and physical properties of surface soil layers on the clear-cut area were discussed. Changes were characterized of density and biomass under the influence of thinning in the mature spruce stand and during the progressive stage of secondary succession of the clear-cut vegetation. Succession stages are expressed by aboveground and underground biomass and areal dominance of prevailing species, concentration and supply of bioelements as well as relations to quality and quantity of humus and rate of decomposition.

Keywords: Norway spruce forest ecosystem, clear-cut area, biomass, humus, nutrients.

INTRODUCTION

The study of forest ecosystems using long-term integrated multidisciplinary projects realized on stationary objects (long-term research areas) is carried out in many countries of the world. One of the research projects is conducted by the Institute of Forest Ecology, University of Agriculture, Brno, in the region of the Drahanská Uplands about 30 km north of Brno in Czechoslovakia. Problems of the dynamics of abiotic

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factors, populations of plants and animals, production and various biological processes are the most important questions in the study of relations and functions in the ecosystem.

The problem of plant succession in these studies is, however, studied as a minor one. Processes of changes in plant and animal populations as a result of competition and response of biota to the environment are in a close relation to problems of succession and, therefore, they should be investigated in the ecosystem studies.

The paper presents selected results of the ecosystem study dealing with the several years course of the first stages of secondary plant succession and their relation to soil processes and bioelement balance on a clear-cut area. Changes in the herb layer under a mature Norway spruce pure stand, a part of which was cut, are compared with conditions on the clear-cut area including impacts of management practices on soil and nutrients.

MATERIAL

The forest stand in site conditions of the area under study are characteristic of man-made Norway spruce pure stands in the region of Central Europe (49°26'31'' N, 16°41'30'' E): altitude 625 m, average annual precipitation 683 mm, average temperature 6.6 °C, max precipitation in the summer months, snow cover from November to March, relatively clear atmosphere (17 ug m^{-3} SO_2). Soil: oligotrophic brown soil, loamy with gravel, pH of A horizont 3.7, layer of raw moder 6 cm. Forest type: beech forest with silver fir, sporadic occurrence of herb layer with Carex pilulifera as a characteristic species. Mature stand: 75-year-old Norway spruce monoculture, canopy density 0.9 - 1.0, troughfall 65 - 70% of precipitation, illumination of soil surface 1.5 - 3% of full light, standing volume of large timber (over 7 cm d.o.b.) 480 m^3 per ha.

Clear-cutting was carried out at the beginning of 1977, whole trees with crowns were skidded by wheal tractors along skidding trails. Rforestation of the felled area with Norway spruce was made using a rill planting machine in 1978.

METHODS

Methods usual in production ecology (Evans 1972, Šesták et al. 1971) were used for estimating density and biomass of herb populations and juvenile woody species. In the undergrowth of the mature Norway spruce stand the number of plants was determined by direct counting and the parallel biomass sampling of individual species was done using destructive growth analysis. On the densely overgrown clear-cut area "types of dominance" (Whittaker 1973) easily distinguishable in the terrain according to the prevailling species and amount of aboveground biomass were differentiated every year. The areal proportion of these units was established every year using parallel transects covering the whole clear-cut area in constant intervals. Density and aboveground biomass were sampled according to the types of dominance by destructive sampling (Traczyk 1967) in the period of maximum values of biomass. Some growth-analytical characteristics including the aboveground/underground ratio of phytomass were estimated using specially selected sets of samples of individual species. On 40 permanently fixed plots of 0.5 x 10 m, values of density and dominance of individual species were estimated to express successional changes in figures (Maarel et al. 1985) and spatial changes by means of isopleths (Numata 1982).

Analyses of soil and humus were carried out using standard methods usual in forest pedology. Chemical composition of organic matter was determinated by atomic spectrophotometry. Soil respiration was determined by the absorption gravimetric method using soda lime on the soil surface under a metall bell inserted 8 cm deep into the soil.

RESULTS AND DISCUSSION

Mature Stand

In the undergrowth of the mature Norway spruce stand 44 herb and naturally seeded juvenile woody species were presented in the period under study, viz 10 phanerophytes, 5 chamaephytes, 24 hemicryptophytes, 3 geophytes and 2 therophytes. The number of woody species in the undergrowth in the period 1977-1980 ranged from 62 to 365 individuals per ha. Populations of Picea abies and Sorbus aucuparia from self-seeding showed dominant position. In 1980, thinning was carried out in the spruce stand and a seed year also occurred. About 7.5 x 10^6 Norway spruce seedlings emerged in 1981. In 1982, their number decreased below 1.0 x 10^6 and in 1983 in the second half of the growing season, drought stress occured in surface layers of the soil and the number of plants from self-seeding decreased to 0.46 x 10^6. In 1984, only 2100 spruce plants per ha were found.

The number of herbs in the undergrowth of the mature spruce stand did not exceed 1000 plants per ha in the period 1977 - 1979 (Vašíček 1979). Their number approximately doubled in 1980-1981. In 1983, it increased to 13 000 and in 1984 ca. to 19 000 plants per ha. The effect of thinning became more evident only after 2 years, with the number of heliophilous species increased. The drought stress had no significant effect on the density herb species. Response to thinning expressed in increased density was recprded mainly in Galium scabrum, Chamaenerion angustifolium, Maianthemum bifolium, Mycelis muralis, Oxalis acetosella, Rubus idaeus, Vaccinium myrtillus and Viola sylvatica.

Values of aboveground biomass

	Year							
	1977	1978	1979	1980	1981	1982	1983	1984
Juvenile woody species $g\ ha^{-1}$	3	7	3	4	31 463	4218	2094	85
Herb species $g\ ha^{-1}$	47	71	61	142	223	2798	2019	4026

Clear - cut Area in Conditions Parallel to the Mature Norway Spruce Stand

At the beginning of 1977 whole-tree logging was carried out in a part of the stand leaving only some small brances and foliage on the felled area. In the next year, the area was reforested with Norway spruce in 2 x 2 m spacing by means of a rill planting machine. This practice caused changes in soil surface layers creating specific conditions for secondary succession of plants:

(a) Changes in physical propeties of the soil surface on skidding trails

	Year				
	1976 Before felling	1977	1979	1981	1981 Under herb roots
Bulk density					
skidding trails	1.27	1.79	1.68	1.72	1.50
other area	1.27	1.57	1.51	1.45	1.43
Porosity					
skidding trails	52.15	32.19	35.36	35.14	43.90
other area	52.15	40.65	41.69	45.70	46.80

Physical propeties of the soil on skidding trails are affected mainly in the type of vehicle and the travelling frequency. In the loamy soil of the felled area it may be supposed thad the initial values of soil bulk density and porosity on the skidding trails were restored within 10-15 years. The roots of the clear-cut area vegetation accelerate the process of improving physical properties of soil.

Parts of areas of the skidding trails were at the first stage occupied by the population of Juncus bufonius which decreased its density in 1978 and during 1979 it almost disappeared.

(b) Changes in the structure of surface humus appeared in the felled area. The total supply of organic matter on the soil surface increased from ca. 5.0 kg m^{-2} under the stand to 7.8 kg m^{-2} in the clear-cut area as a result of the fall of small and died branches and needles. Heterogeneity of humus distribution increased: the coefficient of variation (V) under the stand and in the clear-cut area amounted to 15 and 46 percent, respectively. Humus was accumulated in places around stumps and roots and soil wounding occurred as a result of skidding trees. The initial structurr of the L, F and H layers was destructed and mixed. This resulted in the different quality of the surface humus in the clear-cut area.

(c) In the space of the rill planter local changes in the structure of soil surface layers appeared (mineral soil on the ground surface and changes in moisture conditions in the space of rills). Average moisture content in the soil 10 cm below the rill bottom amounted to 21.1 % in the growing season 1978 and 21.8 % in 1979 whereas in the depth of 10 cm below the soil surface outside the rill the moisture content amounted to 19.5 % in 1978 and 18.1 % in 1979 (Prax 1985).

(d) In the first 2 years after felling the stand microbial activity of humus decomposers considerably increased. This is illustrated by values of CO_2 production during soil respiration: average values for 1977-1978 in the old stand amounted to 1188 g m^{-2} $year^{-1}$ and in the clear-cut area free of vegetation 1306 g m^{-2} $year^{-1}$ (Grunda 1981). At the same time the decrease of pH and the increased shift of nitrates into lower horizons occured.

This preparatory stage of plant succession lasting for about 2 years is charactrized by the slight occurence of remaining vegetation from the old stand and temporary occupation of skidding trails with Juncus bufonius. Uptake of nutrients was very low. This fact indicates occurence of stress in the turnover of nutrients on the clear-cut area (see Ulrich 1981).

The third year after clear cutting is characterized by the stage of intensive occupation on the clear-cut area by vegetation. In the first half of the growing season 1979, the area was occupied by initial stages of clear-cut area vegetation, maximum density being in the vicinity of reforested rills. Juncus conglomeratus and Picea abies seedlings from natural regeneration, in particular, occupied the edges and sides of the rills more densely than the other area. The vicinity of the rills was occupied mainly with Senecio sylvaticus, Veronica officinalis and Acetosella vulgaris. This initial stage was charactrized as follows: density 8.8 plants per m^2, aboveground biomass DM 5 g per m^2. Maximum proportion in phytomass showed juvenile plants of Rubus idaeus, Calamagrostis epigeios, Carex leporina and Juncus conglomeratus. Chamaenerion angustifolium showed the greatest number of plants but also the smallest phytomass. In the second half of the growing season very rapid growth and development of all clear-cut area vegetation species appeared supported by considerably high precipitation. Chamaenerion angustifolium occupied in the same year the larger part of the area with vigorous fertile plants. Biomass of the herb layer increased by the end of the growing season to several thousands of kg per ha, Chamaenerion angustifolium being a dominant plant.

In 1980, i.e. four years after establishment of the clear-cut area, the stage of full occupation of the area by the herb vegetation and naturally regenerated trees and shrubs began as well as the stage of the optimum development of the clear-cut area vegetation. Changes of areas represented by main types of dominance of the herb layer and areas occupied by woody species as well as bare areas are represented for the period 1980-1984 in Tab.1. During this period 98 plant species occured in the clear-cut area, viz 10 phanerophytes, 7 chamaephytes, 65 hemicryptophytes, 3 geophytes and 14 therophytes.

Out of the total number of species only 9 herb species and 5 naturally regenerated tree and shrub species showed dominant or subdominant position. Othes species occured only sporadicly. Some species, e.g. Epilobium collinum, gradually disappeared from the area, other species disappeared and later appeared again. Of the most represented species the maximum of areal do-

Table 1. Areas covered by herb and woody species in 1980-1984 on the clear-felled area Rájec

(m^2)

Species	1980	1981	1982	1983	1984
Agrostis stolonifera	91	38	43	24	79
Calamagrostis epigeios	537	1 318	1 724	2 916	3 036
Carex leporina	862	475	282	190	64
Carex pallescens	113	70	67	78	54
Carex pilulifera	386	318	232	190	174
Chamaenerion angustifolium	3 315	3 333	3 130	2 316	1 583
Juncus conglomeratus	1 522	2 109	1 390	1 460	1 381
Rubus idaeus	1 305	1 770	2 356	1 843	1 776
Veronica officinallis	115	40	34	24	9
Other herb species	133	5	9	51	11
Herb layer total	8 379	9 476	9 267	9 092	8 156
Areas not covered by vegetation	1 180	254	42	48	73
Areas covered by naturally sown woody species	441	270	691	809	1 256
Areas covered by tree species from planting	-	-	-	51	515
Area total	10 000	10 000	10 000	10 000	10 000

minance was achieved in Juncus conglomeratus in 1981, Chamaenerion angustifolium in 1981 and Rubus idaeus in 1982. Calamagrostis epigeios as the major competitor of all other species increased the occupied area up to the end of the period studied. Other species mentioned in the table, particularly species of the genus Carex, gradually decreased their dominance.

The layer of naturally seeded woody species comprises mainly Betula verrucosa, Sambucus racemosa, Salix caprea and Populus tremula. In 1981, this layer, especially Sambucus racemosa and Salix caprea, was partly reduced by cutting off shoots adjacent to planted Norway spruce but the layer regenerated later again by sprouting. Some groups of naturally regenerated Norway spruce plants, mainly in the southern part of the felled area, grew vigorously and as soon as in 1983 and 1984 they occupied nearly the whole area of the naturally regenerated species. During these years, also planting of target species plays more important role in the occupation of the clear-cut area. Thus the area covered by herb vegetation becomes gradually reduced.

In 1980-1983 the aboveground biomass of the herb layer was approximately 8000 kg ha^{-1} (Tab.2). This corresponded to the undergroud biomass of about 2000 kg ha^{-1} (Tab.3). The abovegroud and underground biomass of breadleaved woody species, the number of aboveground shoots and leaf area are given in Tab. 4. Data for the year 1981 are calculated from places occupied by this layer, and each year thereafter from the whole area. In 1981, a part of young trees was cut off, as mentioned above.

The whole biomass of naturally saded herb and woody vegetation (except for Norway spruce) recorded in the period of a seasonal maximum ranged from 950 to 1167 g m^{-2} in 1980-1983, a peak being in 1981. Of the total amount, 200-276 g m^{-2} accounted for the underground biomass. The proportion of woody plants was 3-6 %.

Density of the herb layer decreased in the order: 1226 (1980) > 916 (1981) > 747 (1982) > 656 (1983) > 355 (1984) plants per m^2. As for species growing in bunches, every shoot was considered an individual. Dynamics of Norway spruce in the felled area was not included in the calculation.

Analysis of the proportion of the total biomass of dominant species related to the total biomass of the herb layer in 1980-1984 showed that Chamaenerion angustifolium accounted for 41.4 % in 1981 and 1982 but its proportion decreased to 22.2 % in 1984. Juncus conglomeratus showed maximum proportion of 22.5 % in 1980 but its proportion decreased to 4.9 % in 1984. The proportion of Rubus idaeus increased from 19.9 % in 1980 to 31.9 % in 1984. The same applies to Calamagrostis epigeios, the proportion of which 6.2 % in 1981 increased and reached 38.1 % in 1984, thus becoming an absolute dominant species.

Table 2. Aboveground biomass of the herb layer at the time of seasonal maximum in the clear-felled area Rájec in 1979-1984 ($kg\ ha^{-1}$ DM)

Species	1979	1980	1981	1982	1983	1984
Agrostis stolonifera	-	42.6	17.5	26.9	56.0	37.8
Calamagrostis epigeios	18.3	796.1	622.2	1 339.8	1 743.3	1 506.5
Carex leporina	4.1	467.8	182.0	74.4	46.4	8.8
Carex pallescens	0.3	95.9	55.3	10.9	16.3	26.9
Carex pilulifera	1.1	353.7	251.6	89.5	53.6	11.7
Chamaenerion angustifolium	1.0	2 857.0	3 393.0	3 130.5	2 311.8	732.3
Juncus conglomeratus	3.2	1 813.4	1 748.3	980.1	936.3	161.7
Rubus idaeus	20.2	1 798.6	2 148.2	2 342.8	2 022.9	1 178.1
Veronica officinalis	-	68.7	42.7	7.0	4.8	1.2
Other herb species	1.7	54.7	58.8	13.6	7.9	1.1
Herb layer total	49.9	8 345.5	8 519.6	8 015.5	7 199.3	3 666.1

Table 3. Underground biomass of the herb layer at the time of seasonal maximum in the clear-felled area Rájec in 1979-1984

($kg\ ha^{-1}$ DM)

Species	1979	1980	1981	1982	1983	1984
Agrostis stolonifera	-	19.6	8.1	12.4	25.8	17.4
Calamagrostis epigeios	3.0	95.5	74.7	160.8	209.2	180.8
Carex leporina	1.9	191.8	74.6	30.5	19.0	3.6
Carex pallescens	0.1	52.8	30.4	6.0	9.0	14.8
Carex pilulifera	0.6	137.9	98.1	34.9	20.9	4.6
Chamaenerion angustifolium	0.2	971.5	1 153.6	1 064.4	786.0	249.0
Juncus conglomeratus	1.3	633.7	611.9	340.3	327.7	56.6
Rubus idaeus	5.1	359.8	373.2	468.6	404.6	235.6
Veronica officinalis	-	34.3	8.5	3.5	2.4	0.6
Others	0.3	18.8	20.3	4.9	2.8	0.4
Herb layer total	12.5	2 515.7	2 453.4	2 126.3	1 807.4	763.4

Table 4. Basic productional characteristics of the layer of naturally seeded woody species on the clear-felled area Rájec in 1981–1984

Biomass in DM

Year	Species		Aboveground biomass total	From it leaf biomass	Underground biomass	Biomass total	Leaf area	Number of shoots
			kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	m^2 ha^{-1}	Ind. ha^{-1}
1981	Betula verrucosa		5.7	1.6	1.7	7.4	18.0	15
	Salix caprea		67.9	14.4	23.9	91.8	202.5	425
	Sambucus racemosa		294.5	122.9	274.4	568.9	2 260.0	1 500
	Populus tremula		18.5	4.8	8.6	27.1	76.0	182
		Σ	386.6	143.7	308.6	695.2	2 556.5	2 122
1982	Betula verrucosa		44.9	10.8	9.6	54.5	140.2	147
	Salix caprea		20.6	4.2	8.2	28.8	57.7	225
	Sambucus racemosa		88.8	107.2	110.0	196.8	188.7	1 065
	Populus tremula		34.5	7.6	12.6	47.0	94.5	279
		Σ	188.8	129.8	140.4	327.1	481.1	1 716
1983	Betula verrucosa		75.7	15.7	9.4	85.1	224.8	124
	Salix caprea		22.5	4.3	10.2	32.7	57.3	306
	Sambucus racemosa		160.0	76.7	154.5	314.4	1 404.2	1 023
	Populus tremula		28.0	6.2	10.6	38.5	77.3	231
		Σ	286.2	102.9	184.7	470.7	1 763.6	1 684
1984	Betula verrucosa		93.3	21.8	14.5	107.8	383.0	153
	Salix caprea		37.5	7.9	12.2	49.7	108.0	150
	Sambucus racemosa		68.5	24.0	66.6	135.1	442.3	564
	Populus tremula		100.6	87.5	25.7	126.4	509.8	1 023
		Σ	299.9	141.2	119.0	419.0	1 443.1	1 890

From the viewpoint of clear-cut area vegetation and its development the period 1980-1983 can be regarded as the optimum stage. The values of the total biomass were relatively steady and preponderance of Calamagrostis epigeios over other herb species was evident. The proportion of naturally regenerated woody species was relatively uniform and had no marked effect on the growth of herbs.

In this optimum stage of development, soil processes and bioelement cycling acquire new qualities in the conditions of the clear-cut area. The distribution of populations of the dominant species is to some extent related to the state of humus layer on the soil surface. Bioelement fixation by the herb layer is very high compared with fixation by the mature stand.

	Bioelement							
	N	P	K	Ca	Mg	S	Fe	Mn
Mature Norway spruce stand in 1981 $kg\ ha^{-1}$	58	11	42	66	7	12	6	19
Herb vegetation of the clear-cut area 1981 $kg\ ha^{-1}$	221	28	176	28	28	12	5	17

According to the table, considerably higher values of bioelement uptake (N, P, K, Mg) were recorded in the felled area vegetation. Calcium is fixed more intensively by the mature stand. Bioelement concentration in herb tissues of various species is very different. Of the dominant herb species, the highest concentration in the aboveground biomass was recorded in N, viz Chamaenerion angustifolium 3.45 %, Rubus idaeus 2.03 %, Calamagrostis epigeios 1.47 % and Juncus conglomeratus 0.77 % DM. The total bioelement supply in the aboveground and underground biomass of the herb layer per ha in the period 1980-1984 is given in Tab.5 which provides further information on the input of elements into the process of decomposition. Control analysis of N concentration in selected herb species was made in 1983 and 1984 to compare the results with those obtained in 1980 and 1981. For example, in Chamaenerion angustofolium N concentration decreased from 3.45 % in 1981 to 1.23 % in 1984, in Rubus idaeus the drop was from 2.03 % in 1981 to 1.32 % in 1984. N concentration in the aboveground biomass of calamagrostis epigeios was in 1984 at the level of 1981. This indicates that changes in N concentration in the upper soil layers bring about changes in N concentration in some plant species.

At this optimum stage of the development of felled area vege-

Table 5. Supply of bioelements in DM of the herb layer phytomass in the period of seasonal maximum in 1980–1984. Clear-felled area Rájec.

(kg ha^{-1})

Year	N	P	K	Na	Ca	Mg	S	Mn	Fe	Zn	Cu 10^{-3}		Ash	Biomass DM
Aboveground														
1980	172.87	26.61	240.68	0.49	23.95	18.71	10.29	14.97	1.99	0.64	0.08	411.08	471.92	8,345.68
1981	194.21	23.35	143.37	0.50	27.29	20.97	10.28	15.51	1.99	0.66	0.09	438.12	473.90	8,519.64
1982	167.29	21.81	130.54	0.28	26.18	19.62	9.46	14.77	1.75	0.59	0.08	412.37	454.25	8,015.53
1983	103.71	18.16	111.47	0.26	21.12	15.60	8.43	13.15	1.62	0.51	0.07	294.30	407.29	7,199.28
1984	55.54	7.94	50.78	0.06	9.31	6.64	4.06	6.79	0.90	0.23	0.03	142.32	212.27	3,666.04
Underground														
1980	33.79	4.40	30.45	0.79	5.71	3.76	2.19	1.52	3.10	0.24	0.03	85.90	203.10	2,515.57
1981	26.90	4.75	32.72	0.67	6.45	3.63	2.06	1.36	2.72	0.21	0.02	81.68	191.73	2,509.64
1982	23.74	4.37	28.23	0.45	5.69	3.31	1.55	1.28	1.70	0.20	0.02	70.74	145.98	2,128.90
1983	19.91	3.31	22.62	0.40	4.53	2.68	1.36	1.18	1.66	0.20	0.02	57.97	129.69	1,607.41
1984	8.56	1.37	8.17	0.13	1.67	1.03	0.51	0.66	0.59	0.12	0.01	22.62	262.54	763.29

tation, more intensive process of organic matter decomposition occurs owing to the input of herb dead matter into the decomposition chain. Comparisons of soil respiration in the Calamagrostis epigeios population in the clear-cut area and under the mature Norway spruce stand in 1981 and 1982 showed, that the average production of CO_2 was 1826 and 1160 g m^{-2} $year^{-1}$, respectively. Cellulose decomposition under the spruce stand and in the felled area amounted to 3.18 and 6.54 mg per day per g, respectively. Rapid decrease of surface humus occurs in spite of increased contributions of dead herb matter. In 1978, immediately after clear cutting, the average supply of surface humus was 78 027, in 1981 it decreased to 57 850 and in 1983 the supply was only 10 369 kg ha^{-1}. Bioelement supply in A_o- horizon in the clear-cut area in 1983 compared with the supply under the mature stand as well as supply simulated according to the state under the mature stand and subjected to felled-area conditions without herb input into the decomposition process is given in Tab. 6. Low supply of bioelements in the A_o- horizon in the felled area occupied by vegetation was induced by rapid decomposition, nutrient uptake by vegetation and their leaching to lower horizons. This promotes higher concentrations of some elements prodominantly in F and H humus layers in the clear-cut area compared to the concentrations under Norway sprucestand, mainly in N and K.

Humus amount and quality and concentration of available nutrients in A_1 horizon increased under the influence of vegetation during the optimum stage of succession in the felled area.

Decline in phytomass production of herbs and decrease in N concentration in biomass of some herb species recorded in 1984 together with rapid growth to the retarding effect of the target species on production represents the beginning of the further stage in the development of felled area vegetation in which the target woody species will become dominant.

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Table 6.

Total supply of bioelements in A_0 horizon on the clear-felled area and in the stand in 1983 - Rájec

(kg ha^{-1})

	N	P	K	Ca	Mn	Fe	S
Clear-felled area 1983	145	13	36	29	18	16	11
Norway spruce stand	756	47	66	66	?	263	65
Simulated area +	444	42	91	43	21	?	37

+ Area with the same A_0 horizon structure as under the stand but located on the clear-felled area (without vegetation influence)

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4. ANALYSIS AND MODELLING OF TREE AND FOREST DYNAMICS

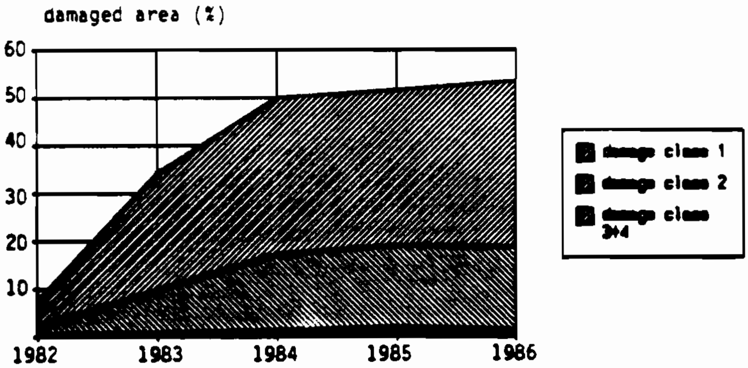
4.1 MODELLING THE DYNAMIC PROCESS OF TREE DIEBACK FOR SPRUCE*

H. Bossel, H. Krieger, H. Schäfer and N. Trost
Environmental Systems Analysis Group
University of Kassel
D-3500 Kassel, FEDERAL REPUBLIC OF GERMANY

1. THE DYNAMICS OF FOREST DAMAGE: OBSERVATIONS AND SOME CONCLUSIONS

Forest damage in Western Europe has progressed from a rare phenomenon to an existential threat in a very few years. For the development of a coherent strategy of forest damage control, it is essential that not only the causes but also the dynamics of the phenomenon be understood. The dynamics observed are determined (a) by the dynamics of stress factors (pollutants, biotic causes) and (b) by the dynamic response of the forest ecosystem - in particular, trees - to these external forcing functions. A better understanding of the dynamics of this system can come from the construction and use of dynamic simulation models. This paper focusses on modelling the tree as a system and on studying its response to impairment of leaf and/or root functions. If tree processes are modelled correctly, then some correspondence between simulation results and tree dieback observations should be expected.

The temporal development of forest damage in the Federal Republic of Germany since 1982 (the first year of an annual national survey) is shown in Fig. 1. The method of assessment was standardized in 1984; data before 1984 are not very reliable and probably too low. The slowing down of the rate of increase of forest damage after 1984 is a result of the cool and moist weather conditions causing optimal growth conditions which partially compensated the negative effects of immissions.



1-weak damage (11-25% foliage loss and/or discoloration)
2-medium damage (26-60% foliage loss)
3-heavy damage (more than 60% foliage loss)
4-dead (deadwood already removed is not accounted for!)

FIG. 1 Temporal development of forest damage in F.R. Germany. (after BSFV 1983, BML 1986)

The rapid progress of tree dieback becomes especially obvious in the data from permanent observation sites (Fig. 2) (Moosmayer et al. 1984, Schröter et al 1986).

*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

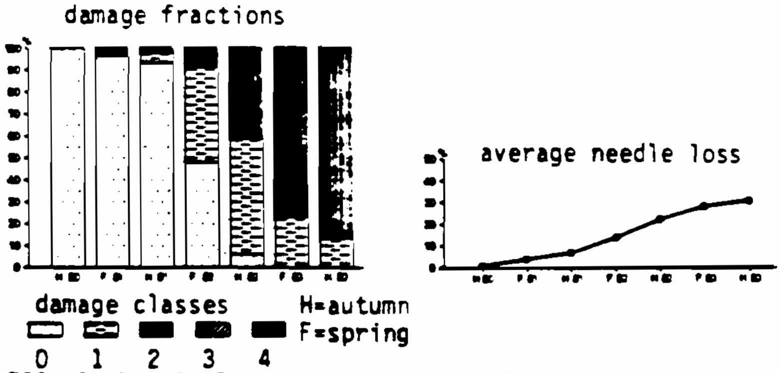


FIG. 2 Needle loss and dieback development of spruce in mixed stands. (Moosmayer et al. 1984)

Dieback affects all forest tree species, but it is more severe in older stands than in younger stands (Fig. 3). This obvious age-dependence of the degree of damage points (a) to age-dependent responses to pollution stress, and (b) to cumulative processes in the development of the disease.

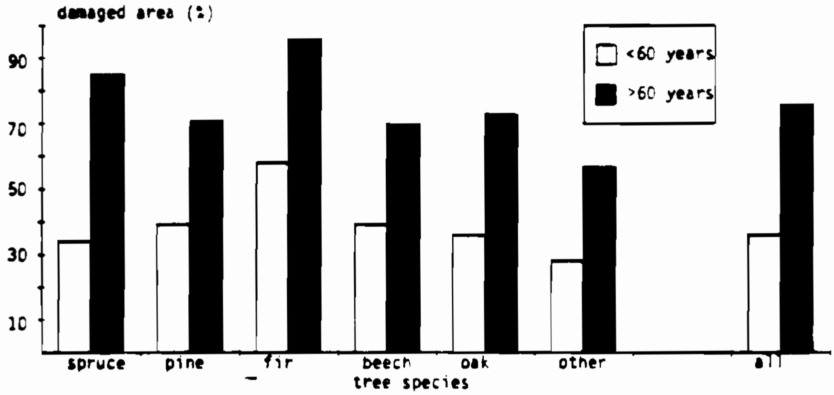


FIG. 3 Fraction of damaged trees in the younger and older age classes. (after BML 1986)

Data from other European countries show that forest dieback is not an isolated phenomenon, and that it is most severe in the central European countries (Tab. 1).

TABLE 1 Forest damage in Europe (damaged forest area in percent).

Finland	35	Great Britain	6-20	German D. R.	?
Norway	?	Netherlands	50	Poland	26
Sweden	?	Belgium	?	CSSR	27
Danmark	4	Luxemburg	52	Austria	26
Ireland	?	France	24	Hungary	11
Spain	?	Switzerland	36	Yugoslavia	10
Portugal	?	F. R. Germany	52	Greece	?

(after Giesen 1986)

Empirical data show dependence of the damage state on different factors: the social position of singular trees (dominant trees show the most severe damage, Kenk et al. 1984), stand structure (higher damage at forest edge and in stands having nonuniform height structure and/or reduced crown closure; Schöpfer/Hradetzky 1984), altitude (damage increases with altitude, FBWL 1986), and exposition (less damage in areas protected from prevailing winds, Schöpfer/Hradetzky 1984). Higher exposure to airborne pollutants therefore increases damage intensity.

These facts, as well as the well-known damage symptoms (Braun 1984, Wentzel 1985), and empirical data on the physiological reactions of plants to pollutant immissions (IMA-QS 1986, Jäger/Weigel/Grünhage 1986, Kozlowski/Constantinidou 1986a,b) all point to air pollution as a significant, if not the exclusive cause of forest dieback. Biotic causes and other factors (radiation, climatic extremes etc.) can now be excluded with certainty as primary causes (Schütt 1985, BML 1986, FBWL 1986, Moosmayer 1986, PEF 1986). Nutrient deficiencies (Mg, K, Ca, Zn, Mn) often observed in connection with forest damage are not causes, but rather symptoms and consequences of immission loads (leaching of basic cations from foliage and soil) (Hüttl 1985, Zöttl 1985, Evers 1986).

The site-specific damage symptoms and damage dynamics lead to the conclusion that no single cause or pollutant is responsible for the observed damage, but that rather region-specific combinations and concentrations of air-borne pollutants together with the specific site factors combine in complex ways to initiate a more or less rapid deterioration process not just of the individual tree or forest stand, but rather of the complete ecosystem (Manion 1981, MELUF-BW 1986).

The hypotheses explaining pollution-induced forest dieback can be grouped in two categories according to the location of primary damage:

(1) Hypotheses assuming direct effects of pollutants on assimilation organs (Ashmore/Bell/Rutter 1985, Schütt/Cowling 1985, Wentzel 1985); and

(2) Hypotheses assuming damage to feeder roots from the release of toxic metal ions resulting from soil acidification (Ulrich 1986), resp. damage to mycorrhiza from nitrogen oversupply (Meyer 1985, Nihlgard 1985, Schütt/Cowling 1985).

Obviously, these effects should not be viewed in isolation from each other (Ulrich/Matzner 1983).

New findings of tree growth studies have revealed a reduction of annual increment (tree ring width and terminal shoot length) in formerly seemingly healthy, but now damaged trees beginning in the late 1950's and early 1960's (Fig. 4) (Adams et al. 1985, Aldinger/Kremer 1985, Franz/Röhle 1985, Greve et al. 1986, Köhler/Stratmann 1986). Although on first sight this appears to be in disagreement with the temporal progress of forest damage (cf. Fig. 1), these observations reveal that visible tree damage is only the final stage of a process which has reduced the vitality of trees for many years.

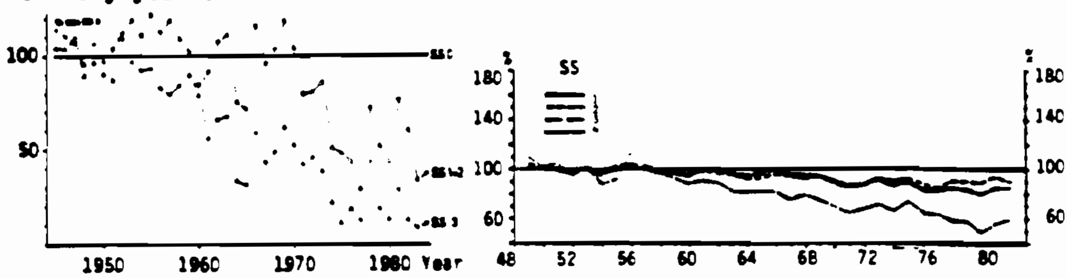


Fig. 4 Terminal shoot development in healthy and damaged beech (SS = damage classes) (left) (from Roloff 1985) and increment in healthy and damaged spruce (from Kenk/Unfried/Evers/Hildebrand 1984).

2. MODELLING TREE PROCESSES AND RESPONSE TO POLLUTION

The tree is a living system. The dynamic effects of leaf or root impairment on the life processes of the tree can only be studied by looking at the tree as a dynamic system composed of many interrelated and functionally different components. Empirical observations clearly show that forest dieback occurs at the level of the individual tree, not the stand as a whole. The proper level for analysis, therefore, is the individual tree.

We have developed several computer simulation models at various levels of complexity describing tree growth dynamics in the absence and presence of pollution damage. These models range from a simple qualitative model with no seasonal effects (BAUMTOD model, Bossel 1985), to a quantitative model of a coniferous tree (SPRUCE model; Bossel/Kretschmer/Schäfer 1985 and Bossel 1986), to a similar model including soil water, mineralization and soil chemistry (IAGM model; Bossel/Metzler/Schäfer 1985), to a complex model for a deciduous tree (BEECH model, Schäfer/Bossel/Krieger/Trost 1986). Although they differ widely in their complexity, these models have a similar structure describing the life processes of the tree. We have found that the dynamic response of the tree is mainly determined by this structure - adding submodels of the soil components does not change the response characteristics. The overall structure will therefore be briefly described before we point out differences in the model formulations and describe some characteristic results.

The approach used in all models is to model essential processes of tree development, and to study how impairment of essential functions (photosynthesis, feeder root renewal) affects this development. Hence, no attempt is made to model the effect of pollutants themselves on leaves or feeder roots. Instead it is assumed that (due to air pollutants or other causes) (1) the photosynthetic capacity of the foliage is reduced by a certain percentage, and/or that (2) the feeder root turnover (replacement) rate is increased by a certain factor. In the simulations, these damage factors can be freely specified as functions of time. This approach avoids the discussion about which pollutants are to blame for what damage, and it focusses the analysis on the issue of how trees may react dynamically to chronic impairment of leaf or feeder root functions. In particular, it can address the question of whether the system structure may indeed allow sudden collapse as a result of constant chronic leaf or root impairment, as it is now observed in our forests.

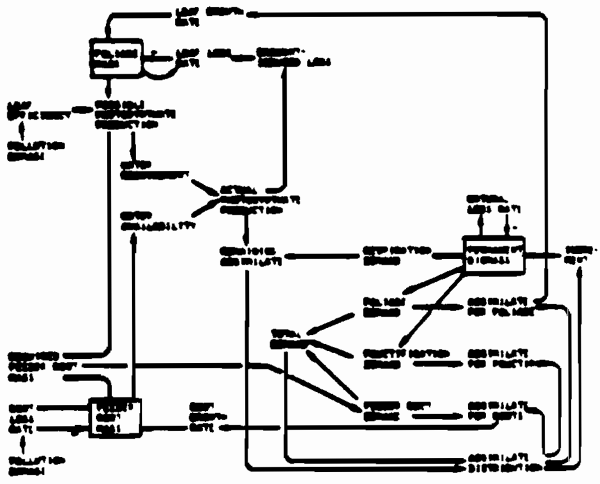


FIG. 5 Basic structure of tree models.

The essential state variables (boxes in Fig. 5) are the foliage mass, the feeder root mass, and the permanent biomass (stem, branches, coarse roots). The possible photosynthate production follows from foliage mass and the specific photosynthetic productivity of the leaves. The latter may be reduced due to the effects of pollutants, leading to a lower possible photosynthate production. This production requires a certain amount of transpiration flow from the feeder roots to supply it with the necessary water and nutrients, and hence a certain amount of feeder root mass must be available to supply this flow. This required feeder root mass may or may not be available. If it is unavailable, then the transpiration flow will be correspondingly reduced, leading to an actual photosynthate production which is lower than the possible production.

The assimilate produced is partly used for respiration of leaves, stem, and roots. The remaining asimilate is available for distribution to leaf growth, feeder root growth, fructification, and biomass increment. The corresponding assimilate demands are a function of the current biomass (which requires a certain amount of foliage), of the current feeder root requirement (which is strongly affected by the feeder root turnover rate as a function of pollution), and of the fructification demand (as a function of biomass). If the remaining assimilate is more than enough to meet these demands there will be wood increment. If the demands cannot be met, the assimilate supplies to each of these functions are reduced in proportion to the available amount, and no assimilate will be available for increment.

The possible effects of pollutants enter this system in two ways: (1) the decrease in specific photoproductivity of the leaves reduces the available photosynthate, and (2) a higher feeder root turnover rate drains the assimilate pool. If insufficient assimilate is available to replace this feeder root drain, then the feeder root mass becomes smaller than required for full photosynthetic production, and the assimilate production is reduced correspondingly, leading to further aggravation of the problem.

The actual model formulations are considerably more complex than indicated in this overview. While the BAUMTOD model is qualitative, the SPRUCE, IAGM, and BEECH models are entirely based on empirical data for the different processes (e.g. specific photoproduction as a function of light and temperature, transpiration coefficient, respiration demands, etc.).

The objective of the relatively simple BAUMTOD model (Bossel 1985, 1986) is the study of the possible behavioral modes of the tree resulting from its most important structural elements and their interconnections. If the system structure is indeed responsible for such observed behavior modes as the dieback phenomenon, then this process should be relatively independent of the exact quantification of the model. Hence the model purposely uses relative (normalized) quantities and approximate factors. No seasonal variations of radiation, leaf and root growth are introduced.

It is possible in principle that a more accurate representation of the tree system could lead to different conclusions than were found using the BAUMTOD model. In order to gain clarity concerning this point, a more realistic model was developed for conifers. The SPRUCE model (Bossel/Kretschmer/Schäfer 1985, Bossel 1986) is fully based on empirical data, uses absolute variables, accounts for the seasonal effects of insolation, temperature, leaf and feeder root growth and loss, and assimilate production and requirements. The constantly changing assimilate supply is computed as a separate state variable. The needle mass is computed by keeping track of the needle mass in each needle age group, and their individual losses and gains during the year. Needle damage is assumed to be a cumulative process affecting the photosynthetic efficiency of the needles. These are shed when the efficiency drops below a certain (empirical) limit. Needle damage therefore also results in premature loss of needles and fewer needle age classes. Losses of biomass, foliage, and feeder roots may occur either due to insufficient assimilate supply for respiration, or due to insufficient water supply. Where necessary, nonlinear functions based on empirical observations are used.

The tree as a system is interacting strongly with its environment, in particular the forest soil from which it draws its water and nutrients, and where its litter is mineralized. The soil chemistry is modified by pollutant immissions, thereby changing nutrient availability, ion flows, acidity and root environment. In the **IAGM** model (Bossel/Metzler/Schäfer 1985), additional submodels for mineralization, soil water, and soil chemistry were added to a simplified SPRUCE model (no needle age classes) in order to investigate the possible effects of soil processes on tree dynamics. In the **mineralization** submodel, the ammonification and nitrification processes are simulated as functions of soil temperature, soil moisture, and soil pH-value (which determine the activity of the relevant soil microorganisms). In the **soilwater** submodel, the soil water content in the two upper soil layers is determined as a function of precipitation, water withdrawal by roots, field capacity, wilting point, percolation and capillary rise. The soil **chemistry** submodel determines hydrogen, calcium, and aluminum ion concentrations in response to acid deposition and hydrogen ion release during mineralization using a chemical equilibrium model.

If simulation models are to be used for quantitative forest damage forecasts, they must be formulated and validated using real data. It then becomes necessary to take into account the diurnal, even hourly variations of weather and radiation conditions, and to account for water, nutrient, and root penetration gradients in the soil. This high spatial and temporal resolution is achieved in the **BEECH** model, which was developed using a consistent set of empirical data from a single experimental beech stand. The model consists of eight interacting submodels: The submodel **environment** generates the necessary weather and climate data on an hourly basis, presently using weather service data describing the 'average' year. The **photosynthesis** submodel distinguishes between sun leaves and shade leaves and their different photosynthetic response. The **respiration** submodel accounts for maintenance and growth respiration (including ion uptake) in each of 9 structural compartments of the tree. In the **growth** submodel, the assimilate distribution to the different compartments and functions of the tree (renewal of leaves and roots, increment, fructification - a total of 15 state variables) is computed. The distribution of fine, medium, and coarse roots in different soil horizons is accounted for. The **soil water** submodel simulates the soil water budget in 6 soil horizons, accounting for horizontal and vertical diffusion and differentiating between an inner region close to the stem and an outer region. The submodels for **transpiration**, **soil chemistry**, and **mineralization** are still under development and are now being represented by corresponding table functions.

3. THE MODELLING AND SIMULATION METHOD

All of the models were developed using the system-graphic method (Hudetz 1977, Bossel 1981, 1985) which circumvents mathematical formulation and reduces the programming process to entering descriptions of model blocks and connections into the computer using an appropriate software. We are using three of these block-oriented simulation methods for microcomputers and mainframes: ASS (Hudetz 1977, Bossel 1981), DYSYS (Bossel 1985), and DYSS (Frees 1986). The advantage of the system-graphic method is that it enables people with no background in mathematics or programming to develop and run complex simulation models with only a minimum of basic instructions.

System-graphic modelling proceeds in four steps: (1) verbal description of all aspects of the system, (2) drawing of a causal loop diagram, (3) developing this diagram into a simulation diagram having the same system structure by defining and quantifying functional relationships, and (4) reading off the relationships from the simulation diagram and inputting them to the computer by one of the block-oriented methods mentioned. Each of the blocks in the simulation diagram is equivalent to a program statement. In the DYSS method, submodels can be defined as blocks, which makes it easy to develop complex models in a modular fashion. The integration method is chosen according to the task in order to assure the required computational accuracy. Simulation results are presented in graphic or tabular form, and are available as files for further processing.

4. SIMULATION RESULTS

All of the models exhibit the same behavioral modes:
(1) **Growth** for zero or small pollution damage to foliage and/or feeder roots. (The SPRUCE model reproduces growth table data)
(2) **Stagnation** (zero increment) for subcritical pollution damage to foliage and/or feeder roots. (The tree survives 'indefinitely' in this state).
(3) **Breakdown** and death for supercritical pollution damage to foliage and/or feeder roots.

The distinctiveness of these three behavioral modes becomes obvious in phase diagrams: as the pollution damage is increased in successive runs, the state trajectory 'flips' to another of three different paths (Fig. 6).

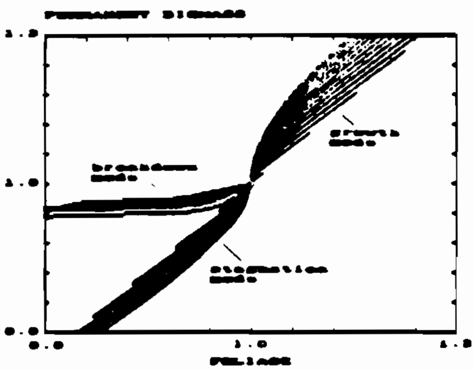


FIG. 6 Three distinct behavioral modes of tree development under stress. (BAUMTOD model, from Bossel 1986)

Another major conclusion from the simulations is the observation that there is little qualitative difference in the tree response to either leaf damage, or root damage. In the first case, assimilate production is reduced, in the second, assimilate consumption is increased. In both cases, the relative assimilate surplus is reduced. If the surplus is sufficient to cover the full respiration and renewal needs, then only the increment will be reduced, but the tree is still in the growth mode. If the damage is subcritical, reducing the increment to zero but allowing renewal needs to be met, the tree will survive (stagnation mode). However, if the assimilate generated cannot fully cover renewal needs, then next year's production is reduced further, respiration needs cannot be covered, and the tree collapses (breakdown mode).

Subcritical pollution damage to foliage and roots can result in a supercritical combined load leading to breakdown. This becomes obvious in stability diagrams such as Fig. 7 showing regions of growth, stagnation, and breakdown as functions of leaf and root damage. These simulation results also show the greater tolerance of younger trees to pollution stress, in agreement with empirical observations.

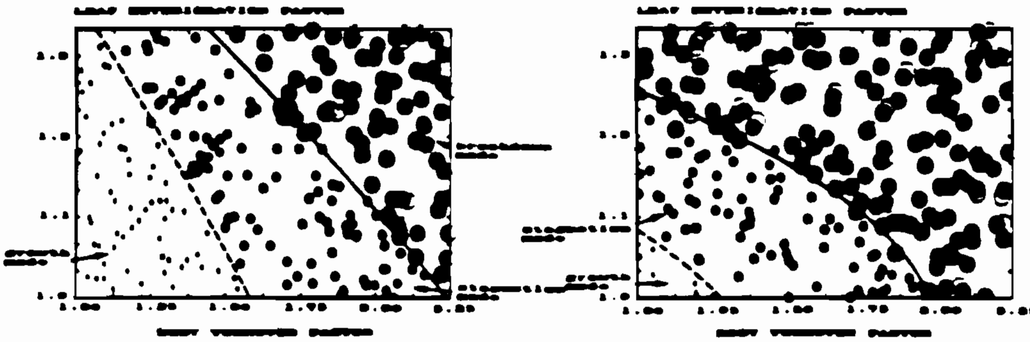


FIG. 7 Behavioral mode diagrams for young (left) and old spruce (right). (SPRUCE model; from Bossel 1986)

The simulations show no qualitative difference between coniferous and deciduous trees. Results of simulations for spruce under breakdown conditions caused by leaf damage are shown in Fig. 8. The tree sheds four of the original eight needle age classes in the first few years (damage begins in year 85), but then seems to stabilize for several years, while the increment decreases to zero. Thereafter, renewal needs can no longer be fully met, and the tree collapses after a few years.

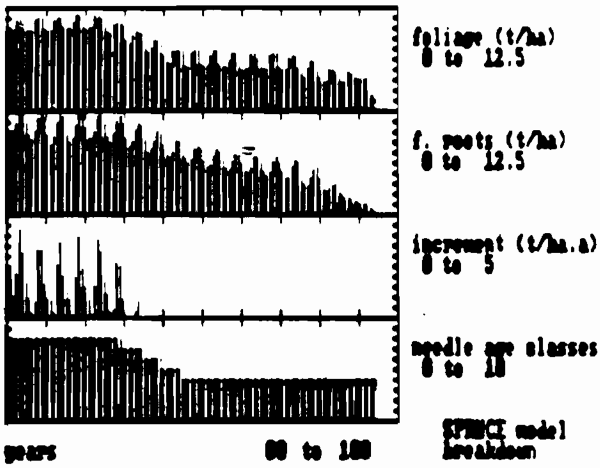


FIG. 8 Simulation results for spruce suffering chronic needle damage. (SPRUCE model; Bossel 1986)

Results of simulations for beech under breakdown conditions caused by combined pollution damage to leaves and feeder roots are shown in Fig. 9. In this case also, the increment curve is an early indicator of impending trouble: The increment is gradually reduced to zero, but the tree hardly changes its outward appearance for many years, until finally it breaks down rapidly "for no apparent reason" about ten years after zero increment has first been reached.

All of the models can of course be run under a wide range of parameters. Other examples are described in the original references.

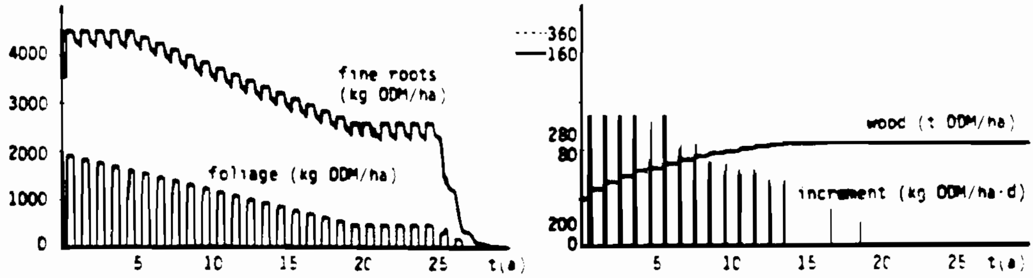


FIG. 9 Simulation results for beech suffering both needle and root damage. (BEECH model; Schäfer/Bossel/Krieger/Trost 1986)

5. MATHEMATICAL SYSTEMS ANALYSIS

All of the simulation models (BAUMTOD, SPRUCE, IAGM, BEECH) show the same behavioral modes in response to foliage and/or root damage: growth, stagnation, breakdown. This raises the obvious question concerning a common mechanism in all of the model formulations. This question has been investigated by studying the structure of the system of differential equations describing tree dynamics in the IAGM (resp. SPRUCE) model (Krieger 1986).

In this model, the tree subsystem is described by a nonlinear, nonautonomous system of differential equations for the five state variables (foliage, feeder roots, wood mass, assimilate, needle damage). The rates are nondifferentiable functions of the state variables. By introducing certain simplifying assumptions which do not affect the basic structure of the system, the set of differential equations is reduced to two nondifferentiable, nonlinear equations for the two state variables leaf mass l and feeder root mass r:

$$\dot{l} = \frac{\alpha_1 \cdot l^2 + (\alpha_2 \cdot CRT + \alpha_3) \cdot l + c_1 \cdot r}{c_2 + \alpha_4 \cdot l}, \quad \dot{r} = \frac{(\alpha_5 \cdot CRT + \alpha_6) \cdot l^2 + \alpha_7 \cdot l \cdot r - c_2 \cdot r}{c_2 + \alpha_4 \cdot l}$$

Here c_1 and c_2 are constants and α_i (i=1...7) are functions of the damage parameter λ. The nondifferentiable part of the system is incorporated in the limiter CRT(x), where $x := (1/\alpha)\cdot(r/l)$, $(\alpha := \alpha_4)$ and

$$CRT = \begin{cases} 0 \text{ for } x<0 \\ 1 \text{ for } x>1 \\ x \text{ for } x \text{ in } [0,1] \end{cases} \qquad (2)$$

For the relevant parameter range, existence and uniqueness of solutions of (1) for the initial condition (l(0),r(0))=(18,7) can be proved locally. The existence of global solutions can be discussed by considering the direction field in the (l,r) phase plane. Numerical solutions of (1) for different damage parameters λ and the initial condition (18,7) are shown in Fig. 10.

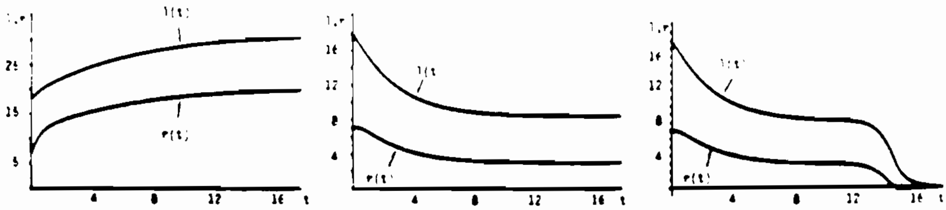


FIG. 10 Numerical solutions of Eqs. (1) for (a) normal growth ($\lambda = 0$), (b) stagnation ($\lambda = 0.28$), (c) breakdown ($\lambda = 0.29$). (Krieger 1986).

Finding equilibrium points and their stability characteristics from (1) directly is hardly possible. The stability analysis is therefore performed separately for each of the three systems of differential equations resulting from applying each of the conditions (2). It can be shown that for each of the three systems there exists the trivial solution $(l_1(t), r_1(t)) = (0,0)$ as well as an additional equilibrium point $(l_2(t), r_2(t)) = (l_2, r_2)$. The stability properties of the two equilibria are summarized in Fig. 11.

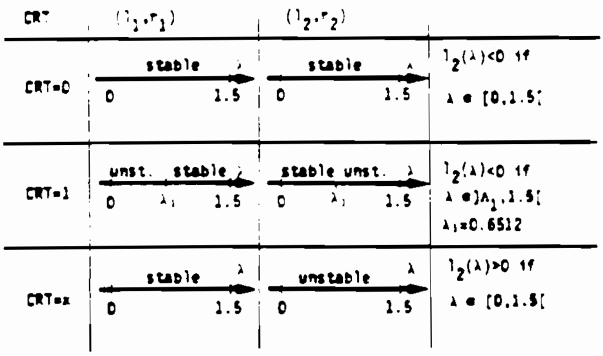


FIG. 11 Stability of the equilibrium points of Eqs.(1) as a function of λ. (Krieger 1986).

From the definition of x and the conditions for CRT in (2) we note that the two cases CRT=1 and CRT=x are separated in the (l,r) phase plane by the straight line $r = \alpha \cdot l$ (x=1) (where α is a function of λ) (see Fig. 12). For the initial condition (18,7) it can be shown that in the interval [0.28,0.29] the case CRT=1 always applies. Hence (according to Fig. 11), the corresponding solution will approach the non-trivial, stable equilibrium point (l,r). However, for $\lambda > \lambda_1$ the state trajectory moves into that part of the (l,r) phase plane where CRT=x (from (2) one can compute $\lambda_1 = 0.2837..$). According to Fig. 11, the only stable equilibrium point is now the origin: the system collapses. The three possible state trajectories (growth, stagnation, breakdown) are shown in Fig. 12.

Mathematically, the breakdown phenomenon can therefore be explained by the action of the limiter CRT in the model, which introduces a nondifferentiable change in (1) as a function of the location of the solution vector in the (l,r) phase plane. Provided that this limiter represents limiting processes in the tree correctly, this confirms that the three behavioral modes are indeed characteristics of the system, and not artifacts of numerical analysis.

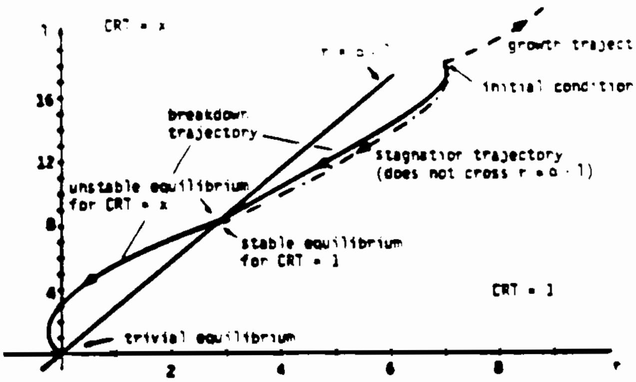


FIG. 12 State trajectories for the three possible cases (a) growth, (b) stagnation, (c) breakdown. (after Krieger 1986).

6. CONCLUSION

The major result from all models is the conclusion that trees (and hence forests) are indeed capable of breaking down rapidly as a result of chronic pollution stress. The validity of this conclusion hinges on the structural, behavioral, and empirical validity of the model formulation (discussed in Bossel 1986).

The major conclusions from the modelling efforts are identical, despite their significant difference in sophistication (Bossel 1986):

(1) Systems analysis of the structure and major processes of a tree suggest forest dieback to be a 'natural' reaction of trees to chronic pollution stress.

(2) The simulations suggest that the breakdown of trees is caused by insufficient assimilate production or excessive assimilate consumption due to pollution stress. Deficient leaf and/or feeder root renewal leads to increasingly rapid deterioration.

(3) The breakdown mode will only occur if the assimilate deficiency reaches a critical level. This may occur as the result of constant chronic pollution stress over many years.

(4) It therefore makes sense to speak of 'subcritical' stress (no breakdown, but reduced growth) and 'supercritical' stress (eventual breakdown).

(5) In the subcritical regime, the tree still looks 'healthy', even though growth may be absent. Two distinct behavioral modes - growth and stagnation - are possible in this regime.

(6) The simulations suggest that there is no difference in principle between the systemic effects of leaf damage and of feeder root damage: both reduce assimilate production and accumulation and act on the same life processes.

(7) Older trees have a much smaller margin of tolerance of leaf and/or feeder root damage.

(8) There is considerable inertia in the response of trees to pollution reduction, especially with conifers with many needle age classes. Also, the dynamics of the breakdown phase are selfsustaining. Hence pollution reduction to subcritical levels will only save those trees which have not yet entered the breakdown phase.

ACKNOWLEDGMENT

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4.2 SIMULATED EFFECTS OF CLIMATE WARMING ON THE PRODUCTIVITY OF MANAGED NORTHERN HARDWOOD FORESTS*

C.S. Binkley and B.C. Larson
School of Forestry and Environmental Studies
Yale University
New Haven, CT, USA

Elevated atmospheric concentrations of carbon dioxide will influence the development and productivity of forest ecosystems. Climate warming is one of the mechanisms through which increased atmospheric carbon dioxide concentrations will affect forests. Ecological changes in the forests will translate into economic changes in forest management and in the forest sector as a whole. Stand-level assessment of ecosystem change is fundamental to tracing out this web of interactions.

This paper analyzes the changes in productivity and species composition of forest stands due to the changes in growing season, heat sum and evapotransipiration which are associated with a three degree Celsius climate warming. To analyze these changes, we apply a physiological process-based ecosystem simulation model to two actual stands located in the mixed northern hardwood forest of northern New York state.

Previous research on the effects of climatic warming ignores the effect of forest management on forest response. Because forest management activities alter the pace of natural ecosystem processes, managed forests are apt to respond to climatic change differently than unmanaged forests. To account for the "acceleration" effects of forest management, we simulate stand development in each climatic regime under a simple diameter-limit harvesting policy.

Increased atmospheric carbon dioxide levels may affect forest growth both directly and indirectly (Kauppi, 1986; Smith, 1985; and Shugart et. al., 1985). In laboratory and greenhouse settings with all other growth requirements optimized, increases in carbon dioxide concentrations directly enhance net productivity of seedlings (Lemon, 1983). Increased carbon dioxide concentrations also apparently increase water use efficiency (Rogers et. al. 1983).

Increases in atmospheric concentrations of carbon dioxide may also cause changes in climate, including elevated temperatures (Manabe and Stouffer, 1980) and changes in precipitation (Manabe and Wetherald, 1986). These changes are apt to be greatest at high latitudes and in

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the winter. Increases in temperature enhance net forest growth by lengthening the growing the season and by increasing net productivity within the growing season. Lengthened growing season may also increase the probability of frost damage to young shoots, with consequent detrimental impacts on forest growth (Cannell and Smith, 1985). Increases in temperature and in carbon dioxide concentratations will probably increase the acivity of soil microorganisms, including those which fix nitrogen, and will thereby alter rates of decomposition and nutrient cycling. The range and activity of microbial pathogens and harmful insects will also probably be altered, with unknown positive or negative effects on the net production of usuable dry matter from the forest (Smith, 1985, 1987).

The temporal pattern of forest response is critical to any assessment of the social or economic implications of ecosystem change. Previous research on this problem has emphasized the natural process which might influence long-term vegetative changes, focusing either on the equilibrium conditions (Emmanuel et. al. 1985) or the dynamics of the approach to this equilbrium in unmanaged forests (Solomon, 1986). But forest management activities are purposefully designed to alter the pace and direction of natural forest development trajectories. Consequently, managed forest are likely to respond to climate change differently than do unmanaged forests. This paper emphasizes the impact of forest management on the transient and equilibrium response of forests to increases climate change.

To assess the economic impacts of carbon dioxide-induced changes in forest productivity, it is useful to distinguish three levels of analysis: the forest stand; the forest maanagement unit and the forest sector taken as a whole on a regional, national or international basis. As the basic unit of forest growth, response of the forest stand underlies all other levels of analysis.

Economic analysis carried out at the stand level will inevitably overstate the total economic consequences of climate change. The error arises because stand-level economic analysis cannot account for the adjustments which would be induced in the management unit or in the forest sector taken as a whole. For example, optimal forest unit management generally requires that changes in forest growth result in immediate changes in harvest levels (Binkley, 1984). At the sectoral level, changes in forest growth associated with climate warming are likely to result in significant changes in the global patterns of forest products production, prices and trade (Binkley, 1987).

This paper focuses on stand-level phenomenon. The first section briefly describes the forest sites, the simulation model, and the climate/management scenarios. The second section shows (i) that forest management accelerates the processes of ecosystem change associated with climate change, and (ii) that the economically important ecosystem responses transcend the changes in production of forest biomass alone. The concluding section discusses the implications of this work for assessments of the large scale impacts of climate change on forests.

1. METHODS: Stand Simulator, Study Sites and Climate/Management Scenarios

The Tug Hill Stand Management Model (THSMM; Binkley and Larson, 1987) is one in a long line of the JABOWA (Botkin et al, 1972) family of mixed species, mixed age stand simulators designed to mimic the processes of forest growth, mortality and regeneration. THSMM's closest relative in this family of models is FORTNITE (Aber and Melillo, 1982). In order to assess the impact of forest mangement activities on nutrient cycling and long-term forest productivity, both THSMM and FORTNITE model the forest floor as well as the above ground portions of the forest. THSMM also includes simulation models of harvesting, log and chip transportation and lumber processing production and costs, but these components of the model were not used in the present study.

Climatic variables enter the model through two parameters, the number of degree days and the actual evapotranspiration available for plant growth. Degree days, measured from a four degree Celsius base, are recorded only during the growing season defined by the times of leaf expansion and leaf fall. Actual evapotranspiration is estimated using the Thornwaithe equations which are based on temperature, rainfall and soil characteristics.

THSMM has been carefully calibrated to simulate forest growth in the birch-beech-maple (Betula-Fagus-Acer) forests of the Tug Hill region (42 degrees N, 77 degrees W) of northern New York state. The results reported below are per-hectare averages for two actual sites selected to reflect representative conditions for the region. The deep, gravelly soils are moderately well-drained with a fragipan at a depth of about 50 cm. Both sites lie in climatic zones providing 1606 degree-days/year and actual evapotranspiration of 498.5 mm/yr. The stands are 30-40 years old, with remnant older trees left from past harvesting. Other characteristics for two 200 square meter plots in each stand are given in Table 1 below.

Table 1. Characteristics of Sample Stands

Site	A		B	
	% basal area	# stems	% basal area	# stems
Acer rubra	33.6	6	36.4	11
Acer saccharum	51.7	21	58.2	26
Fagus grandifolia	12.9	6	-	-
Prunus serotina	-	-	5.4	1
Basal Area (mm/ha)	23.4		44.4	
Mean DBH (cm)	25.4		18.0	

These plots were grown for 120 years under three climatic regimes. The first, called "BASE" below, refers to the current climate—temperature, rainfall, insolation, growing season,...—as measured by twelve year averages from a nearby weather station. The second scenario, called "WARM" below, refers to a three degree Celsius warming phased in linearly over 100 years. From year 100 to the end of the simulation the temperature is held constant at the year 100 level. The increase is assumed to be distributed uniformly within each year. This level of climate warming equals the steady state temperature increase for this location used in the IIASA/UNEP Climate Project (Parry, Carter and Konijn, 1987) which was derived from the GISS model results for a doubling of atmospheric carbon dioxide (Hansen et. al. 1983).

If rainfall is held constant, increased temperature implies a higher degree of drought stress. Many northern forest sites are presently too wet for optimal forest growth, so increased water stress can actually increase forest growth. Predictions concerning changes in precipitation due to climate warming are much less certain than are the predictions of temperature increase themselves (Manabe and Wetherald, 1986).

Available precipitation may increase concomitant with increases in temperature. To begin to assess the potential importance of such changes, we developed a scenario which increased the amount of usable moisture during the growing season. In this scenario, called "WARM/WET" below, actual evapotranspiration increases linearly from 489.5 mm/yr to 583.4 mm/yr. as temperature rises.

The scenarios were run under two harvesting conditions. In one case the initial stand was grown for 120 years without any harvest. Then all trees greater than 7 inches (18 cm) in dbh were harvested in order to calculate merchantable volume production. This situation is called "unmanaged" below. The second regime havested all trees 7 inches (18 cm) and larger both in year 30 (when the trees are roughtly 70 years old) and then again in year 120. All volumes reported refer to stem and branch wood, but exclude roots and leaves.

2. RESULTS

Table 2 shows the production of merchantable volume in each of the six scenarios. Climate warming alone increases mean annual increment

TABLE 2. Production of Merchantable Volume (bole and branches, trees ≥ 18 cm)

	Managed			Unmanaged	
	30*	120*	MAI**	120*	MAI**
BASE	247.0	348.9	4.97	483.1	4.03
WARM	281.6	626.7	7.57	711.6	5.93
WARM/WET	264.1	113.7	3.16	89.2	0.74

*harvest volume, cum/ha
**mean annual increment, cum/ha/yr

by 2.60 cum/ha/year with management (52.3%), and 1.90 cum/ha/yr in the unmanaged case (47.1%). Growth in the WARM/WET scenario falls considerably, by 1.81 cum/ha/yr and 3.29 cum/ha/year in managed and unmanaged cases respectively.

Forest management clearly affects the ways in which climate change influences forest growth. In the BASE scenario, management increases the production of merchantable volume by 0.94 cum/ha/yr. In WARM, the increase is 1.64 cum/ha/yr, and in WARM/WET, the increase is 2.42 cum/ha/yr. Management increases the production of merchantable volume by harvesting trees which would otherwise die as a consequence of climate change. The greater the potential mortality, the greater the impact of management.

Harvesting mature trees also hastens the time that the forest can regenerate to species which are better suited to the new climate. Table 3 shows the simulated shifts in species composition in the six scenarios.

Table 3. Species Composition in Year 120
(% basal area except total in sq. m/ha)

	Initial	BASE		WARM		WARM/WET	
		M	UM	M	UM	M	UM
ASA*	51.5	89.0	94.2	34.8	47.6	-	-
ARU	38.9	-	-	-	0.2	28.1	59.2
FGR	7.3	8.8	5.8	64.8	50.7	71.9	40.8
OTH	2.3	2.3	-	0.4	1.5	-	-
Total	33.9	38.8	51.5	55.2	61.9	12.9	12.0

ASA: Acer saccharum (sugar maple), ARU: Acer rubra (red maple), FGR: Fagus grandifolia (beech), OTH: other species, including Prunus serotina, Fraxinus americana, and Betula alleghaniensis. - indicates that the species is not present.

In the base case, the stands tend to become dominated by sugar maple. The intermediate harvest in the managed stand slightly increases the amount of beech. Climate warming favors beech, and management reinforces this effect. In the WARM/WET scenario, management significantly shifts the species composition, from red maple to beech.

3. CONCLUSIONS

Many uncertainties attend predictions of forest ecosystem development in response to poorly understood changes in atmospheric levels of carbon dioxide and consequent changes in climate. The precise quantitive magnitude of our results must be regarded as speculative. Nonetheless, three conclusions seem warranted.

First, forest management accelerates the effects of climate change. Harvesting mortality before it occurs not only increases the production of merchantable volume from the stand, but also permits more rapid conversion of the stand to species which are better adapted to the changed climatic regime. In the complex mixed forests of North America, the portfolio of species present on a particular site is adequate to insure fairly rapid transition to the new, beter adapted forest type. In other situations, enrichment planting might be required to hasten the transition.

Second, a three degree increase in temperature leads to an increase in average annual growth of from 1.9-2.7 cum/ha/yr in a mixed hardwood forest at a location 42N 77W. In their global studies of forest response to climate warming, neither Emmanuel et. al. (1985) nor Kauppi and Posch (1987) predicted any significant change in the forests at this location. This suggests that the global extent of carbon dioxide-induced increased in forest growth may be larger than previously estimated.

Third, the problem of geographic scale continues to impede better assessments of the impacts on forest ecosystems of global climate change. Ecologically defensible models, disputed as they are, operate on a scale of about 0.1 hectare. Assessments at the global or large regional scale, particularly those involving social or economic concerns, necessarily operate on a scale six to nine orders of magnitude larger. Spanning this gulf remains a challenge to the architects of large-scale climate impact assessments.

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4.3 MODELLING FOR FOREST DECLINE: PROBLEMS AND SOLUTION CAPACITIES*

J.W. Owsiński, A. Straszak, A. Kałuszko, and T. Romanowicz
Systems Research Institute
Polish Academy of Sciences
Warsaw, POLAND

Summary. The outline of the problem area in modelling of processes related to forest decline in given. Examples are presented of exiting capacities of solving some of these problems within the current state-of-art. Relation between the real-life needs of decision-making and research, leading to modelling of crucial questions, is established.

1. INTRODUCTION: THE SUBJECT OF MODELLING

This introductory part is meant to highlight certain issues which arise with regard to modelling of such complex system as biological and ecological ones. Although it is true that applications of mathematical and computerized models in these domains are so numerous that several journals devoted at least partly to such considerations are published and reference lists grow importantly every year, it is also true that these applications are primarily of theoretical nature and if their empirical justification is better founded, then they usually pertain to some quite narrowly defined subjects. Nevertheless, the present authors maintain that at the present state of art modelling can be usefully applied to the problem of forest decline, its consequences and management thereof. Arguments supporting this view shall be expounded in due course in the paper.

A model is an abstract representation of a real system, process or phenomenon. The word "abstract" does not mean uniquely that the representation should not have the physical nature - in fact, children playing with their building elements are engaged

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in modelling - but rather, that the process of extracting the representation involves abstracting of certain characterictics of the reality to be modelled. Models are made for two purposes: first, to enable easy operations on the model in conditions when such operations on the respective reality are cumbersome or impossible, and second: to enable easy assessment of various possible states of this portion of reality. Thus, "real" does not refer to existing, but also to potential like e.g. in egineering design.

This general quasi-definition is very broad indeed, but it certainly is proper. In case of engineering design a move from a pencil-and-paper analysis of beams to integrated software for construction design is just a quantitative change from a simpler partial model to a more complex, automatized one. The intermediate step consists in programming of individual beam equations, that is, models of individual beams. Even farther - not only pencil-and-paper analysis of an equation should be considered a model, but also its mental concept. Nowadays such mental constructs enter computers without the intermediary of pencil-and-paper stage. Without even this, however, distinction between the mental concept and its - whatever - more material reflection can hardly, if at all, be made.

Thus, a classification of models can be made along these lines, based upon the degree of specification or explicity:

* mental models,
* verbal models,
* qualitative models,
* quantitative ("mathematical") models,
* computerized models.

As mentioned, distincions between these categories are by no means obvious,with, perhaps an exception constituted by the distinction between the two latter categories, since computer implementation may provide adequate discrimination.

Two remarks are due on this list of model categories. First, that this list corresponds to a high degree to chronological stages of development of a model, from an idea and knowledge to fully automatized computerized construct. Then, when representing a real system one does in practice usually progress to various model categories for different constituents of this system. Hence, a portion of such representation can be fully automatized, while other portions may be withheld at the "qualitative" or even "verbal" stage of development. This implies a very important requirement as to model specification, namely: when considering a model of a certain system, all its components, of whatever category, have to be made explicit. In practical terms this usually means that when a computerized model is being used or tested, its assumptions must be made explicit, its inputs explained and its output evaluated through explicit criteria. A framework for a systematic approach with that respect is given in Duinker and Baskerville (1986), for modelling used in the EIA procedure.

In commenting the quasi-definition of a model let us return to the functions of models. As mentioned, models are built because of the need of facilitating certain operations, whose final aim is to perform some action in/on reality. These operations, facilitated by models, fall into three broad classes:

* cognitive analysis, leading to understanding,
* projection analysis, leading to forecasting,
* evaluation analysis, leading to decision-making and planning.

There is, again, a succession of stages linked with this classification, although more loosely than in the case of model categories presented before. There may be, namely, projection models which are in fact not based upon an in-depth cognitive analysis, but which still may be very useful for short-term purposes. This applies primarily to various regression models, which may ultimately be determined in quite a mechanical way using, loosely speaking, "correlations" rather than "cause and effect" relations. Even in this case, though, provision of adequate understanding helps a lot in determination of good regression models, through choice of variables and functions, see Fig. 1.

"Understanding precedes modelling". Assume that this phrase applies to models other than just mentioned. How, then, with regard to such models, can modelling enhance understanding? There is a mechanism which leads to such enhancement in case of complex systems. Namely, while it is obvious that modelling of individual processes studied through empirical work may help only to a limited degree in reaching of satisfactory understanding, it seems equally obvious that when behaviour of complex systems, composed of numerous individual subprocesses - even quite well understood - is studied, understanding of this systemic behaviour is by no means a trivial problem and modelling may be of great help, see Fig.1.

With respect to the question of complexity it is often argued that "true" systems must display certain "holistic" features which cannot be found by simply superposing their constituent parts. Insfar as this statement is technically true, i.e. true from the point of view of practical analysis and modelling, in which certain aspect have to be considered on the macro- rather than micro- level, it is by all means an a posteriori statement whose contents cannot be a priori assumed. Thus, it can be often conjectured that system-like properties are related to existence and particular form of a purpose for this system, whether internal

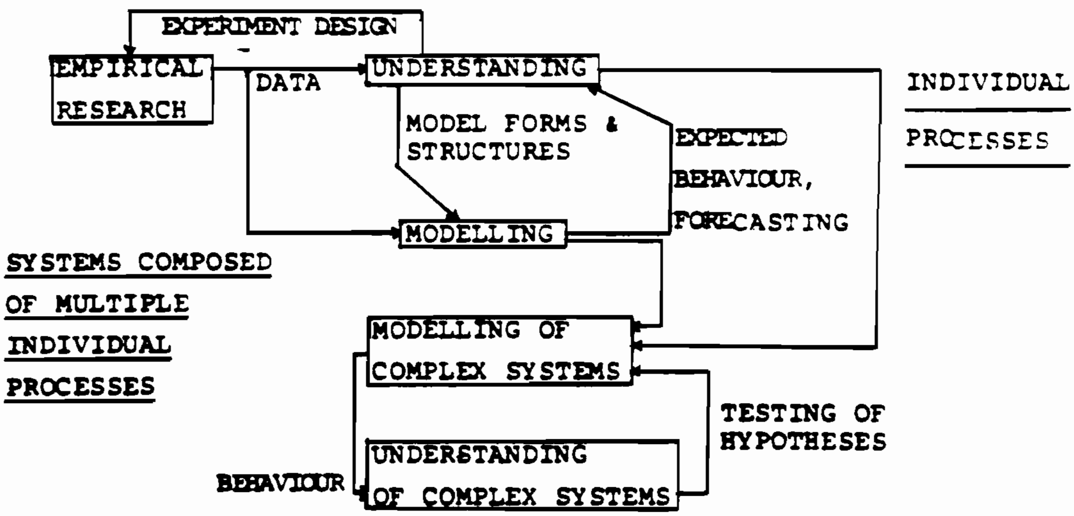


Fig. 1. Relation between modelling and understanding in individual and complex processes and systems

or external to it. The question of what is purpose and what is not, shalln't be dwelt upon here except for two remarks: 1) it is often technically useful to regard and represent as purpose an aspect of a system which is in fact generated by its elements' characteristics, and 2) that purpose appears in modelling under the form of objective function or objective functions, being explicit expressions of purpose in the adopted terms.

Thereby the question of evaluation apprears, since evaluation is based upon the existence and form of an evaluation criterion, embodied as well by an objective function, whether explicit or implicit. This is not to say that "purpose" ought to be represented via the same expression as "evaluation criterion". A model may simulate behaviour of a system guided by a well defined internal purpose to be represented by an explicit objective function. Outcome of this behaviour, though, should be evaluated. Thus, there appears sometimes a superposition of criteria, which may even be contradictory.

When there exists a possibility of changing the behaviour of a system in such a way that would yield significant differences in its evaluation, then control and/or planning become feasible. Generation of alternative behaviours and choice of - evaluation-wise - best ones may also be performed by a model, which then takes often the form of an optimization model, Fig. 2.

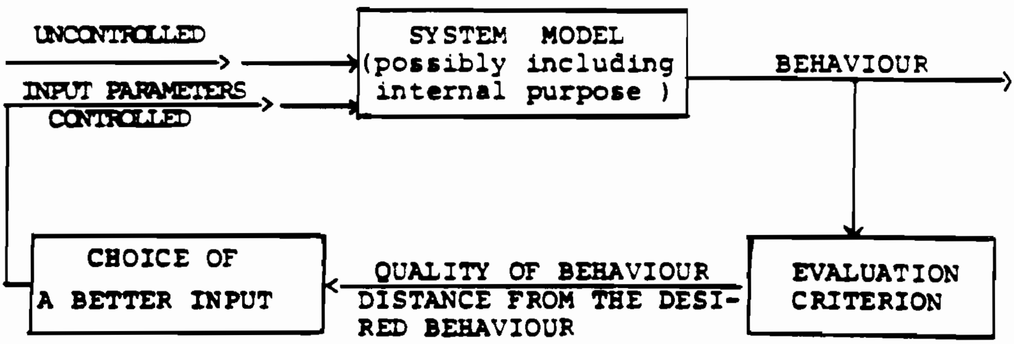


Fig. 2. Principles of model application to choice or optimization of system behaviour

To sum up this section let us state that models, whether called that way or not, are constructed and used in everyday life and in all scientific work. Model-building is enhanced by understanding of the phenomena considered, but models can also help a lot in understanding, especially of more complex phenomena. Models can, however, be built even in cases when there is not sufficient understanding, but only appropriate data, and such models can also be effectively used. Model building involves development and/or identification of criteria. Finally, under well-defined situations models can help in rationalization of decision making.

2. FOREST DECLINE: THE UNIVERSE OF DISCOURSE

2.1. General view

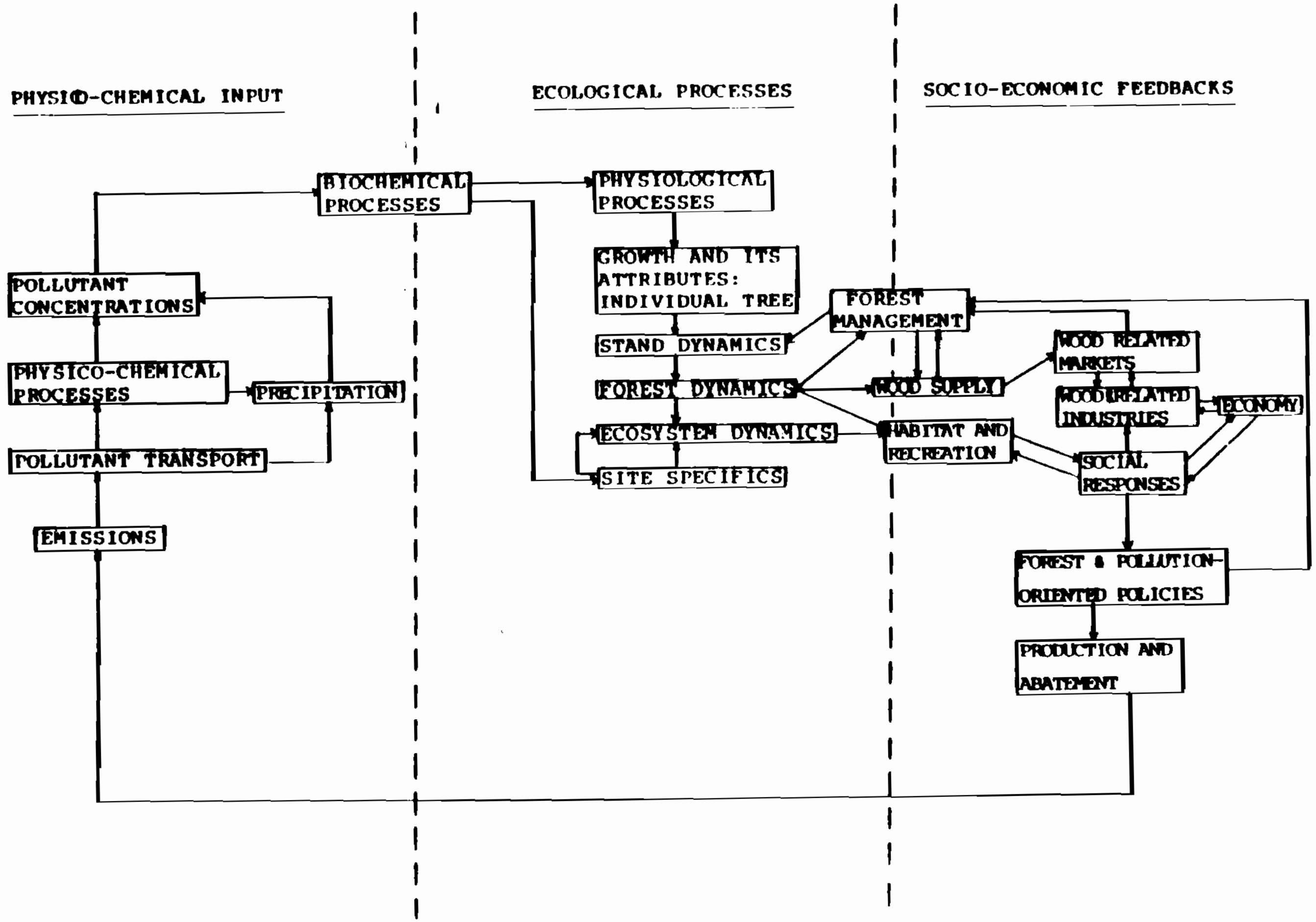
Forest decline, its course, causes and consequences, constitute a study area composed of several interconnected subdomains. This setting can be perceived as forming in fact a system, outlined in Fig.3.

Several remarks of general nature should be made with regard to the diagram. First, that subdomains presented as individual blocks need not have sharply defined "boundaries" among and between them. Analyses may pertain to parts of several of them at the same time. Then, there may be by-passes where a sequence of blocks is indicated: a block may be omitted. This would first of all occur when a regression-type approach is used. It is also important to note that a variety of purposes may appear in different parts of the diagram.

Now, remarks of more particular nature shall be forwarded.

The diagram can be regarded both as a list of areas of study and as a generalized cause and effect scheme. First, it is easy to notice that the system outlined is in fact very closely internally connected - a change in one of the elements entails changes in all the other ones. Thus, when envisaging the study of the whole forest decline, it is necessary to take into

Fig.3. Domains of study pertaining to forest decline: a systemic setting.



account work in many different scientific domains, or, even more than that: interdisciplinary work. This applies, in particular, to modelling studies. In fact, it is modelling that, according to previous considerations, can secure requisite variety of perception of the problem, including multidisciplinary. In-depth studies can be effectively conducted only within particular subdomains of Fig. 3. and their interrelations. In many cases, however, full, or even satisfactory understanding of ongoing processes and cause-and-effect chains will take a lot of time. This is particularly true for the analysis of physico-chemical processes in the atmosphere, and especially in contaminated clouds and fogs on mountains slopes, that is, for one of the most important elements of the hypothesis explaining the very frequent forest decline phenomenon: spruce forest in medium-height mountains. There may be, on the other hand, a need for a much sooner action, in view of the dynamics of forest decline and the threat of its consequences.

Thus, in view of internal connectivity and complexity of the causal system related to forest decline phenomenon, and of the significant risk attached to action delay, the necessity of modelling becomes obvious. No wonder, therefore, that a number of models have been developed, directly or indirectly concerning forest decline. Let us quote five subareas cut out of the system depicted in Fig. 3, in which modelling has either much progressed or is very much called for. They shall span in a way the whole of the diagram of Fig.3.

2.2. Transport and distribution of pollutants

This subject has been treated through modelling for quite some time. The major cause was, of course, more generally environmental, not specifically forest-orientation. In particular, the International Institute for Applied Systems Analysis, IIASA, is engaged since 1983 in work on the Acid Rain project, aiming at elaboration of a set of models that would describe acidification and its regional effects in Europe. Since two other papers in this volume are this effort in more detail, see Alcamo (1987)*/ and Mäkelä (1987)*

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*) references contained in this volume shall be denoted by an asterisk

it will not be treated in any length here. Let us only quote some other references, which seem of importance. Seminal are works by Fisher (1975,1978). An interesting and well elaborated implementation is provided by the Quebéc model, Lelievre et al. (1985). Other appropriate references contained or pointed in this volume are Adema (1987)*, Kauppi (1987) and Dykstra and Kallio (1986).

Each such model, when aiming at final concentrations or depositions of pollutants refers to two time horizons:

* short term transport phenomena, and their
* integration over seasons and years.

Models take source characteristics and then wind directions, strength and duration distributions together with appropriate atmospheric behaviour features to obtain emission trajectories and their ultimate distibution with resulting concentration increments.

Approaches applied usually short-cut physico-chemical and bio-chemical processes occurring within these two time horizons. This concerns as much processes taking place in the atmosphere as those in the soil and in the ecosystems affected. The models concentrate also on just a few pollutants, mainly SO_2, mainly because of data difficulties with the other ones. Still, when properly specified and applied these models are capable of providing geographical distribution of origins and destinations of flows as well as relative distribution of loads.

Proper specification applies, for instance, to scales adopted in the model, with regard, e.g., to breakdown of geographical space into regions of origin and of destination. On the one hand there is the question of dimensionality of the model, but on the other hand - the risk of committing grave errors due to scale misspecification.

One of the interests behind development of such models is identification of "polluters". In fact, many modelling projects

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*) references contuined in this volume shall be denoted by an asterisk

in this domain were motivated by transboundary flows of pollutants. Thus, results of calculations lead to conclusions of multinational importance. Such conclusions may further constitute a basis for potential negotiations. An important aspect of this situation is that although resulting transboundary flows are usually highly asymmetric, which makes negotiations more difficult, these flows involve usually more than two countries, so that finding of a modus of solution becomes simultaneously necessary and more feasible. This problem, however, related to social reactions, negotiations and policies, belongs primarily to the SOCIO-ECONOMIC FEEDBACK subdomain.

2.3. Factor and forest decline incidence

A great weight in forest-decline-related research is devoted to establishment of causes leading to decline. It seems that there is still a long way ahead to obtaining well founded, even if partial results of that sort. On the other hand there is overwhelming incidental evidence coming from two main sources:

* local impact phenomena, where attribution of forest and other ecosystem damages to pollution coming from local sources is well established if not self-evident, see, e.g. Vaichys et al. (1987)* and Linzon (1987)* in this volume, and
* regional dieback frequencies which to a large extent coincide with areas of higher and longer-term pollution, especially with SO_2.

Thus, a need arises of documenting this (missing?) link by performing adequate data analysis for a large number of sites distributed over very broad territories. Methods to be used include classisal statistical analysis, factor analysis, cluster analysis and the like, see e.g. Naeve (1983), Owsiński (1984), and Leplay (1985) for examples of applications. Further, various sorts of regression techniques can be tried out, like e.g. the one proposed in Owsiński (1987). None of these methods, however, and especially the latter ones, can be sensefully used without a priori hypotheses at least roughly outlining a model, so that at first the adequate data can be subject to analysis and then data acquisition and/or model-generating hypothesis modified according to the results obtained.

Some such initial hypotheses can be formed on the basis of considerations of the type presented by Grodziński (1987)* or Molski (1987)*, or in a different manner, by Grossmann (1987)*.

Existing models which try to bridge the gap between the two subdomains indicated in Fig. 3, i.e. the on related to pollution and the second related to biology - see also simplified diagram of Fig. 4 - do of course assume certain rough connections, like e.g. in Mäkelä (1987)* or Dykstra and Kallio (1986), but these are just proxies which can not for the problem here outlined serve as basic hypotheses, nor as models. Similar is the situation with assumptions made in the paper by Bossel et al. (1987)*, which are limited to triggering off of the decline process, the whole model being contained in the eco-biological subdomain, see Fig. 4.

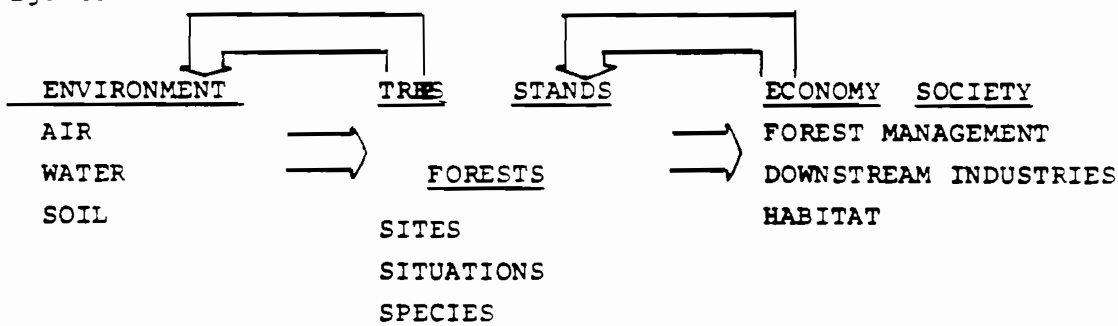


Fig. 4. Simplified diagram of the subdomains

It is, naturally, recognized that pollution is not the only direct factor. Thus, Binkley and Larsson (1987)* take climate to model change resulting from climatic shift. Generally, it is taken for granted that the non-specific, widespread forest decline is due to a number of causes, acting in various ways depending upon the site and especially combining in various manners.
The multi-factor hypotesis on its aggregate level repeated in this volume by Aculair (1987)* after Manion and Houston and, also on the aggregate level, is elaborated for the modelling purposes in the

following chapter of this paper. On the other hand this hypothesis on its detailed level (elements, compounds, reactions, processes,...) is still by no means clear. That is why it is proposed to start with widely geographically distributed data analysis exercise referring to it. Negative results to date, see Binns et al. (1986), point out existing needs in basic research and in data analysis as well.

2.4 Forest and forest ecosystem dynamics

Forest growth is not only, it seems, a good subject for modelling in terms of modelling capacities, but also the one which is interesting for industry and trade, since it constitutes the ultimate input to appropriate industry branches and markets. Thus, quite some forest growth models have been developed, as referenced in Antonovski (1987)*, or Shugart (1984) encompassing various sorts of forest micro and/or macrosystems. This distinction can well be illustrated by some papers from this volume: modelling on the micro-level, where individual trees are distinguished, being represented by Bossel et al. (1987)*, and also, but to a much lower degree, by Antonovski (1987)* and Grayson (1987)* and modelling on the macro-level, represented notably by Dakov and Raffailov (1987)*, and, partly - Prins (1987)*, through a scenario-based approach.

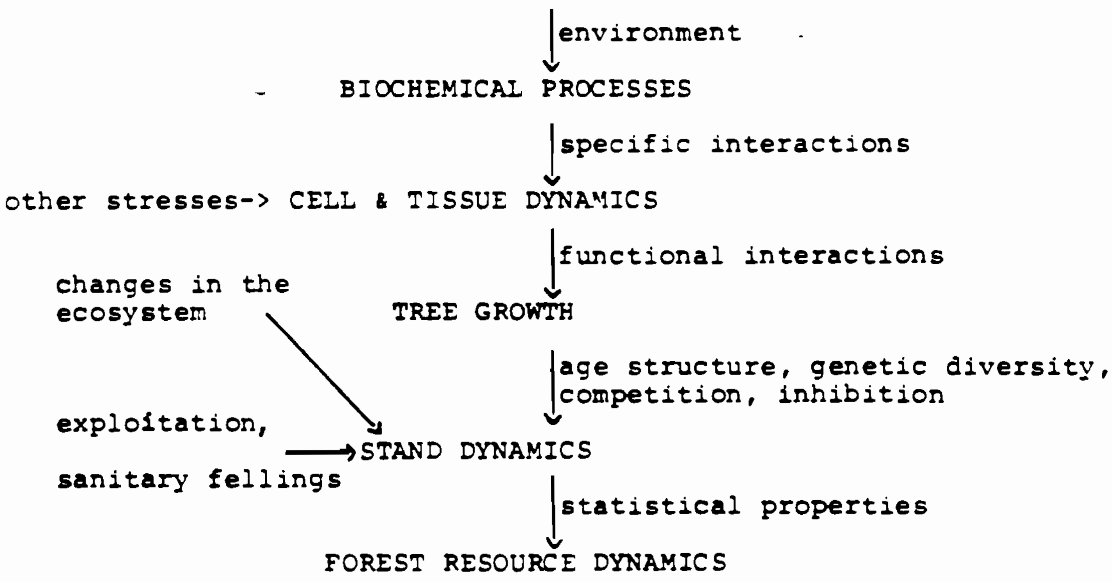
A model of a complex system refers usually to the elements of this system and their interactions. That is why individual tree growth models make physological processes appear. With that respect the report of Bossel et al. (1987)* presents the structure which seems to be quite complete, although somewhat - of necessity - simplified. As mentioned before, the causal link leading from environmental conditious to tree dynamics is missing. This lack is due, as well, to the still persisting lacunae in the knowledge of proper physiological processes. Nevertheless, essential dynamical features of tree growth and decline can already be analyzed, and this is of foremost importance because of the time scales involved in the decline and possible countermeasures and because decline appears at the level of individual trees.

If a tree is represented by a simple growth curve then modelling of a tree system is simple. It may be kept at the complexity of biological population dynamics models. Even such models, though, can provide insight into dynamic behaviour, see Owsiński and Romanowicz (1984) and can be useful for trade and industrial forecasting and planning, see section 2.6 of this paper.

In fact, however, forests, especially under stress, behave in a much more complex way, involving competition and succession, see Antonovski and Shugart (1986). On the other hand, though, these simpler formulations may ultimately lead to control-theory-oriented formulations, see Antonovski (1987)* or Lyon and Sedjo (1983).

2.5. Forest management: forecasting, planning and control

Optimization does not necessarily have to enter via control theoretic framework.
Examples of other approaches are provided by Kairiukstis and Juodvalkis (1986) and Kurth (1987)* whereby management may be enhanced. In these two cases, though, purposes are characteristically different so that a proper middle way is necessary. Between optimum forestation and yield policy based upon market conditions, cost of provision to the market and forest dynamics and optimum policy aiming at the "best" forest, there might be a path for minimum risk maximum sustainable yield under cost constraints. Anyway, the question of objective not being quite settled down, at least limits for possible action are there. That is the contens of the EVALUATION box in Fig. 5.



Blow-up of forest-oriented inter-level relations

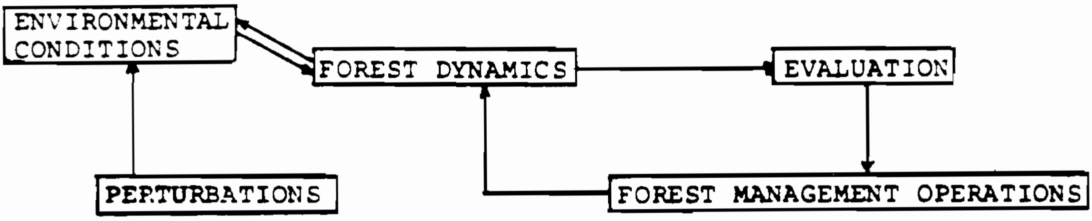


Fig. 5. Feedback loop in forest management

Working of the system of Fig. 5 is totally different if results of perturbations are simply being observed than whan these results are being forecasted. Thus, while models of forest systems of the macro-type, mentioned in the previous section, may be effectively analysed even when they are quite complex it is lack of forecasting capacity, for reasons mentioned also before, that constitutes the proper bottleneck. Otherwise, it would be relatively straightforward to develop - whatever - optimum policies.

One way of overcoming this difficulty is to elaborate sufficiently accurate forecasting models, whence we return to the ultimate cause-and-effect question. There is, however, also another way. Owing to incidental evidence it is possible to secure significant diminishing of the risk of perturbations and their effects by, say, decreasing pollution and improving ecological conditions.

This brings us back to two previously commented problems: the one of section 2.3, i.e. of gathering and analysing data concerning evidence on contribution of particular factors to forest decline, and the one of section 2.4, i.e. the dynamics of forest decline and other processes caused, no matter how, by various sorts of perturbations. Such a knowledge would also give the possibility of properly monitoring the forests so that early warning signals could be issued on time.

2.6. Economic and social feedback

This area is again quite densely populated by models developed for market assesment and alike purposes. Very often these models encompass, at least partly, some aspects of forest dynamics, commented upon before, see Amano and Noda (1987)*, Sedjo (1987)*, Lønnstedt (1987)* or Peyron (1987)*. These models are often quite complicated and they represent wider systems, including multi-specie markets, world markets etc. It is easy to see, however, that these models are orinted primarily at an extension of forest management optimization in the downstream economic direction. Two basic feedback aspect are here missing:

* economically driven pollution-abatement policy feedback, and
* consideration of social responses forcing certain value trade-offs leading to modifications of apparently market--optimal policies.

These two aspects would require, though, accounting for much wider set of values, primarily in terms of time horizon and types of goods considered. Some work in this direction has, though, already been done, see e.g. Lakshmanan and Nijkamp (1980) or Foell (1975). Unless such aspects are internalized, first in modelling and then in practical decision making, there will always be a risk of external action of disruptive, even if justified, nature.

3. A HYPOTHESIS: FRAMEWORK FOR MODELLING

The hypothesis shortly presented here may be used to develop designs of research as mentioned in section 2.3, through the intermediary of a model, a qualitative one or only partly quantified one. The hypothesis is as follows:

Let us distingnish a relatively homogeneously behaving forest system, i.e. the one that would react sufficiently uniformly to incoming stimuli, in order to treat it as a separate unit. Such a forest unit may be viewed as located in the space of factors determining its growth and survivability conditions. The hypothesis goes on to assume that for a given unit, with all its significant features there exist a subset of this factor space which represents the best conditions for a given unit.

At this point two comments are due. Both of them concern the notion of "best conditions". First, of course as mentioned already before, there may be different definitions of measures of goodness, i.e. of objective functions. For purposes of the present outline, however, it is sufficient to state that the goodness criterion should involve long-term biomass increment and/or maintenance. This question is, though, of less importance. Second question concerns the state (perhaps a dynamic state) achieved for the "best" conditions. This state is different for every unit, just as conditions defining these best conditions are different. Such a situation results from such internal features of the unit as soil, slope, climate, tree species, other unit-forming species etc. It is easy to imagine that some units would not be able to achieve very good best states, because of lack of sufficient ecological fit within these units (e.g. human-planted forests, or forests constituting transitional phase in a succession). It is feasible to assume for every such "misfit" unit - if the degree of fit could be sufficiently well established - a replacement management directing it towards a better best state. This, however, is not the point here. Moreover, this could lead to the adaptation vs. adaptability question, too complex for the setting (see next chapter of this paper). Even in, say, the specie-wise "best of best" there will be differences resulting from natural conditions.

Thus, it is hardly possible that a number of adjacent units have the same "best" conditions. Therefore, some of them shall always be off the best ones, although, of course, always the different ones. Un-best conditions create a stress. Certain degree of stress is, however, very well withstood.

In some cases the stress takes on dimensions to which a unit was not at all prepared (adapted). Stress responses are still reversible, but are of pathological nature. Beyond certain threshold are irreversible, and even further they lead to tree, and then forest death.

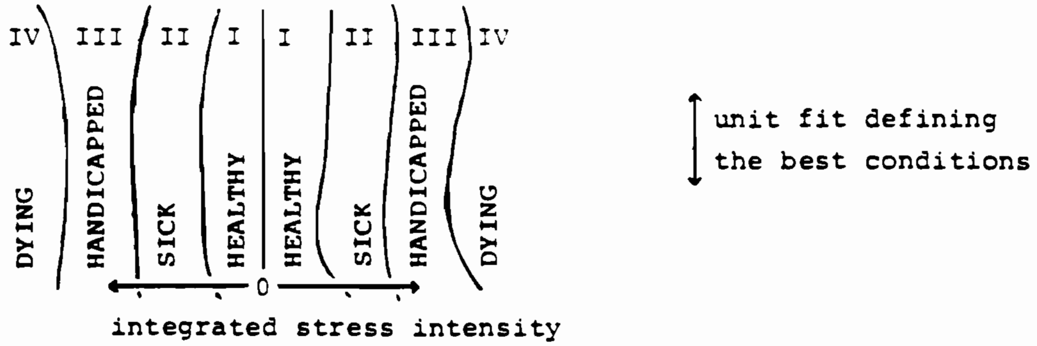


Fig. 6 . Zones of stress

This reasoning is illustrated in Fig. 6 . 0 corresponds to best conditions, defined by the unit fit, whose changes can occur along the vertical axis. Area I corresponds to normal responses to stress, area II to onset of irreversible changes, III to such phenomena as stunted growth, and IV to dying. Note that by changing internal unit features one can also change vulnerability to stress. Within particular areas of Fig. 6 changes are merely quantitative, while between them they are of qualitative nature.

Factors determining stress, i.e. pushing the unit away from the best conditions, and those defining these conditions can be portrayed as follows:

Stress	Fit
* weather	* climate
* insects	* species
* diseases	* soil
* anthropogenic pressure	* landscape

The first item on the left encompasses temperature, precipitation and wind. The last one mainly pollution and direct mechanical damage.

Variables listed under Fit are in more model-oriented considerations referred to as "slow variables", while those under stress - as "quick variables". This illustrates well their temporal relations.

Time is, in general a very important factor here. Total stress is therefore an increasing function of stress forming variables integrated over the last period of transgression of the boundary between I and II of Fig. 6.

This stress + fit -> response qualitative model can be easily made operational in a data setting, where it can be turned into a family of identifiable quantitative models, given appropriate data set are available on all the three constituent elements of the hypothesis for a number of units (sites) in comparable and different circumstances. A number of measures and superposition mechanisms can be tried out in these models even prior to ultimate knowledge of causal chains.

4. ADAPTATION,DYNAMICS AND STRESS

A model was developed by Romanowicz and Owsiński (1982, 1984) meant for analysing biological populations characterized by age groups and fit-related, so called adaptive, feature. The population lives off a self-renewing resource. This model was meant to study relations betweeen adaptability and adaptation in various contexts. The model has definitely shown that increased adaptation means decreased adaptability and therefore greater vulnerability. This should certainly be taken into account when trying to find the ways of replaing valnerable and/or dying species by " better adapted" ones, guaranteeing quick and effective replacement. Leaving a room for less adapted, i.e. slowlier accomodating, but more versatile species may be a solution with longer perspective.

Another type of study performed with this model of the population involvedtesting against certain extreme conditions, including stress resulting from the resource situation change (change of self-renewal rate, change of volume, harvesting by other population and the like), from changes in internal features of the population (mortality and/or birth rates) and also from changes in the environmental genetic preference. In all cases of conditions close to causing collapse, but approaching it from survivability side there is <u>no possibility of distinguishing a priori the situations of future collapse and of survival</u>. A long period of latency typically followed a change, with durations of up to tens of basic periods (seasons, years or several years each). This phenomenon, illustrated in

Fig. 7, corroborates the conclusion reached by Bossel et al. (1987)*. It is, simultaneously true that the forests of Europe

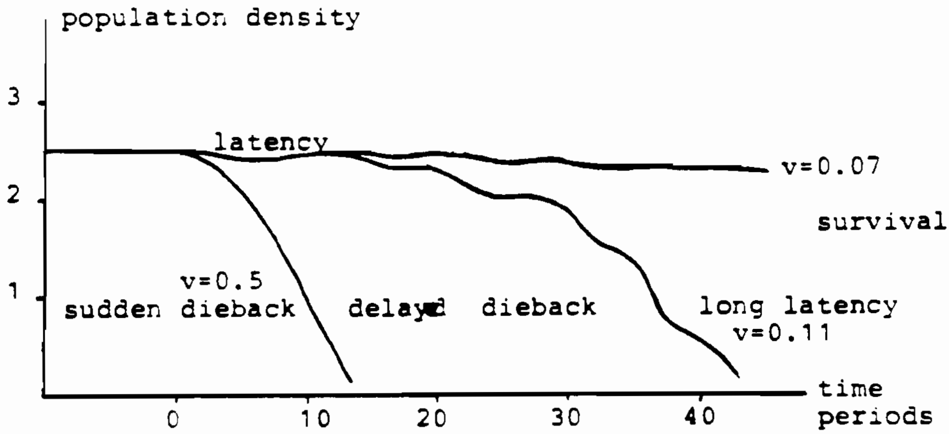


Fig. 7. Period of latency for a near-survival case
v - speed of genetic fit shift

and other industrialized parts of the world are not, as yet in the "sudden dieback" mode of Fig. 7. Some of these forests are certainly in the "delayed dieback" mode. How much of them are in the "long latency" mode?

5. FINAL REMARKS

Modelling means making explicit the type of thinking which is common for human beings wanting to discern, to understand and to plan. Making it explicit means making it more effective, for it allows performing conscions operations on models: testing, choice, rejection and development. Hence, they can be made better and better to help in understanding, in designing fundamental research and in policy making. Even when criticizing models one is usually referring simply to some other constructs of the type kept in the mind.

Time is running out quickly. Since we cannot understand everything at once, we should explore partial knowledge, hypotheses and scenarios, and try to find these solutions which shall save forest now and not when it is gone.

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4.4 PRESENT STATE AND POSSIBLE FUTURE HISTORY OF FOREST DAMAGE ATTRIBUTED TO AIR POLLUTION IN BULGARIA*

M. Dakov, G. Raffailov, Ch. Bojinov and G. Kostov
Higher Institute of Forestry and
Forest Technology
Sofia, BULGARIA

1. INTRODUCTION

The aims of the present paper are in a close conection with the goals of the IIASA's study on development and consequences of forest damage attributed to air pollutipon and change of climate, i.e. "to gain an objective view of the future development of the forest damage attributed to air pollution and change of climate and the effects of this damage on the forest sector, international trade and society in general" (Nilsson, 1986).

The problem of forest damage due to air pollution is rather new for Bulgarian forestry. The increased attention dates several years ago, when alarming reports for a large scale forest die-off in some Central European countries has appeared. The situation of this country, as regards extremely air polluted areas and forest damaged regions, and direction of the prevailing winds, as well, are also reasons for alarm. Increased mortality in pine plantations and natural oak forests, decreased stability to biotic and abiotic disturbance factors and the reports for acid rains in many regions of the country in recent years made the problem of possible forest damage due to air pollution very important.

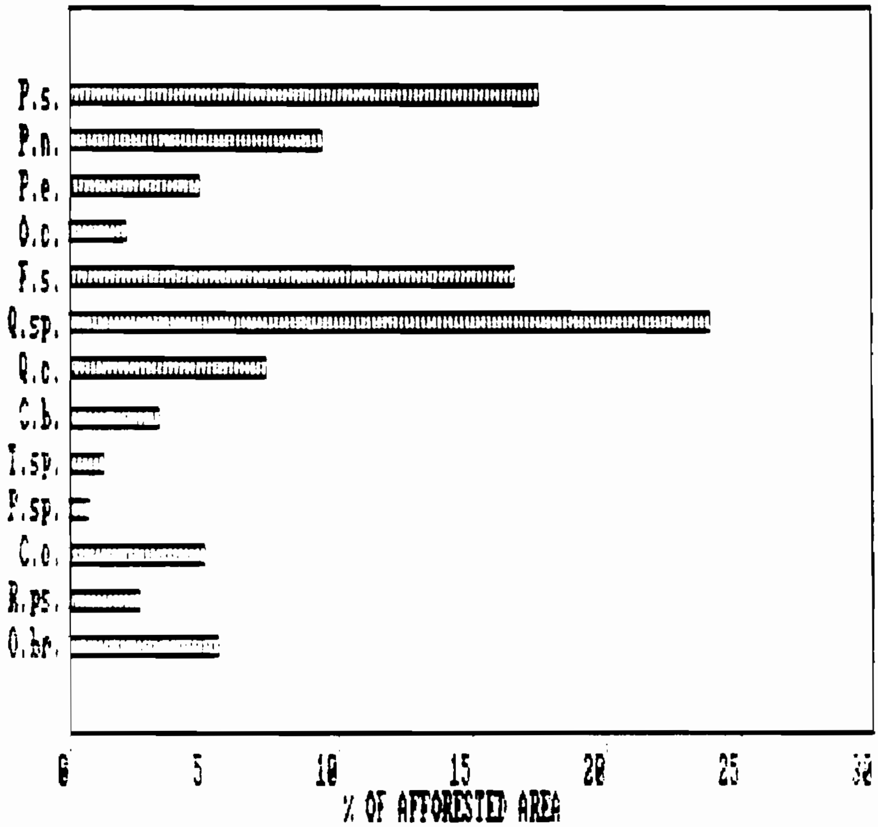
The society became aware of the need of a new approach in talling this problems, including divelopment of a nationwide permanent sample plots network, new monitoring methods, new tools and methods for laboratory analyses, development and implementation of computer models and an active collaboration within Europe, East European countries, IIASA et al.

2. FOREST DAMAGE DATA

Forest damage data set for Bulgarian forests is still very poor. In fact there is not any official report or publication with reliable summerised information for forest damage possibly due to air pollution. The existing data consern mainly acid rains in some regions near big domestic pollution sources and mountains (Argirova at al., 1986). The increased mortality in scotch and austrian pine plantations was explained with cold winters and dry summers in recent years.

*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

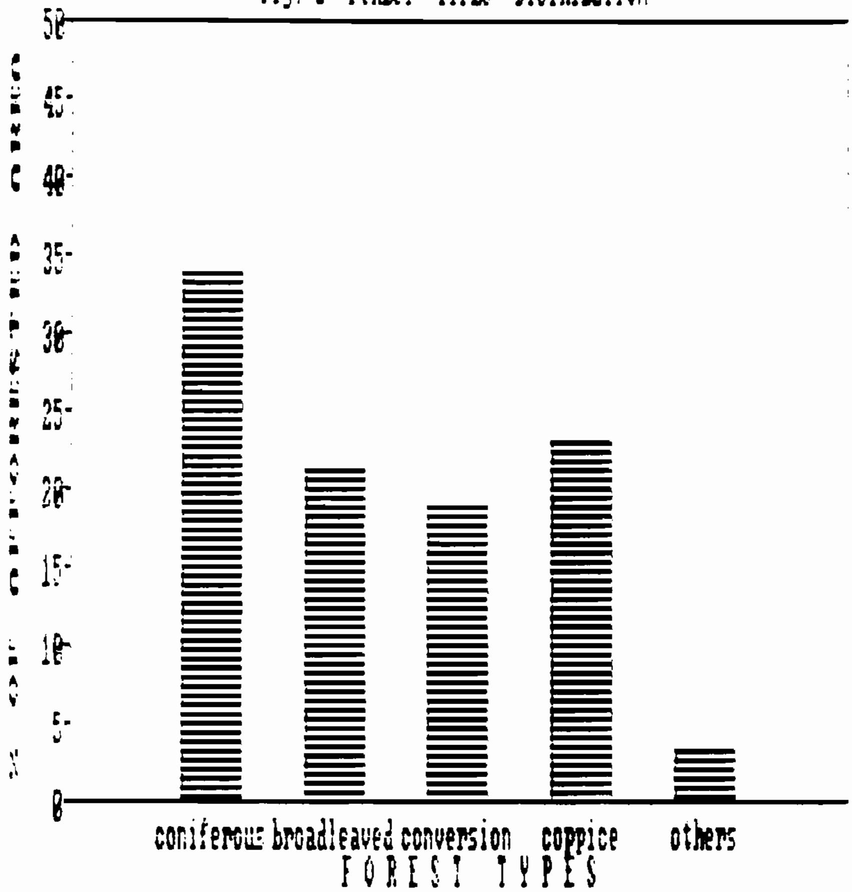
Fig. 1. TREE SPECIES DISTRIBUTION



P.s. - Pinus silvestris
P.n. - Pinus nigricans
P.e. - Picea excelsa
O.c. - Other coniferous
F.s. - Fagus silvatica
Q.sp. - Quercus spp.
Q.c. - Quercus cerris
T.sp. - Tilia spp.
C.b. - Carpinus betulus
C.o. - Carpinus orientalis
R.ps. - Robinia pseudoacacia
P.sp. - Populus spp.
o.b. - Other broadleaved

In order to get more realistic picture of the present situation, a nationwide research project is currently being carried out in Bulgaria into the effects of air pollution on forest ecosystems. A monitoring network comprising around 300 permanent sample plots will be estableshed. The purpose of the network is to provide a base for determing the current state of the forests and for monitoring future changes in their condition. The project is a joint effort between the Committee for Enwironment Protection, the Higher Institute of Forestry and Forest Technology and Forest Research Institute. The work has started in 1986 and 50 permanent sample plots are already established. The results are still very preliminary to be presented.

Fig. 2 FOREST TYPES DISTRIBUTION



A - Coniferous forests
B - Broadleaved hight forests
C - Broadleaved low forests
D - Forests for conversion
E - Other forests

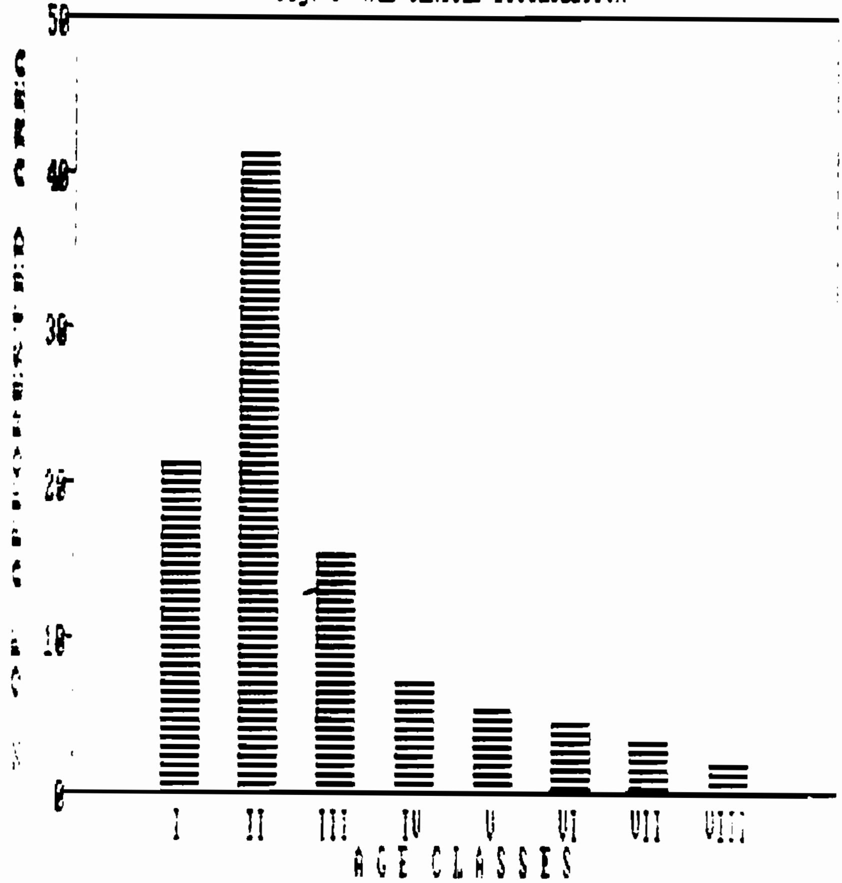
The monitoring methodology adopted is coordinated with the coordinating centers West and East.

3. FOREST RESOURCES STRUCTURE

The general characteristics of the forests in Bulgaria related to their stability and disturbance carrying capacity are: species composition, age and management forest types structure, natural to man-made forests ratio et al.

A characteristic feature of Bulgarian forests, compared with the Central and North European forests is their greater

Fig. 3 AGE CLASSES DISTRIBUTION

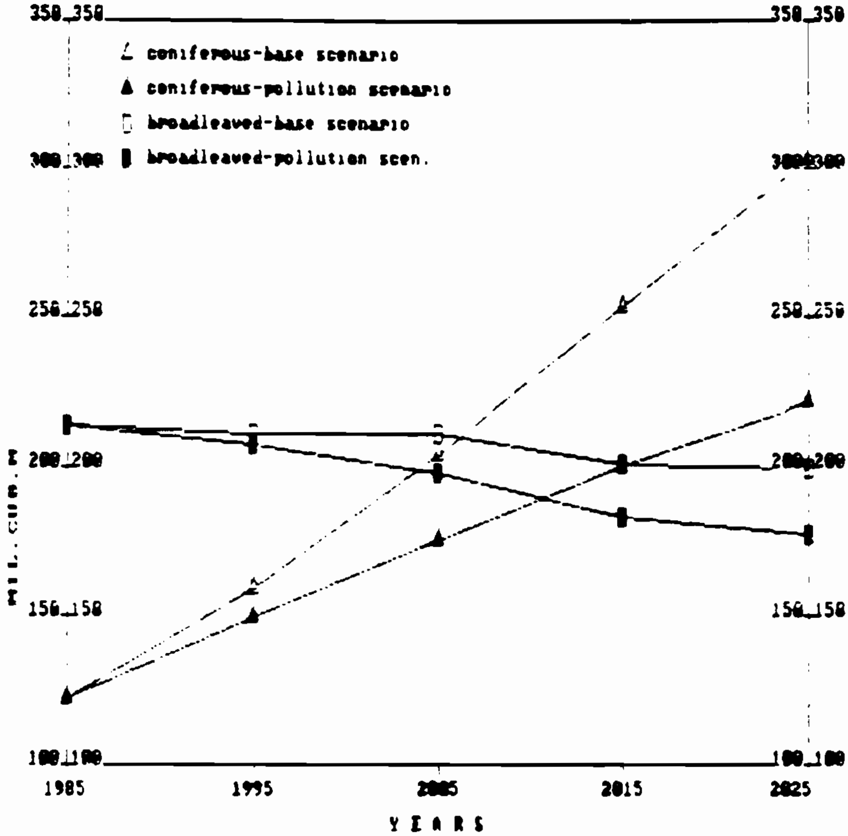


diversity (Fig.1.). The percentage of the area of the coniferous forests in 1985 was 33.8, incl. scotch pine - 17.5 %, austrian pine - 9.4 %, spruce - 4.7 %. The broadleaved forests (66.2 %) are presented by oaks - 23.9 %. beech - 16.6 %, turkey oak - 7.3 % et al. The mixed forests dominate. In spite of the fact that the advantages of mixed forests,regarding their productivity, are still not verified (see e.g. Auclair, 1983) the most of the foresters belive that mixed forests are more resilient than the poor ones.

A large part of the broadleaved forests are low forests which are intended to be converted into high forests and very low productive coppice stands for convertion (mainly) into coniferous forests (Fig. 2.). which usually become mixed single- or two-storied pine-broadleaved stands.

The grater part of Bulgarian forests are young (Fig. 3.). The average age is 30 years. This age structure from management point of view is not favourable but due to the better vitality of younger stands their stability is expected to be a higher one. The ratio of natural to man-made forests is approx. 80 to 20 %.

Fig. 4 A FORECAST OF THE GROWING STOCK



4. POSSIBLE FUTURE DEVELOPMENT

The possible future developments of the growing stock and annual harvest are predicted by a Forest Resources Dynamics Model (FRDM). The model was developed primarily for forecasting the forest resourses structure in a medium and long-range for the strategic planing of the forest sector (Dakov et al., 1986).

Two scenarios were used. In the first one (named "base scenario") it was assumed that the level of forest damage now is low and there will be no increase up to the year 2020. The development of forest resources will depend only on adopted management policies. For the second scenario it was assumed that the forest damage depicted by defoliation classes distribution and percent of air covered vill increase up to the year 2000 and then a slight decrease will occure. The increment loss for a 10 years period (in %) was intended to be 15, 30 and 70 % for 1, 2 and 3-rd class respectively for coniferous species and 5,10 and 30 % for 1, 2 and 3-rd class for broadleaved. The second scenario was named "pollution scenario".

Fig. 5 A FORECAST OF THE TOTAL GROWING STOCK

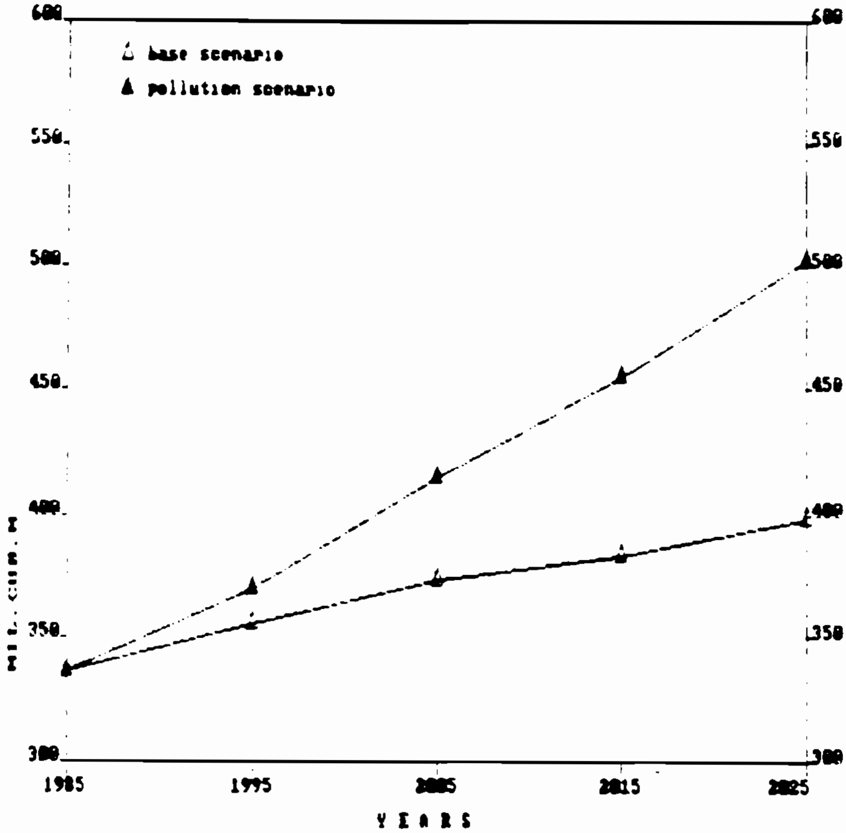
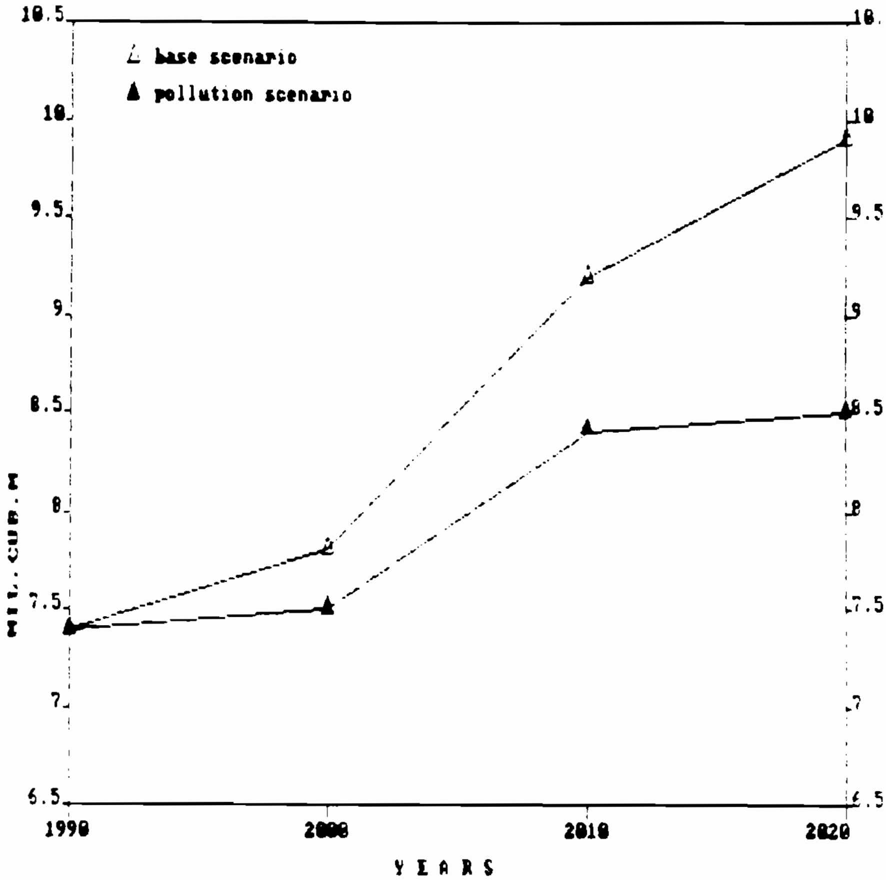


TABLE 1 "Pollution scenario" assumptions

	1985-95		1995-2005		2005-2015	2015-2025	
Defoliation classes	1	2	2	3	2	1	2
% of damaged area	50	50	75	25	100	50	50
Increment reduction for 10 years period in % :							
a) coniferous	15	30	30	70	15	15	30
b) broadleaved	5	10	10	30	5	5	10

Fig. 7 A FORECAST OF THE TOTAL ANNUAL HARVEST



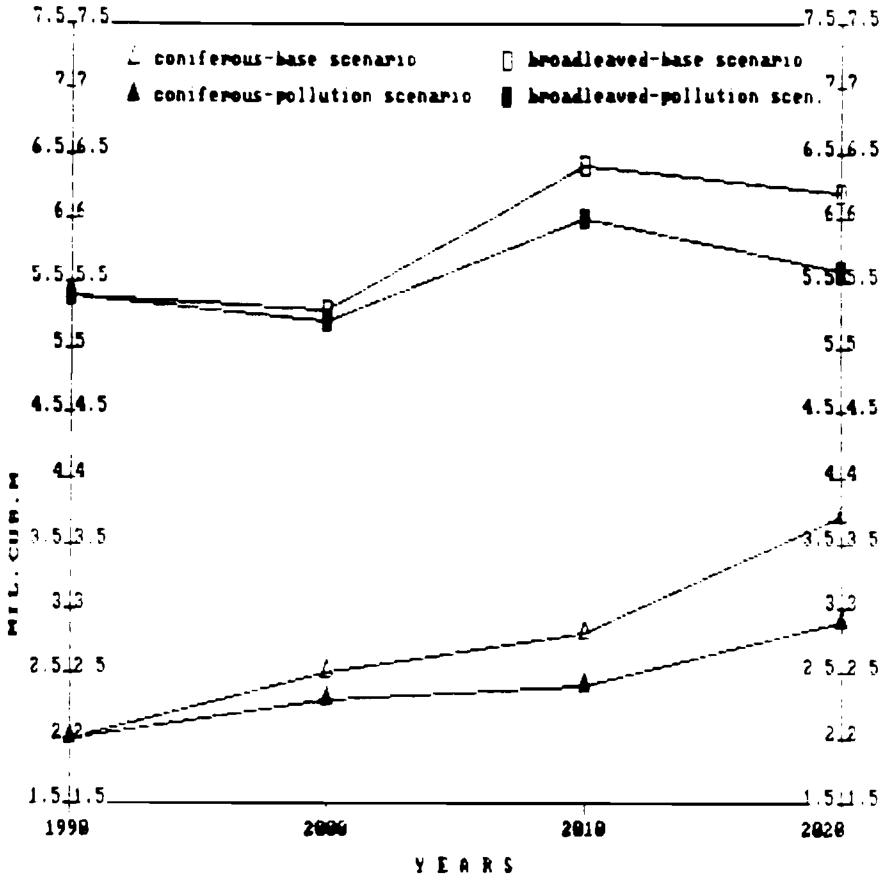
The consequences of those assumptions are that the total growing stock (Fig.5.) within the period of 40 years (1985-2025) will be reduced and reach approx. 400 million cub.m.in 2025 instead of approx. 500 million according to the base scenario.

The reduction of coniferous growing stock for the same year is expected to be approx. 70 mill.cub.m and of broad-leaved tree species - approx. 30 mill.cub.m (see Fig.4.).

As a result of assumed decrease of annual increment and growing stock, the annual harvest also decreases and in 2020 it will be approx. 1.5 mill.cub.m less compared with the base scenario (Fig. 7.).

The dynamics of annual harvest by tree species groups is shown on Fig. 6. The decrease at the end of the period is aprox. 0.8 mill. cub.m for coniferous and 0.7 mill. cub.m for broadleaved. The annual harvest due to increased mortality

Fig. 6 A FORECAST OF THE ANNUAL HARVEST



of damaged trees was not taken in account.

As a summary it should be stressed that the "pollution scenario" and the results generated by the model are hipotetical. We hope that having in hand the results from the national monitoring system and within the efforts of national teams and in collaboration with IIASA's projects, European Coordination Centers et al., a new set of scenarios would be tested and better results would be available.

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4.5 TARGET FOREST AND PLANNING OF FOREST REGULATION*

H. Kurth and D. Gerold
Technical University of Dresden
Dresden, GERMAN DEMOCRATIC REPUBLIC

ABSTRACT

The sustained yield is an objective inherent law of economical management und thus a basic principle of intensive forestry. It consists in securing the natural conditions of the forest reproduction, i.e. in ensuring an optimum, continuous growth process by a stable forest structure. The extension of the normal forest as a theoretical ideal system it necessary due to new, changed social conditions and the deeper penetration into the structure and behaviour of the ecosystem. The target forest is the externally stabilized state of equlibrium in the structural development of the dynamic system of sustained yield unit. The target forest is the result of a forecast of the real forest an it is the product of the reflection of a realistical and dynamic development process. The development to the target forest is aimed at not exclusively by planning of man, but it is also "forced upon" by the environmental influence. With consideration of the targets for the composition of the (tree) species, the age-class-, density- and site-class-structure a target forest was established by a simulation model for a real sustained-yield unit consisting of six management classes of tree species. An exemple is given in the workshop.

1. Introduction

The sustained yield is an objective inherent law of economical management and thus a basic principle of intensive forestry. It consists in securing the natural conditions of the forest

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reproduction, i. e., in ensuring an optimum, continuous growth process by a stable forest structure. For the forest regulation the question arises how planning is possible more realistically, and thus more adapted-to-the-site, when the real forest development is known. Obviously, the real development of the structure differs considerably from the ideal assumptions made for the classical normal forest. The dialectic of ideal and reality proves to be a crucial question for progress of knowledge in forestry concerning an adapted-to-the-site regulation of the structural behaviour of forests and thus for the derivation of target forests.

2. Content and Constitution of a Target Forest

The first concrete target conceptions on the managed forest originated in the form of the normal forest at the end of the 18th/beginning of the 19th century. As a theoretical ideal system, it constitutes the theoretically widest framework of knowledge on the ecosystem forest and, therefore, it should be better disignated as an ideal forest. Its extension is necessary due to new, changed social conditions and the deeper penetration into the structure and behaviour of the ecosystem. The development from the ideal forest to the present-day conceptions of management-class models and models for sustained-yield units must be interpreted as a uniform process, the system relations must be reflected more and more realistically and new findings must be continuously derived from these models. The process of development is not yet concluded. The following aspects must be in the centre of further considerations:

- the precise and complete characterization of all the individual targets concerning the forest with respect to target object, target content, target amount and target date
- the analysis of the target relations and the solution of possible target conflicts
- the coupling of the individual targets to obtain a target hierarchy, a target forest.

The content and constitution of target forests is dependent on the state of knowledge of man on the ecosystem. The derivation of target forests demands a deeper and deeper penetration into the system relations. Starting from a system analysis, the following definition is proposed:

The target forest is the externally stabilized state of equilibrium in the structural development of the dynamic system of sustained-yield unit. In the hierarchical structure of categories of forest areas, the sustained-yield unit is the forest area for which an adapted-to-the-site growing-stock structure should be strived for. It consists of stands as the smallest relevant units and management classes with different functions and tree species. The target forest must include individual targets for the following criteria:

- Targets for the whole sustained-yield unit:
  1. a target for the composition of tree species
  2. targets for improving the soil fertility
  3. targets for the opening-up of forests and division into compartments, subcompartments and stands
  4. a target for the volume
  5. a target for the current increment
  6. a target for the total yield according to quantity, structure and quality
  7. targets for beneficial effects
- Targets for yield-regulation classes:
  1. a target for the rotation period
  2. a target for the age-class distribution
  3. a target for the volume
  4. a target for the current increment
  5. a target for the overall utilization according to quantity, structure and quality
- Targets for spatial management classes:
  1. stable shelter
  2. stable border protection

- Targets for stands:
  1. a target for the density of stocking
  2. a target for the productive time
  3. a target for the target type of stocking
  4. a target for the production target
  5. a target for the size, form and width of areas
  6. a target for the establishing and opening-up of stands

The mentioned individual targets have to be examined with respect to their target relations and a target pyramid has to be created by coupling them via target chains and levels.

3. Possibilities for Establishing a Target Forest

The real state of a sustained-yield unit is the result of all adverse factors and technical and silvicultural measures which have affected this sustained-yield unit so far. Even after one and a half to two centuries of planned forestry in the region of the GDR it has not been possible to achieve the optimum forest structure. Therefore, it is necessary to establish realistic target forests which represent an objective reference level for the sustained-yield regulation.

In the figure 1 the connection between real, ideal and target forests is shown (cp. KURTH/GEROLD, 1984; GEROLD, 1986).
It is found that the target forest is no abstract model. It is always
- integrated in the social and economic conditions,
- valid for a concrete sustained-yield unit and
- valid for a specific time.

The following steps are necessary for the establishment of a target forest:
1. Analysis and assessment of the real forest of the sustained-yield unit and, if available, also of the previous forest development in the past.
2. Analysis of the environmental states and their effects on the development of the forest structure.
3. Analysis of the effect of control measures by man on the development of forest structure and the environmental states.

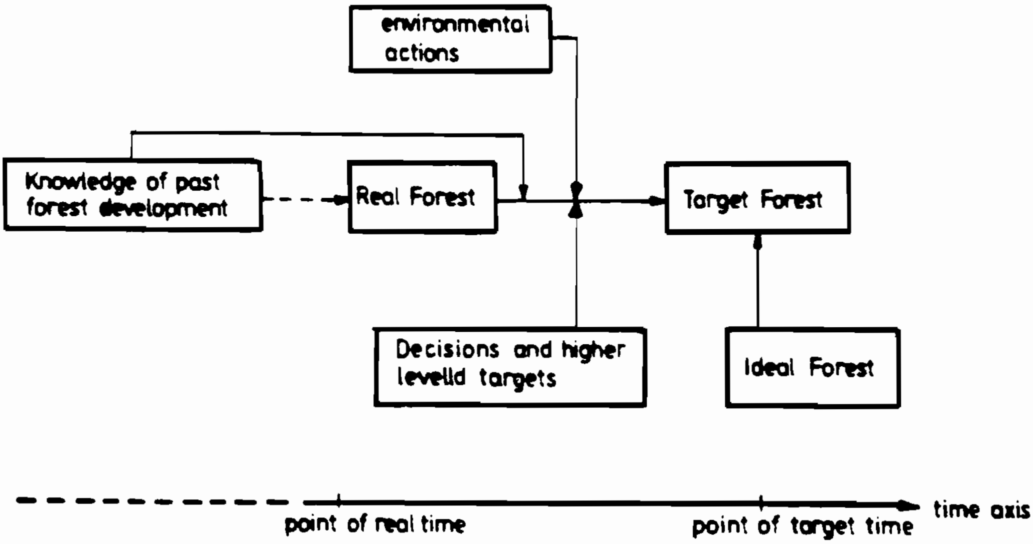

Fig. 1: Relationship between real, ideal and target forests

4. Establishment of the target forest, taking into account the decisions, formulations of goals, environmental effects and control measures by means of a simulation model.
5. Assessment of the established target forest and comparison with the real and ideal forests.

As the mentioned steps show, the target forest is the result of a forecast of the real forest of the sustained-yield unit and it is the product of the reflection of a realistic and dynamic development process. The development to the target forest is aimed at not exclusively by planning of man, but it is also "forced upon" a sustained-yield unit by the environmental influence. The task set to man consists in minimizing this constraint by improving stability. For the establishment of target forests the hierarchy of silvicultural sustained-yield units should be taken into account. Target forests should be established primarily for the sustained-yield units of the lowest order, i. e., the conservancy or the state forest enterprise. The target structures of sustained-yield units of a higher order result from aggregation, in general.

4. Fundamentals for the Establishment of a Target Forest

Of the individual goals already mentioned the following are analysed in the course of the establishment of the target forest:

1. Composition of tree species
2. Age-class distribution
3. Structure of volume-related stocking degrees (density of stocking)
4. Quality structure, site-class-structure

It is proceeded from the assumption that the target forest and the ideal forest have an equal composition of tree species. The structure of volume-related stocking degrees of the target forest is between that of the real forest and the volume-related stocking degrees of 1.0 of the ideal forest. One starts from a realizable, minimum mortality rate of the stand volume (KURTH/DITTRICH, 1984). The target site-indices were slightly improved as compared with the real values. This corresponds to an increase of the average site-indices of the management classes by 0.2 to 0.4 units. The differences between the ideal and target age-class distributions are exemplified by the management class of spruce in figure 2.

It is found that the target age-class distributions are "skew on the left" and suggest a realizable, minimum mortality rate per area prior to the final felling according to plan (KURTH/DITTRICH, 1984).

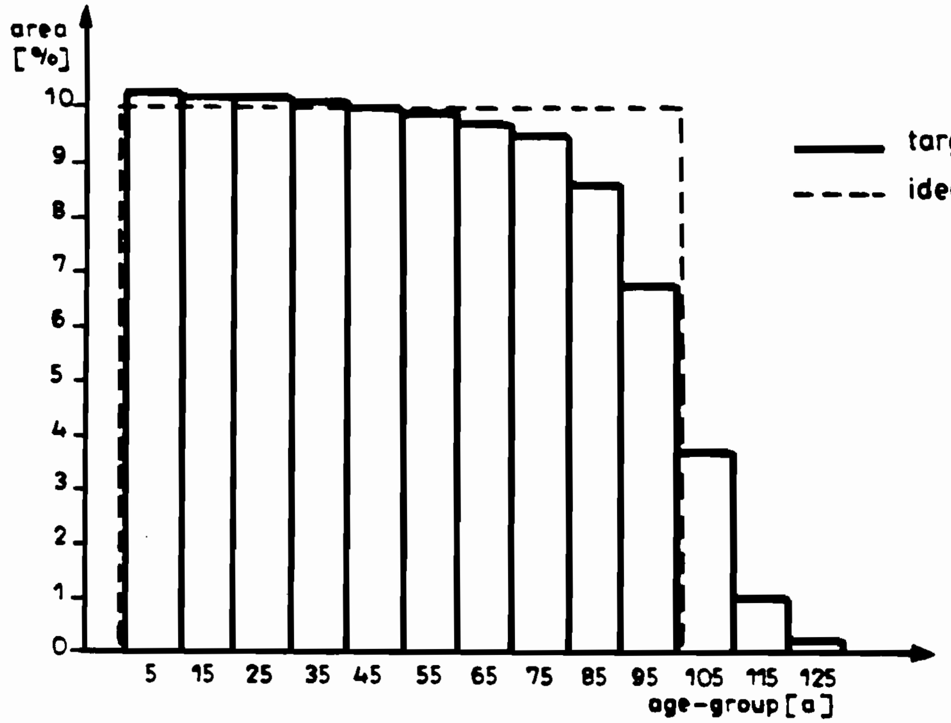

Fig. 2: Comparison of the ideal and target age-class distributions of a management class of spruce

5. Example of a Target Forest

With consideration of the targets for the composition of tree species, the age-class distribution and the structures of volume-related stocking degrees and site-indices, a target forest was established by a simulation model for a selected real sustained-yield unit consisting of six management classes of tree species. In table 1 this target forest is compared with the real and ideal forests by significant characteristics. The comparison leads to the following results:

- The target volumes lie below the ideal volumes by 7 to 15 per cent, by 13 per cent on an average. The real volume of the sustained-yield unit differs from the ideal volume by 28 per cent, but from the target volume by only 17 per cent.

Table 1: Comparison of different characteristics of the real, target and ideal forests

Characteristic	Real Forest	Target Forest	Ideal Forest
<u>1. Management class of pine</u>			
volume (m^3/ha)	145	190	215
current increment (m^3/a.ha)	6.7	6.9	7.1
total yield (m^3/a.ha)	3.5	6.9	7.1
mean final age (a)	89	102	110
<u>2. Management class of spruce</u>			
volume	222	275	310
current increment	8.2	9.4	9.9
total yield	6.1	9.4	9.9
mean final age	87	97	100
<u>3. Management class of beech</u>			
volume	291	215	230
current increment	7.9	7.2	7.6
total yield	8.1	7.2	7.6
mean final age	115	135	130
<u>4. Management class of oak</u>			
volume	201	192	207
current increment	5.9	6.2	6.5
total yield	4.8	6.2	6.5
mean final age	112	135	140
<u>5. Management class of soft broadleaved wood</u>			
volume	116	135	159
current increment	4.2	4.5	4.2
total yield	2.7	4.5	4.2
mean final age	50	66	90
<u>6. Management class of hard broadleaved wood</u>			
volume	154	168	180
current increment	4.8	4.4	4.6
total yield	3.6	4.4	4.6
mean final age	75	98	100
<u>7. Sustained-yield unit</u>			
volume	173	208	240
current increment	6.8	7.4	7.7
total yield	4.4	7.4	7.7
therefrom realizable		6.4	

- The target values for the current increment and the total yield are by 3 to 5 per cent lower than the ideal values, with the exception of soft broadleaved wood.
- The real current increment of the sustained-yield unit differs from the ideal increment by 12 per cent, but from the target increment by only 8 per cent. For the total yield the differences of 43 and 41 per cent, respectively, are considerably greater.
- The ratio of intermediate yield/final yield of 45 : 55 per cent of the ideal forest shifts to 50 : 50 in the target forest.
- The mean final ages of the target management classes are lower than the rotation periods of the ideal management classes, with the exception of beech.

The differences between the target age-class distribution and the ideal age-class distribution of the management classes have also effects on some characteristics which are important for the sustained-yield regulation of forest management as well as the practical cultivation of forests:

1. The area of final felling and thus also the regeneration area of the target forest increases by 2 to 36 per cent in accordance to the management classes.
2. The new-growth and young-stand area to be tended increases by 1 to 6 per cent, by 4 per cent on an average, as compared with the ideal forest.
3. The area of the middle-aged stands to be thinned is reduced by 1 to 7 per cent, with the exception of pine.

The investigations show also that not all of the grown wood of the target forest is utilized by the national economy. This non-realized increment of 1 cubic metre per year and hectare, i. e., 20 per cent of the total timber volume to be removed, is of a considerable order of magnitude. On the one hand, it should be regarded as a reserve in the management by system which has to be made accessible more intensively and, on the other hand, one should proceed from the fact that losses are a feature of production bound to nature which cannot be fully eliminated.

6. Application of the Target Forest in Forest Regulation

With the target forest there is given for the first time an achievable goal of forest development - though a long-term one - which is different from the ideal forest in significant characteristics. The transition from the ideal forest to the target forest leads to an improved level and a gain in reality in the sustained-yield regulation. Target forests have effects on the inventory, planning and control of forest regulation. The following aspects or demands are essential:

- Forecasts are an important component of the whole process of planning, since they mark out the framework for the medium-term planning. Any medium-term planning must be embedded in long planning-horizons. Medium-term plannings plot the way towards the goal.

- The regulation of the system structure is very important. Of special importance for the planning of forest regulation are interactions between the composition of tree species and the age-class distribution. The models for the yield regulation and the strategy of forest regeneration should be thought out from this angle.

- The application of transition probabilities for the age-groups constitutes a new quality of the connection of yield regulation and production regulation. By this, for the first time the determination of the area of final felling, the selection of the areas of final felling and the mean final ages are seen in connection with the development of the age-class distribution of management classes.

- The target-forest investigations unambiguously emphasize the importance of the cycle of volume, current increment and total yield for all cases of planning of forest regulation. The non-realized increment and the establishment and liquidation of management classes should be taken into account in particular. The effects of the non-realized increment on the updating of the data store of forest fund (recording of forest operations), on the effectiveness of tending operations and on long-term forecasts are considerable.

- The formation of management classes for specific goal formulations is of great importance (functions of a forest, intensity levels, inter alia). From this point of view, besides yield tables for stands there should be prepared "tables for management classes".
- The rotation periods have to be newly determined with consideration of the goals for the age-class distribution, the volume-related stocking degree and the site-index structure.

In all investigations on target forests there are examined both, planned and random influences on the development of the forest structure. This allows also much better statements for all subsequent economic calculations.

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4.6 AIR POLLUTION, GROWTH AND YIELD EFFECTS AND LESSONS*

A.J. Grayson
Forestry Commission
Alice Holt Lodge, Wrecclesham
Farnham, Surrey, UK

Abstract

As well as their direct implications for the economy and environment, the effects of air pollution on the growth and decline of trees, both observed and assumed, have important lessons for forest scientists. Familiar concepts such as the doctrine of uniformitarianism may have to be discarded and severe tests of adaptability to changed circumstances are imposed. The paper outlines the stages of conventional procedures of yield planning, running from models of growth and potential yield under different environmental and cutting regimes, through descriptions of the growing stock to the selection and application of a criterion that satisfies prevailing objectives. An example is presented to illustrate the effects of increment reductions as shown through an application of the British system of planning the cut. Uncertainties in the steps leading to the final plan are discussed and implications for biological and economic research identified.

INTRODUCTION

The forest scene changes more rapidly today than ever before and speedier adjustment is called for if the collapse of either forests or forestry as an activity is to be avoided.

It is sometimes argued that foresters cannot and should not adjust to keep pace with the vagaries of demand. This is only defensible as a thesis where changes in demand are thought of in terms of every small perturbation in the outside economic and political climate. But where trends emerge on time scales of years but over very much shorter periods than a single crop rotation, foresters ignore the signals displayed by society at peril. Thus, in Britain, considerable areas of old woodland, often of low timber value but of major ecological and conservation interest, were cleared for agriculture during the 1950s. Now, thanks to the contribution of science in such fields as plant and animal breeding, crop nutrition and protection, the area required by agriculture with these technologies and intensities of cropping is falling and tree planting is proposed as an activity to absorb surplus resources of land, labour and entrepreneurship. In another sphere, uncertainties about future energy supply lead to the proposal that demand for energy cannot be satisfactorily met unless novel technologies such as short rotation coppice for biofuel are developed.

It is less likely that foresters will ignore changes on the supply side of their own livelihood, such as new technologies for growing trees, and it would be absurdly short-sighted not to take account of changes in the biological or physical environment which may seriously damage forests,

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reduce growth, and even kill trees. It is a strange commentary on fortune that changes on the supply side of forestry such as air pollution may be causing the loss of forests and uncertainty about the practicability of their replacement while in other regions changes on the supply side in agriculture lead to new planting of high site quality land promising a new source of the sawlogs and other assortments no longer available elsewhere. There is indeed an even more bitter irony in the raising of renewable energy crops which may themselves contribute to air pollution in due course.

DAMAGE AND RESPONSE

Certain sorts of damage to trees are more important for their effects on the environment than on their impacts on timber production and income from that activity. A notable example is the killing of most of the elms (Ulmus spp) in Britain as a result of the activity of an aggressive strain of Ophiostoma (= Ceratocystis) ulmi (Burdekin, 1983). For traded products, the loss of a source of supply is, because of immediate impacts on income and employment, often more directly observed by people than a loss of non-tradeables such as landscape or nature conservation. Nevertheless, in considering the impact of air pollution on forests it is important to attempt an assessment of the values at risk in both categories. In this paper reference is made solely to timber value impacts but the importance of balancing efforts in this field with studies on environmental aspects should be stressed. Recognition of this point emphasises the need to apply techniques such as contingent valuation (see Grayson, 1987) which may help policy makers to grasp what have often, pessimistically, been termed 'intangibles'.

The two essential requirements faced by foresters in regions which display the symptoms of forest decline on a significant scale are

a. knowledge of the effects,

b. ability to change management practices.

In particular, information is required in order to allow predictions to be made of the consequences for increment, yield, watershed protection, recreational value, etc. of different courses of action. The ability to change management practices, such as felling age, regeneration technique and species, in the light of knowledge is necessary if foresters are to act rationally. It is even possible that the critical factor which the Conference is considering may require such changes as will influence practice in other areas and in the longer term in ways which might not occur without such a shock to the system.

DAMAGE ASSESSMENT AND PREDICTION

Perhaps the greatest single difficulty surrounding the current debate about forest decline is the lack of clear evidence on effects arising from wide-scale air pollution as opposed to other anthropogenic factors (such as poor choice of species) or natural events (such as droughts). Until this difficult problem is solved the prognosis of rational responses is hazardous. We are woefully ignorant of the influence of climatic factors alone on tree growth in unpolluted air, and, as Dong and Kramer (1986) emphasise, a combined effort of involving a number of disciplines is called for (see also Rollinson, 1986). An example of the sort of approach is that being followed by Lonsdale (1986) in whose study measures of twig extension of beech (Fagus silvatica) are being combined with studies of insects, fungi, climate and soil. Apart from the difficulties of noise in the system generated by the weather of a given season, there are sources of variation, presumably of a genetic kind, in the trees themselves that influence interpretation and may be selectively influenced. Thus growth differences between healthy, sickly and more seriously diseased trees help one to gain an idea of dependences between crown damage and vigour but these cannot be automatically extrapolated to whole stands.

Quite as important as the observation and disentangling of effects is the building of a model of increment reduction for application in scenarios such as those by Dykstra and Kallio (1986). Model generation is one thing, model fitting another. Where the data are thin and the theoretical basis weak, the main value of model building lies in stimulating further study (see, for example, Hari, Raunemaa and Hautojärvi, 1986) rather than providing a definitive solution.

A WORKED EXAMPLE

The purpose of the illustration provided below is simply to indicate one way of assessing sensitivity to alternative assumptions on both the pollution/increment relationship and pollution variation over time.

There are many approaches that may be used to simulate the consequences for volume and revenue production of changes in environmental conditions which influence growth and hence the yield of forests. The method of predicting yield normally adopted in British forestry management is based on the use of yield tables specifying particular cutting regimes and volume yields. The favoured regime for a specific type of stand (distinguished by species, year of planting, original spacing, expected maximum mean annual increment and cutting regime) is then applied to the area of stands of that type and the resulting quantities summed across the forest. In selecting the particular yield model, the criterion is generally that the cutting regime adopted is the one expected to maximise net discounted revenue at 5%, but provision is made for variation of both thinning practice and felling age in order better to satisfy either wood requirements in the short term (up to 5 years) or certain environmental objectives, such as landscaping or wildlife conservation in specific areas over rather longer periods.

Assuming that pollution, or any other damaging influence, has a known effect on the increment of a stand, it is of course possible to construct an increment model for a given cohort of stands so as to take into account the effect over a particular period of calendar time of an influence such as that arising from damaging combinations of atmospheric pollutants. The calculation is necessarily complicated since it is believed that the effects of such damaging influences differ with age of stand. The process of calculating such models and applying them to the various cohorts of stands constituting the growing stock, while feasible, would however create a rather heavy computing load.

Instead of using this approach, a short cut has been adopted in the calculations leading to the results presented here. While a variety of thinning regimes can be applied the one assumed in this paper is of thinning being conducted at a constant rate, or thinning intensity measured in cubic metres per hectare per year, equal to 70% of maximum mean annual increment. This is broadly expected to be the intensity which, with the price-size relationship applying in Britain, appears to yield the maximum discounted revenue at modest discount rates [1]. The short cut method of assessing thinning yield adopted here is to reduce the normal yield by the reduction factor on increment. Thus, in the presence of a given level of pollution it is assumed that increment to age 30 will fall to, say, 0.9 times normal, and to progressively lower values with advancing age. Thinning yields are thus calculated at 70% times the particular reduction factor for the age concerned. Given the yields from thinning, felling volumes are computed as the residual from total increment less cumulative thinning yield.

Revenues may then be calculated by first regressing mean tree volume on cumulative volume per hectare separately for thinnings and fellings, secondly estimating mean tree volumes for thinnings made at various ages and for fellings at age 55 from these relationships, thirdly using these mean volumes to identify prices per cubic metre and so to calculate revenues year by year, and finally discounting to 1986.

For simplicity a typical species and growth rate for British conditions has been adopted. Table 1 sets out the yields predicted for Sitka spruce, Yield Class (maximum mean annual increment in $m^3 ha^{-1} y^{-1}$) 12 planted at 2 m. spacing. This spacing implies a slight loss of volume (producing a maximum mean increment of 11.7 m^3) compared with 1.4 m. spacing. The final column shows discounted revenue calculated at 5%: this culminates at 55 years.

Reductions in current increment are modelled on the assumption of the relationships shown in Figures 1a and b which are based on the evidence to hand on effects: two are assumed to cover a range of possible intensities of pollution and subsequent loss (see, for examples of loss estimates in older stands, Dong and Kramer 1986, Kenk et al 1985, Kramer 1986 a, b, Schöpfer and Hradetzky 1986). One assumes a reduction to 85% of normal increment at age 50, the second to a heavy reduction to 70%. In addition a profile of increment reduction with age has to be nominated: these are assumed level at 0.9 and 0.8 respectively until age 30.

In order to produce results representative of real forest estates, calculations of yield are based on an age-class distribution up to 55 years very similar to that existing in conifer stands in Britain (Table 5, Locke 1987) and also, for comparison, a normal forest on the same rotation.

Figures 2 and 3 illustrate the pollution scenarios explored, the profile for each running over the period 1900 to 2040 and indicating the effect on reduction in current annual increment at age 50. Combined with the profiles of Figure 1, it is thus possible to generate the increment in any year for a stand of given age. The effect of the base level of pollution on the yield over one rotation is shown in Table 2. It will be seen that for this yield model also, discounted revenue culminates at *ca* 55 years.

Table 3 sets out the results for 'normal' production of wood and discounted revenue, compared with the 4 pollution scenarios of Figure 2 affecting increment at each of two levels, for the two age-class distributions.

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(1) In practice a slightly higher intensity is probably capable of yielding a higher discounted revenue but caution suggests that the reserve of growing stock produced as a result of a slightly lower thinning cut is useful in the provision of wood to new mills adding to wood-using capacity over the next two decades.

TABLE 1 Yield model for Sitka spruce (*Picea sitchensis*) planted at 2 m. and thinned

Age, years	Main crop		Thinnings		Total volume, $m^3\,ha^{-1}$	Discounted revenue at 5% £ ha^{-1}
	Mean volume, m^3	Volume, $m^3\,ha^{-1}$	Mean volume, m^3	Volume, $m^3\,ha^{-1}$		
20	0.04	66	0.00	0	66	
25	0.06	90	0.05	42	132	
30	0.12	131	0.10	42	215	229
35	0.21	181	0.17	42	307	530
40	0.34	232	0.27	42	400	822
45	0.49	278	0.39	42	488	1039
50	0.65	320	0.52	39	569	1184
55	0.81	358	0.66	34	641	1248
60	0.98	391	0.79	30	704	1216
65	1.13	420	0.91	26	759	1151
70	1.26	444	1.02	23	806	1078

TABLE 2 Yield model for Sitka spruce assuming 'base case' increment reduction from date of planting

Age, years	Main crop		Thinnings		Total volume, $m^3\,ha^{-1}$	Discounted revenue at 5% £ ha^{-1}
	Mean volume, m^3	Volume, $m^3\,ha^{-1}$	Mean volume, m^3	Volume, $m^3\,ha^{-1}$		
20	0.03	60	0.00	0	60	
25	0.06	81	0.04	38	119	
30	0.10	118	0.08	38	194	147
35	0.18	163	0.14	37	276	383
40	0.28	208	0.22	37	357	608
45	0.39	248	0.32	36	434	780
50	0.52	285	0.42	33	504	884
55	0.64	317	0.52	29	565	932
60	0.76	345	0.61	25	618	933
65	0.87	369	0.70	21	663	891
70	0.97	388	0.78	19	701	832
75	1.05	388	0.85	19	732	832

It should be noted that in the yield tables and the analysis presented in this paper, it is assumed that to the extent that current increment is affected by the kind and level of components of current pollution only, past increment reductions caused by past pollution having no effect beyond leading to production of a smaller tree on which subsequent growth is laid. Secondly it should be emphasised that the form of the increment response relationship with age is a simplified one. It seems probable that the reduction may be an increasing function of age rather than a linear one.

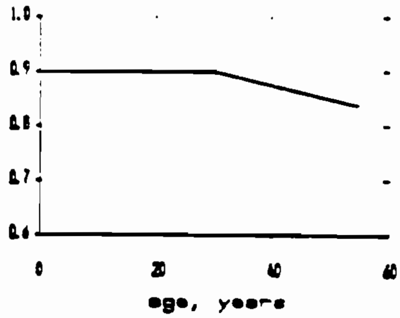

Figure 1a. Effect of pollution on current increment: base case.

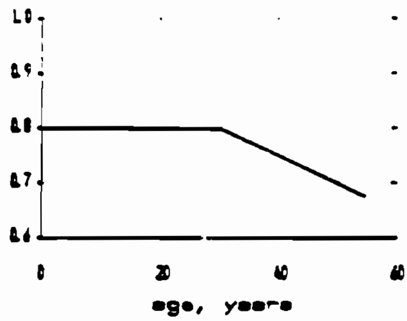

Figure 1b. Effect of pollution on current increment: worse case.

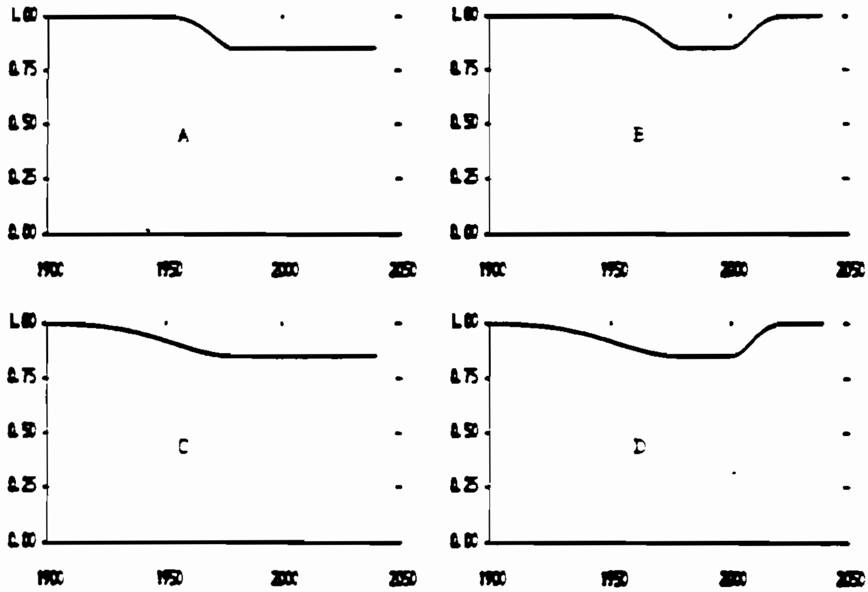

Figure 2. Timecourse of pollution effect at fifty years: base case.

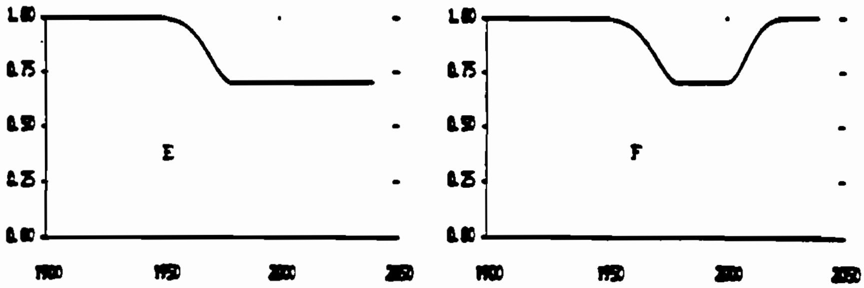

Figure 3. Timecourse of pollution effect at fifty years : worse case.

TABLE 3 Total volume production and discounted revenue 1986-2040 relative to unpolluted case = 100

	Pollution scenario	age-class distribution			
		normal forest		'young' forest	
	base case	volume	discounted revenue at 5%	volume	dis-counted revenue at 5%
A	sudden, then level from 1975	89	81	89	78
B	sudden, followed by remission	93	83	93	82
C	gradual, then level from 1975	88	77	88	76
D	gradual, followed by remission	92	80	92	80
	worst case				
E	sudden, low level flat from 1975	78	63	77	58
F	sudden, followed by remission	86	67	86	66

Three conclusions flow from the results presented above.

a. There are marked differences between losses in volume production over the period compared with reductions in discounted revenue. This is because tree size and hence price is depressed as well as volume.

b. There are no marked differences between the results for the young forest compared with the normal forest. In almost all cases it happens that the volume reduction is exactly the same for the two forests, and the reduction in discounted revenue is only marginally greater for the 'young' forest. This is partly because the age-class distribution is not exceptionally concentrated in one range of ages, and partly because a rather long phase of increment reduction is assumed even in cases B, D and F.

c. The results show clearly that the most vital concern is the level of the effect on increment. The worst case (Figure (b)) assumes twice the reduction of the base case and this relationship is easily seen in the results for the whole forest.

If the current effect attributed to pollution is known, the major policy interest concerns the result in increased growth, and hence volume and revenue, of pollution abatement. Comparing cases A and B, C and D it will be seen that the gains of 1 percentage point in volume and 2 to 3 percentage points in discounted revenue arise from abatement beginning in 2000 and completed in 2025. Subsidiary calculations of abatement beginning 10 years earlier show gains of 2% in volume and a dramatic 3 - 4% in discounted revenue.

FURTHER CONSIDERATIONS

An extension of the point about the pollution-increment relationship is the age profile. If the picture given in Figures 1a and 1b is at all realistic, this emphasises the desirability of maintaining vigorous stands, which necessarily implies those with higher increment and therefore younger. In this regard the need to reconsider management practices hitherto maintained according to uniformitarian principles may well become paramount.

A technical consideration concerns the manner in which damage is described. If damage can be identified, then its importance to managers is economic and these effects are expressed through growth. Growth differs with age, species, site class and other factors and one cubic metre of growing stock in the form of 100 year old trees will be affected very differently from the same volume in the form of 40 year old trees in the same forest. It may thus be more useful to describe damage in terms of volume increment but since this cannot be directly observed it is necessary to use area subdivided by appropriate maturity classes.

It is assumed here that it is usual forestry practice in moderately intensively managed forests to remove any trees that die. Indeed it is common practice in many forests to deal with recent mortality in this way, as with windthrow and even more urgently with trees killed by insects. There may however be circumstances in old stands and in forests with a high proportion of such stands where mortality may rise rapidly. The removal of such material over a short period may well have repercussions on marketing. But when mortality does rise rapidly and can be foreseen there may be little else that can be done. It is unlikely that such effects will arise contemporaneously over large areas so that the effects should be manipulable via intra- or international trade.

CONCLUSIONS

The analysis described here is no more than a simple piece of micro-economics in which it is tacitly assumed that there are no effects on costs and prices arising from changes in the cut. Circumstances may differ on the grander scale of a region. In particular, prices of assortments produced from older trees will tend to fall and encourage earlier and faster felling of such stands, while, in the process of adjustment of markets for different assortments, prices of small roundwood may rise if harvesting resources limit the scale of the total cut. Other contributors to the Conference will discuss models which aim to derive equilibrium solutions taking full account of likely supply responses. The purpose of this paper is to draw attention to three principal points.

i. The critical consideration is the identification of effects in which air pollution is implicated. At present the features used to describe tree condition centre on damage to the crown and in particular in development, decline and death of recently produced shoots and leaves. These may be poor proxies for increment reduction.

ii. We need to know more precisely than so far the effects on increment across species, ages, etc. and whether there are correlations with past effects. Given the noise in growth records associated with climate and since we are woefully ignorant of the climatic factors controlling growth in unpolluted air, the prospects for attaining this goal do not appear good.

iii. Measures which ensure a higher average level of current increment are desirable from the point of view of reducing the level of increment loss otherwise sustained: quite apart from this, such measures may well produce a higher return on the forest capital, a result which has its own attraction. Such a shift will often require an alteration in goals as a result of a new perception forced on forest managers. It is a common feature of business life that change only occurs when the pressures become intolerable: perhaps forest management, like life itself, evolves largely as a result of the administration of shocks.

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5. NATIONAL AND SUBNATIONAL CASE STUDIES ON FOREST DECLINE

5.1 RED SPRUCE (PICEA RUBENS SARG.) DECLINE IN THE NORTHWESTERN UNITED STATES: REVIEW AND RECENT DATA FROM WHITEFACE MOUNTAIN*

A.J. Friedland and J.J. Battles
Department of Geology-6316
University of Pennsylvania
Philadelphia, PA, USA

1. INTRODUCTION

It appears that red spruce (Picea rubens Sarg.) in the northeastern United States have undergone a decline during the last twenty years. Some of the recent observations on red spruce include: 1) a deterioration of the visible condition of foliage in the crowns of canopy trees; 2) a reduction in basal area during the last twenty years in at least two forested regions of New York and Vermont; 3) a reduction in tree ring-widths that began during the 1960's.

In this paper, we review the evidence and symptoms of the decline of red spruce in the northeastern United States and we present detailed information on red spruce density and basal area from one area, Whiteface Mountain in the Adirondacks of New York. Possible causes of the decline are discussed.

2. THE NATURAL HISTORY OF RED SPRUCE

Red spruce is a long-lived (greater than 350 years), shade-tolerant, coniferous species that is an important component of the low-elevation boreal forests of Maine and eastern Canada. It is often found with balsam fir (Abies balsamea (L.) Mill) and white birch (Betula papyrifera (Marsh) Regel). It occurs in the eastern United States along the Appalachian Mountain chain from New England to Georgia. In the northern Appalachians, red spruce are most important in an elevational band from approximately 800 m to 1200 m. The elevational range of red spruce increases towards the south. In the southern Appalachians, red spruce are most abundant from 1600 m to approximately 2000 m.

There have been a few reports of red spruce decline in North America during the past century. By examining field reports and other published and unpublished documents from the northeastern United States, Johnson et al. (1986) determined that major episodes of red spruce mortality occurred in the 1870's and 1890's. The first confirmed report of red spruce mortality appeared in 1815.

Because the high-elevation red spruce inhabit a narrow elevational band in the eastern United States, they may have become genetically isolated from the major part of the red spruce population. Wright (1955) suggests that genetic uniformity due to isolation and small population size may be a factor in the "lack of success of spruce species." While the causes and agents responsible for periodic mortality of red spruce are not known, it has occurred a number of times in the past century. It has not been determined if the pattern and degree of the present red spruce decline is differ-

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ent from previous declines.

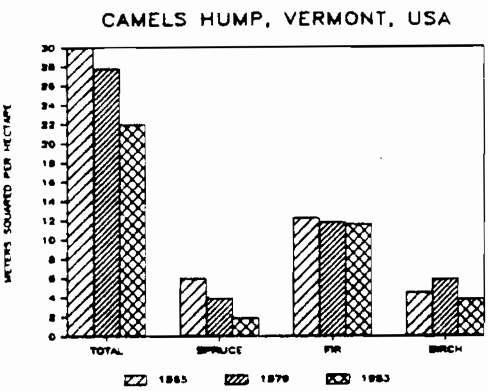
3. HISTORICAL COMPARISONS OF DENSITY AND BASAL AREA

Plot studies were conducted at two locations in the northern Appalachians (Vermont and New York) and one location in the southern Appalachians (Virginia). These studies allow a comparison of density and basal area of red spruce between the present and twenty years ago.

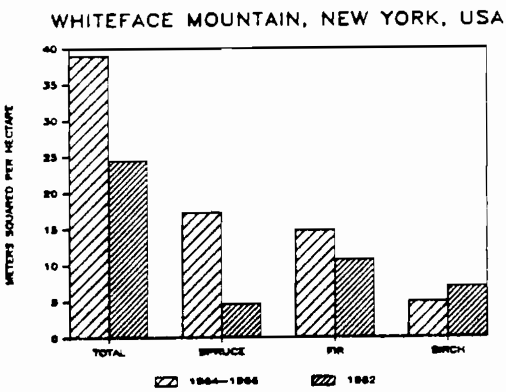
3.1 Camels Hump, Vermont, USA

Camels Hump is a 1245-m peak in the Green Mountains of Vermont. Permanent vegetation plots were established on the west slope of Camels Hump in 1964 to 1966 (Siccama, 1974). The area in which the plots were established is considered undisturbed during the past three centuries (Siccama, 1974). The permanent vegetation plots were remeasured in 1979 (Siccama et al., 1982) and in 1983 (unpublished data, H. Whitney, Univ. of Vermont). Total area of the plots was 8300 m^2. Because all three measurements were done by or in consultation with one person, T.G. Siccama, there is a high degree of confidence that the data from the different sampling intervals are comparable.

In the forests above 880-m elevation, red spruce density decreased by 52% in the greater than 10-cm dbh (diameter at breast height) size class between 1965 and 1979. Red spruce basal area decreased by 44% during that same time period (Fig. 1a). From 1965 to 1983, red spruce basal area decreased by more than 60% while the basal area of balsam fir and white birch did not change (Fig. 1a).



(1a)



(1b)

FIGURE 1 Change in basal area for three species on (a) Camels Hump, Vermont (live trees > 2-cm dbh) and (b) Whiteface Mountain, New York (live trees > 10-cm dbh). Data are from Siccama et al. (1982), Scott et al. (1985) and H. Whitney, Univ. of Vermont, unpublished.

3.2 Whiteface Mountain, New York, USA

Whiteface Mountain is a 1483-m peak in the Adirondacks of New York, approximately 100 km west of Camels Hump. Some parts of Whiteface Mountain were logged and burned in the early 1900's. Vegetation plots were established in 1964 - 1966 and plots in the same general area were resampled in 1982 (Scott et al., 1985). The authors were "highly confident" that most of the high-elevation plots were relocated accurately.

Only results from the high-elevation plots (above 900 m) that were relocated precisely are shown here (Fig. 1b). As at Camels Hump, the decrease in red spruce basal area was large (60 - 70%). At Whiteface, unlike Camels Hump, there was a significant decrease in balsam fir basal area. When this was investigated, it was attributed to blow-downs of balsam fir from wind storms. The decrease in basal area of red spruce was not attributed to wind (Scott et al., 1985).

3.3 Mount Rogers, Virginia, USA

Five stands were measured at 1700-m elevation on Mount Rogers in southwestern Virginia in 1982 and 1983 (Stephenson and Adams, 1984). Results from this study were compared to a study conducted from 1954 to 1961 by Shields. Stephenson and Adams did not discuss the comparability of methods used in the two studies. They did state that their study area was in the same approximate area as the earlier Shields study (Stephenson and Adams, 1984).

The basal area of red spruce (greater than or equal to 10-cm dbh) was 7.1 m^2 ha^{-1} in 1954 - 1961 and 9.3 m^2 ha^{-1} in 1982 - 1983. This is an increase of 31%. While these numbers cannot be considered with the same degree of confidence as those for the northern Appalachians, it appears that the decrease in basal area found in the Adirondacks and Green Mountains is not evident in Virginia.

4. SURVEY OF HEALTH AND VIGOR IN THE EASTERN UNITED STATES

In 1982 Johnson and Siccama (1983) surveyed red spruce populations in six states in the eastern United States. At each site, transects were established at one or more elevations and evaluations of the health of the canopy were made. Crown vigor was determined qualitatively and grouped into four categories: 1-little or no needle loss; 2-some needle loss with less than 50% defoliation; 3-greater than 50% needle loss; 4-no live foliage. Loss of foliage was characterized as usually occurring from the top of the crown down, and from the tips of the branches inwards (Johnson and Siccama, 1983). This dieback from the top down and tips in is the most characteristic symptom of spruce decline in the northeastern United States.

In the northeast (New York, Vermont, New Hampshire), percent mortality and percent of red spruce with greater than 50% foliar loss (crown vigor classes 3 and 4) were positively correlated with elevation. The authors noted that many stresses increase with elevation (e.g. colder temperatures, higher winds, thinner, more nutrient poor soils). The elevational trend was not apparent in the southeast (W. Virginia, Virginia and North Carolina). Sampling sites in the northeast had a higher percent dead spruce and spruce with foliar loss than did sampling sites in the southeast. There was no relationship between percent red spruce in vigor class 3 and 4 and basal area of the stand which demonstrates that it was not competition and stand maturity which contributed to the foliar loss (Johnson and McLaughlin, 1986).

At each sampling site, increment cores were taken from dominant trees.

At all sites, many cores showed the appearance of abnormally narrow annual increments between 1960 and 1970. In many cases, the abnormally narrow rings continued until the time the core was taken. The most frequent year that annual rings began to narrow was 1966. Johnson and Siccama (1983) reported that 1964 to 1966 was the driest period in this century for the northeast. However, there was no moisture stress in the forest on Camels Hump above 900-m elevation (Siccama, 1974). From analysis of the increment cores, it appeared that the more-or-less synchronized decrease in ring width across sites was unprecedented. Of course, only those trees that survived previous declines were alive and could be sampled during the survey by Johnson and Siccama (1983).

Pathogens were considered as a cause of the decline but no primary pathogens were found at those sites where examinations were made (Johnson and Siccama, 1983). Additional analyses for pathogens are underway at a number of spruce sites in the northeastern United States.

5. 1986 DETAILED STUDY OF WHITEFACE MOUNTAIN, NEW YORK

5.1 PURPOSE

Whiteface Mountain (44° 22' N, 73° 54' W) is one of two high-elevation sites in the northeastern United States where there is quantitative documentation of red spruce decline (Scott *et al.*, 1985)(Sections 3.1,3.2). However, Scott *et al.* (1985) and earlier studies of the vegetation (Holway and Scott, 1969) and soils (Witty, 1968) did not take into account the physical and biological diversity of the forest at Whiteface Mountain. The purpose of this study was to obtain a more thorough characterization of the species composition and mortality from 700- to 1200-m elevation on the entire Whiteface Mountain massif. Additional work (still in progress) will relate these parameters to foliar and soil chemistry and tree pathology.

5.2 METHODS

From June through November, 1986, an extensive vegetational survey was conducted. A systematic, random sampling of the forest was obtained by superimposing a twenty-one transect grid on the Whiteface Mountain massif (total area 3326 ha). A point along the primary ridge (north-south trending) was randomly located. From this origin, an initial transect was drawn perpendicular to the contour from the ridgeline down to 700-m elevation. The remaining transects were located at 750-m intervals along the ridgeline parallel to the initial transect on the northwest and southeast faces and perpendicular to the initial transect on the northeast and southwest faces. A permanent point was located at every 120-m interval (contour distance) along the transect lines. Each permanent point was the center of a 5-m radius circular plot ($78.5m^2$) in which all trees greater than or equal to 50-mm dbh were measured and recorded live or dead by species. A total of 305 plots were established. In addition, slope, aspect, elevation, landform, slope position, and microrelief were determined in these plots. Two of the transects have not been completed and those data are not included in this preliminary analysis. Analyses of soil and foliar chemistry and tree pathology are still in progress and will be reported in a future publication.

5.3 RESULTS[1]

The transect grid included what is considered the high-elevation forest (800 m - 1200 m) on Whiteface (Holway and Scott, 1969); the lower margin of the sampling area included the northern hardwood/transition forest and the upper margin included the subalpine fir forest. Three species of trees dominate the forest above 700 m on Whiteface Mountain: balsam fir (RIV[2] = 42.9), white birch (RIV = 23.8), and red spruce (RIV = 16.8). Mountain ash (Sorbus americana Marsh.), an understory species, is the only other tree that occurs frequently in the high elevation forests.

For all trees equal to or greater than 50-mm dbh in all 305 plots sampled, the total density is 2892.1 stems ha^{-1} and the total basal area is $39.2 m^2 ha^{-1}$. Approximately, seventy-five percent of all stems measured are living.

Elevation is an important environmental variable that is correlated with changes in forest composition and mortality (Holway and Scott, 1969; Siccama, 1974). On Whiteface Mountain, the total live basal area of the forest increases with increasing elevation until approximately 1000 m and then decreases with increasing elevation (Fig. 2). Total live density is positively correlated with elevation except at the very highest regions of the sampling area (Fig. 3). Analysis by species shows that live basal area and density of balsam fir steadily increase with increasing elevation (see Fig. 3) while the live basal area and density of red spruce and white birch peak in the forest between 800-m and 1000-m elevation.

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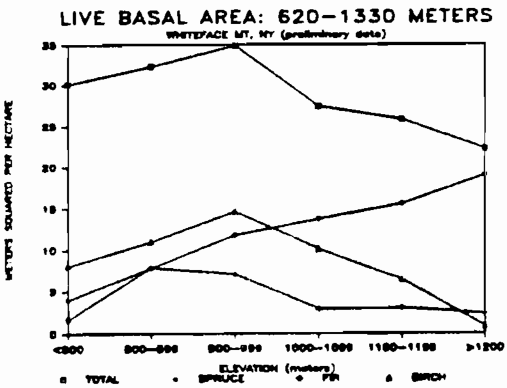
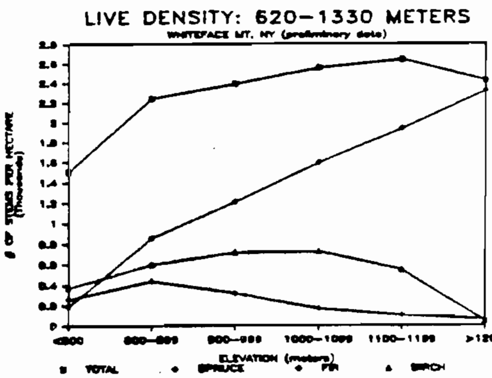
[1] These results are based on preliminary analysis of the data from the 305 plots established during the 1986 field season.
[2] RIV = relative importance value and is the mean of the relative density and the relative basal area.



(2)

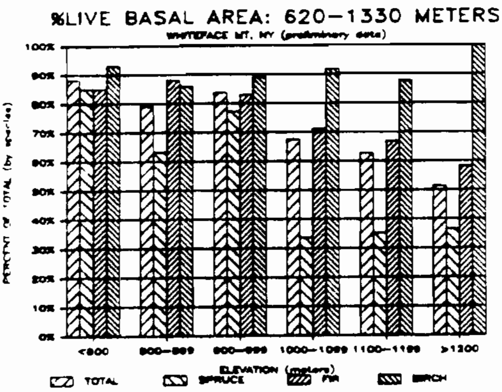


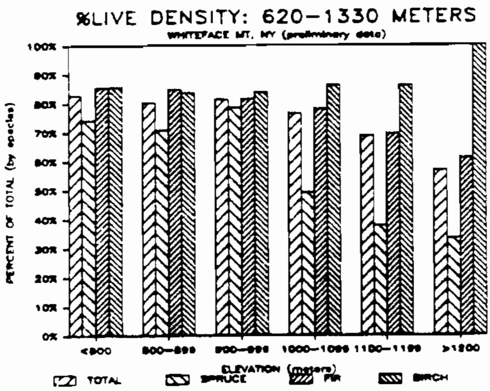
(3)

FIGURE 2. Mean basal area of live trees equal to or greater than 50-mm dbh for six elevational bands on Whiteface Mountain. (TOTAL)= all tree species, (SPRUCE)= red spruce, (FIR)= balsam fir, (BIRCH)= white birch.
FIGURE 3. Mean density of live trees equal to or greater than 50-mm dbh for six elevational bands on Whiteface Mountain. Legend as in Fig 2.

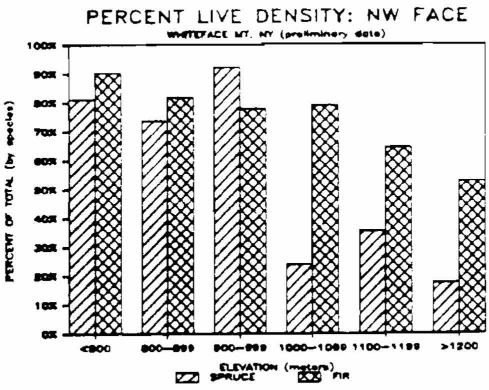
For both red spruce and balsam fir, the ratio of live trees to dead trees is significantly lower in the forests above 1000 m. While the percent live trees by basal area (Fig. 4) and by density (Fig. 5) indicates that there is a decrease in living trees above 1000-m elevation for both red spruce and balsam fir, the decline is more severe in red spruce. Between 620-m and 999-m elevation, 74% of the spruce trees are living; between 1000 m and 1330 m, 43% of the spruce are living. For fir, the percentage of live trees is 83% and 70% respectively.

Aspect is another environmental factor that influences vegetation composition. On the northwest face, the general pattern of tree mortality is similar to the trends observed for the entire mountain. However, the decrease in percent live spruce and fir in forests above 1000-m is greatest on the northwest face (Fig. 6). Below 1000 m, 80% of red spruce stems are alive; above 1000 m only 27% of the spruce stems are alive. For fir, the decrease is only half as much: below 1000 m, 81% of the fir stems are alive; above 1000 m, 64% are alive.





(4) **(5)**



(6)

FIGURE 4. Percent live basal area for trees equal to or greater than 50-mm dbh for six elevational bands on Whiteface Mountain. Legend as in Fig. 2.
FIGURE 5. Percent live density for trees equal to or greater than 50-mm dbh for six elevational bands on Whiteface Mountain. Legend as in Fig. 2.
FIGURE 6. Percent live density for trees equal to or greater than 50-mm dbh for six elevational bands on the northwest face of Whiteface Mountain. Percent live density shown for red spruce (SPRUCE) and balsam fir (FIR).

5.4 PRELIMINARY CONCLUSIONS

There is an increase in red spruce mortality with increasing elevation, particularly in forests above 1000-m elevation on Whiteface Mountain. These results agree with earlier findings in the northeastern United States (Johnson and Siccama, 1983). This increased mortality cannot be readily explained by typical stand dynamic factors (e.g. competition, succession). The significant increase in fir mortality above 1000 m has been attributed to wind generated fir waves and blowdowns (Scott et al., 1985). That the red spruce mortality is most severe for trees on the northwest face suggests that there may be more stresses associated with habitats on the northwest facing slope (e.g. wind, low solar incidence) than on the rest of the mountain. One of many environmental stresses correlated with the increase in mortality above 1000 m is an increase in orographic cloud cover. While all aspects of the mountain have some incidence of cloud cover, the cloud base on the northwest side of Whiteface is frequently at or above approximately 1000-m elevation (J. Battles, personal observation).

6. POSSIBLE CAUSES FOR THE DECLINE

In the previous five sections, we have presented the currently available evidence of and documentation for a deterioration of the red spruce populations in the northeastern United States. This deterioration does not appear to be due to senescence, stand age, drought or pathogens. It is conceivable but not readily apparent that some natural factor or factors could be completely responsible for the observed phenomenon. It is not clear but it appears likely that this decline may be equal to or greater in severity than previous declines. Pollution in remote regions far from urban centers is a relatively recent phenomenon. Because red spruce are declining more severely at higher elevations, and because the deposition of pollutants is greater at higher elevations, many investigators have examined the potential relationship between atmospheric deposition of pollutants and red spruce decline. In addition, there have been some investigations of the influence of natural factors (e.g. climate) on red spruce. In this section we will present and discuss some of the proposed causes or contributors to red spruce decline.

6.1 Climatic Influences

Cook (1985) analyzed increment cores from twenty dominant or co-dominant red spruce trees at one site in the Adirondacks of New York with a variety of dendrochronological techniques. Monthly mean daily temperatures for the current and previous growing seasons effectively predicted annual growth increment from 1750 to 1967. Beginning in 1968, those climatic variable no longer predicted annual growth increment. Cook (1985) concluded that some change in the growth environment must have occurred to cause red spruce to respond differently to the same climatic variables.

Johnson, Cook and Siccama[3] used dendrochronology to analyze approximately 700 trees from New York, New Hampshire and Vermont. They found that red spruce were adversely affected by warm temperatures in late summer and cold temperatures in early winter until the early 1960's. Beginning in the

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3 Climatic influences on the growth and decline of red spruce in the northern Appalachians. A.H. Johnson, E.R. Cook and T.G. Siccama. Unpublished manuscript.

early 1960's, those climatic variable no longer predicted annual growth increment. Previous episodes of red spruce decline also appeared to be related to climate but Johnson, Cook and Siccama[1] were unable to determine if climate alone could cause the decline.

6.2 Winter Injury

During April 1984, Friedland et al. (1984) noticed extensive browning of 1983 foliage—without damage to previous years' foliage—on Camels Hump and other mountains in Vermont. The browning and subsequent loss of needles was associated with injury during winter. Damage to only the newest needles provided an explanation for the observation that foliage loss in red spruce occurred from the top of the crown downwards and from the tips of the branches inwards (Section 4). It was suggested that foliar injury during winter was the mechanism by which red spruce obtained its visible appearance of dieback (Friedland et al., 1984). Johnson et al. (1986) found reports of winter drying of red spruce foliage from 1948 through 1983 but it is not clear if all of these incidents occurred to the newest year's foliage only. Both natural and anthropogenic factors were suggested as possible causes of the winter injury (Friedland et al., 1984).

6.3 Influence of Pollutants

As a result of greater exposure to clouds, high-elevation forests receive greater inputs of water than do low-elevation forests. Cloud water typically has a greater concentration of most elements than does rain water. Thus total elemental deposition is often greater at high elevations (Lovett et al., 1982). Because total pollutant deposition is also greater, many investigators have suggested that red spruce decline, which is more severe at higher elevations, may be related to atmospheric deposition of pollutants and exposure to pollutant gases.

Numerous hypotheses have been suggested for mechanisms by which atmospheric deposition of pollutants can damage forests, both directly to the foliage and indirectly through changes in the soil. One thorough review is by McLaughlin (1985). There have been fewer hypotheses related directly to red spruce.

Adverse effects of acidity and metals to red spruce have been hypothesized but convincing field evidence has not been available (Johnson and Siccama, 1983). The adverse effect of excess or untimely nitrogen inputs to trees has been suggested by Nihlgard (1985) in Europe and by Friedland et al. (1984) in the northeastern United States for red spruce. The hypothesis suggests that untimely or excessive uptake of nitrogen compounds may disturb physiological processes related to winter hardening which, in turn, leads to winter damage of the newest foliage (Friedland et al., 1984). In a study of red spruce foliar chemistry at high and low elevations in northern New York and Vermont, Friedland, Hawley and Gregory[4] found distinct elemental patterns with elevation. During the growing season, nitrogen concentrations in current year foliage were greater at high-elevation plots than at low-elevation plots. The concentrations of Ca and Mg were significantly greater at the low-elevation plots. Thus the ratio of nitrogen to Ca and Mg was much higher at the high elevation plots. A related finding was that Ca, Mg and P concentrations in northern New York and Vermont appear to be lower than any other values for red spruce reported in the literature. While

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[4]Spruce and fir foliar chemistry in northern Vermont and New York. A.J. Friedland, G.J. Hawley and R.A. Gregory. Unpublished manuscript.

these findings are not conclusive, they suggest that low and high elevation trees have different elemental ratios. Such differences may affect physiological processes that could lead to differences in the health of low and high elevation trees.

At least two recent studies suggest that ambient levels of ozone in the northeastern United States can affect productivity of forest tree species without producing visible symptoms. Reich and Amundson (1985) showed that, in the greenhouse, net photosynthetic rate in a number of forest trees decreased with increasing ozone concentrations. Wang et al. (1986) found that quaking aspen (Populus tremuloides Michx.) saplings exposed to ambient levels of ozone had shorter shoot lengths and shorter leaf retention times than those trees that were exposed to filtered air. While these results do not necessarily pertain to mature trees or to red spruce, they do suggest yet another possible agent in red spruce decline.

There is research currently underway to test the relationship between the currently observed symptoms of red spruce decline and a number of atmospheric pollutants, including ozone and nitrogen. Additional research is aimed at determining if changes in red spruce mesophyll cells precede visible injury to foliage. Ultrastructure injury to red spruce (Friedland et al., 1984) may be similar to that reported by Soikkeli and Karenlampi (1984) and could be related to pollution.

7. CONCLUSIONS

It is not clear what is causing the current deterioration of red spruce populations in the northeastern United States. It is possible that a number of stresses are acting simultaneously to bring about the observed pattern of symptoms. If this is the case, it may be extremely difficult or even impossible to identify and isolate in an experimental setting one specific cause of red spruce decline. Certainly the following factors merit further research (modified from Johnson and McLaughlin, 1986): 1) stand dynamics resulting from succession and maturation of the stand; 2) biotic diseases; 3) repeated injury during winter due to climatic change or altered tree physiology; 4) effects of atmospheric deposition of pollutants; 5) a combination of the above factors.

8. ACKNOWLEDGMENTS

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5.2 FOREST DECLINES IN MAJOR FOREST TYPES OF THE EASTERN UNITED STATES*

M.J. Weiss and D.M. Rizzo
USDA Forest Service, Northeastern Area
Forest Pest Management, Durham, NH, USA

1. INTRODUCTION

Forests cover 156 million hectares or 34 percent of the total land area of the Eastern United States (USDA Forest Service 1982). Over 90 percent of the forest area is suitable for commercial timber production with softwood types on 39 million hectares and hardwood types on 100 million hectares (USDA Forest Service 1982). Softwood types include loblolly-shortleaf pine on 20 million hectares, oak-pine, longleaf-slash pine, fir-spruce, and white-red-jack pines. The most extensive hardwood type is oak-hickory which dominates on 44 million hectares of commercial timberland (USDA Forest Service 1982). Other major hardwood types include the maple-beech-birch, elm-ash-cottonwood, and aspen-birch.

Records of insect and disease damage to these forests extend back to the late 1800's, when the first forest entomologists and pathologists began their work in the Eastern United States (Hartley 1950, Knight and Heikkenen 1980). Many insects and diseases have since been reported to cause damage. For example, the spruce budworm and southern pine beetle are two native insects that have caused extensive tree mortality (USDA Forest Service 1985a). During the late 1800's and early 1900's, several forest insects and diseases were accidentally introduced into the Eastern United States, sometimes with devastating consequences. The most notable example is chestnut blight, a fungus disease which destroyed the valuable American chestnut resource and permanently altered the species composition of the eastern hardwood forest. Other examples of introduced diseases and insects are Dutch elm disease, beech bark disease, and the gypsy moth, all of which are continuing to spread to new areas and cause damage. Information on forest diseases in the United States has been summarized by Hepting (1971); information on forest insects in the Eastern United States has been summarized by USDA Forest Service (1985b).

At various times, widespread tree mortality has occurred when no single agent appeared to be responsible. These tree problems have been referred to as "declines" (Houston 1981, Manion 1981). Several factors have been commonly involved in declines including insect defoliation, root diseases, and drought. In this paper, we review the more important tree declines that have been reported in the Eastern United States. We have restricted our discussion to declines which have occurred over wide geographic areas in natural forest stands. Problems specific to forest plantations and urban trees are not included.

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

2. SOFTWOOD DECLINES

2.1 Red Spruce and Balsam Fir Decline

In recent years, large numbers of overstory red spruce, Picea rubens Sarg., and balsam fir, Abies balsamea (L.) Mill., have died in mountainous areas of the northeastern United States (Johnson and Siccama 1983). In a 1984 survey, heavy mortality of overstory red spruce and balsam fir was found to have occurred on an estimated 23,500 hectares or 28 percent of the spruce-fir slope cover type (stands with more than 50 percent spruce or balsam fir) in the Adirondack Mountains of New York, 5,000 hectares or 9 percent of this type surveyed in Vermont, and 30,900 hectares or 43 percent of this type surveyed in New Hampshire (Weiss et al. 1985). Red spruce mortality (in these heavy mortality areas), averaged 15.8 percent in the Adirondacks, 12.1 percent in Vermont and 14.0 percent in New Hampshire; balsam fir mortality averaged 5.8 percent in the Adirondacks, 14.4 percent in Vermont and 5.2 percent in New Hampshire (Weiss et al. 1985). Natural regeneration of red spruce and balsam fir was highest in those stands with heavy overstory mortality, indicating that as overstory trees die, the stands are being re-stocked (Weiss et al. 1985). Growth rates of overstory red spruce and balsam fir have declined in these same forests (Hornbeck and Smith 1985, Hornbeck et al. 1986); however, growth rates have been increasing in other softwood and hardwood species studied in Vermont and New Hampshire (Hornbeck et al. 1987). In West Virginia, about 3,200 hectares or 7 percent of the total forest land with red spruce was recently found to have overstory mortality in excess of 10 percent (Mielke et al. 1986). A decline of red spruce and associated Fraser fir, Abies fraseri (Pursh) Poir., has been recently reported in the Appalachian mountains of the Southern United States (Bruck 1985). In a 1984 survey of the red spruce-Fraser fir type on six Southern Appalachian mountains, overstory mortality in excess of 33 percent was found to have occurred on about 537 hectares or 19 percent of the total area of the type (Ciesla et al. 1986).

Several factors have been associated with mortality and growth loss of red spruce and balsam fir. The spruce beetle, Dendroctonus rufipennis Kirby, was reported to be the cause of widespread mortality of red spruce in the northeast in the late 1800's and early 1900's (Hopkins 1901, New York State Conservation Dept. 1938, 1939) and in recent years, has been detected killing trees in the Adirondacks and New Hampshire (USDA Forest Service 1984, McCreery et al. 1986). Factors associated with both growth loss and mortality at lower elevation sites in the northeast include eastern dwarf mistletoe, Arceuthobium pusillum Peck, a parasite of red spruce (Hawksworth and Shigo 1980), and the shoestring root rot, Armillaria mellea (Vahl:Fr.) Kummer (Carey et al. 1984). Strong winds damage the roots and crowns of overstory trees growing at higher elevations leading to growth loss and mortality (Harrington 1986). The reduction in growth rates may also be associated with normal maturation of these forests (Hornbeck et al. 1986). Acid precipitation has been suggested as another possible cause of the decline in mountainous areas of the northeast (Siccama et al. 1982, Johnson and Siccama 1983), and research has begun to determine whether this or other forms of regional air pollution have contributed to the decline. Cytospora canker, Valsa kunzei Fr., was commonly associated with branch mortality and may be contributing to the mortality of red spruce in West Virginia (Mielke et al. 1986). Mortality of overstory Fraser fir on Mt. Mitchell in North Carolina has been associated with attacks of the balsam wooly adelgid, Adelges piceae Ratzeburg, an introduced insect (Witter and Ragenovich 1986). In northeastern Vermont, extreme northern New Hampshire, and northern Maine, extensive mortality of red spruce and balsam fir has occurred in recent years following several successive years of defoliation by the spruce budworm, Choristoneura fumiferana Clem., (Brann et al. 1985, Kucera and Taylor 1983).

2.2 Littleleaf Disease

Littleleaf, a serious disease of shortleaf pine, Pinus echinata Mill., was first noted in 1934 (Campbell and Copeland 1954). It occurs on about 6 million hectares or 35 percent of the commercial shortleaf pine growing area east of the Mississippi River and has been severe enough on 2 million hectares to seriously interfere with management plans (Campbell and Copeland 1954). The disease affects trees older than 20 years, with death occurring an average of 6 years after the appearance of the first symptoms (Mistretta 1984). In addition to shortleaf pine, loblolly pine can also be affected but to a lesser extent.

The exact cause of littleleaf has not been determined. Several factors have been associated with the disease, including poor internal soil drainage, nitrogen deficiency, periodic water stress, and death of fine roots (Campbell and Copeland 1954). The root fungus, Phytophthora cinnamomi Rands, may be a major factor responsible for death of the fine roots (Mistretta 1984), but the role of this organism in the disease complex is not completely known (Manion 1981).

2.3 Other Softwood Declines

Declines have been reported in some other softwood species. For example, within the past few years, mortality has been reported on several thousand hectares of eastern larch, Larix laricina (Du Roi) Koch, in New York, Vermont, New Hampshire and Maine (USDA Forest Service 1986). Mortality has reached 100 percent in some stands. Armillaria sp. and the eastern larch beetle, Dendroctonus simplex LeConte, have been commonly associated with the dying and dead trees (USDA Forest Service 1986).

In the southeastern United States, growth rates in natural stands of loblolly and other yellow pines have slowed over the past 30 years (Sheffield and Cost 1987). Several possible causes are being studied including increased stand density, increased hardwood competition and air pollution, but so far results are inconclusive. The slower growth rates have not been accompanied by mortality or outward signs of tree deterioration.

Emergence tipburn of eastern white pine, Pinus strobus L., has been associated with exposure to ozone (Berry and Ripperton 1963). This needle blight has been reported intermittently in numerous locations since the beginning of this century (Berry and Ripperton 1963, Hepting 1964). Although eastern white pine is affected by ozone and a variety of insects and diseases, reports of widespread decline or mortality are lacking. No prolonged periods of decreasing growth occurred between 1900 and 1980 in the New England States (Hornbeck et al. 1987).

3. HARDWOOD DECLINES

3.1 Oak Decline

Oak declines have been reported from many areas across the Eastern United States during the past 100 years. These outbreaks have covered thousands of hectares, with mortality up to 100 percent in some stands (Houston 1981, Nichols 1968, Tainter 1985). Numerous species of oak have been affected including northern red, *Quercus rubra* L., scarlet, *Q. coccinea* Muenchh., pin, *Q. palustris* Muenchh., and black oak, *Q. velutina* Lam., in the red oak group and white, *Q. alba* L., and chestnut oak, *Q. prinus* L., in the white oak group (Wargo et al. 1983). Recent reports of oak decline have come from New York, Maryland, Virginia, Iowa, and Missouri (USDA Forest Service 1985c).

Oak decline is generally thought to be stress initiated (Staley 1965, Wargo et al. 1983). Important abiotic stresses are drought, waterlogging, and frost. Poor site conditions, such as ridgetops, sandy soils, and wet areas, may predispose trees to attack by insects and diseases (Staley 1965). Insect defoliators are the primary biotic stress factors. Defoliators that have been associated with oak decline include the gypsy moth, *Lymantria dispar* L., oak leaftier, *Croesia semipurpurana* Kearfott, and forest tent caterpillar, *Malacosoma disstria* Hubner, (Nichols 1968). Actual death of the trees is usually caused by attacks by one or more secondary organisms. The two most common are the twolined chestnut borer, *Agrilus bilineatus* Weber, and *Armillaria mellea* (Wargo et al. 1983).

3.2 Maple Decline

Several symptomatically distinct declines of sugar maple, *Acer saccharum* Marsh., have been reported in the United States in this century (Hepting 1971, Westing 1966). These declines have occurred in unmanaged forest stands as well as in stands managed for production of maple syrup (sugar-bushes) and in maples growing along roadsides.

Maple decline in forest stands is initiated by a stress factor such as drought or insect defoliation (Giese et al. 1964, Griffin 1965, Houston 1981). Major insect defoliators include the saddled prominent, *Heterocampa guttivitta* Walker, forest tent caterpillar, leafrollers, and webworms (Giese et al. 1964, Griffin 1965, USDA Forest Service 1964). Secondary organisms, such as *Armillaria mellea* and *Stegonosporium ovatum* (Pers.:Merat) hasten the death of trees (Giese et al. 1964, Houston 1981). Mortality and dieback of sugarbush maples in the northeastern United States is not completely understood although numerous damage agents have been associated with the decline. These include drought, defoliation, heavy grazing, and over-tapping (Hepting 1971, Houston 1981). In turn, trees under stress are more susceptable to root diseases, decay, and other diseases (Houston 1981). Decline of roadside maples has been associated with use of road salt (Hepting 1971).

3.3 Ash Dieback

Dieback and decline of white ash, *Fraxinus americana* L., was first reported in 1925 from Canada and in 1930 from the United States (Ross 1966). A survey conducted during the mid-1960's found that 27 percent of the ash trees in the northeastern United States were dead or dying (Tegethoff and

Brandt 1964). Ash dieback is still reported from the northeastern and midwestern states at the present time although the occurrence of the disease has stabilized (USDA Forest Service 1986).

Over the years, a number of hypotheses have been proposed to explain ash dieback. Important initial stress factors include drought, climatic change, edaphic factors, and localized air pollution (Houston 1981). Crown dieback may be due in part to canker fungi, such as Cytophoma pruinosa (Fr.) Hohn and Fusicoccum sp., that are considered secondary invaders (Houston 1981, Ross 1966). Recent work has implicated a mycoplasmalike organism and viruses as possible causal agents of ash dieback in the Northeast (Castello et al. 1985, Matteoni and Sinclair 1985).

3.4 Birch Decline

Several separate declines of birch have been reported in the Eastern United States. A decline of yellow birch, Betula alleghaniensis Britton, and white birch, B. papyrifera Marsh., was initially reported in the early 1930's from New Brunswick, Canada (Clark 1961). The decline was subsequently noted in Nova Scotia and Quebec, and in the northeastern United States from Maine, New Hampshire, and New York (Clark 1961). Mortality of over 80 percent of the merchantable birch was reported in certain areas (Clark 1961). Birch decline in the northeast subsided by the early 1960's. A dieback of yellow birch was reported from the Lake States region of the United States in the late 1950's and early 1960's, but did not result in widespread mortality (Kessler 1965). Recently, an apparent new decline of birch has been reported from New York, Vermont, and the Lake States (USDA Forest Service 1985c).

In the northeastern United States and Canada, the cause of birch decline was never conclusively determined. Factors thought to play a role in birch decline included changes in climate (particularly rising temperatures and drought), presence of overmature stands, weakening of trees by insects, and opening of stands by logging (Clark 1961). No disease organism was ever isolated, although certain symptoms and the pattern of spread led some workers to suggest that a virus might be the cause of the decline (Clark 1961, Clark and Barter 1958). In the Lake States, birch dieback was thought to be the result of high water tables causing root mortality (Kessler 1965). Associated stresses included attacks by the bronze birch borer (Agrilus anxius Gory), Nectria cankers, and heavy seed crops (Kessler 1967).

3.5 Sweetgum Blight

A decline of sweetgum, Liquidambar styraciflua L., occurred across most of its natural range in the southern United States between 1948 and 1960 (Toole 1959). In a survey for sweetgum blight in 1954, Hepting (1955) found 36 percent of the trees sampled in the southern United States had some degree of dieback. Annual mortality rates of 1 to 13 percent were reported from some stands (Hepting 1955, Toole 1959). Sweetgum blight was found on a variety of sites, but was more common on upland sites than on river bottomland sites (Toole 1959). Dieback and mortality were most severe in pole and saw-log size trees (Hepting 1955). Sweetgum blight is now thought to have been caused by prolonged droughts in the southeast during the early 1950's (Toole 1959, Toole and Broadfoot 1959). No diseases or insects were consistently associated with sweetgum blight. Most trees recovered with the return of normal rainfall levels in the 1960's (Toole 1959).

3.6 Other Hardwood Declines

Declines have been reported for other hardwood species. For example, hickories, *Carya* spp., have sometimes died over wide areas during droughts and outbreaks of the hickory bark beetle, *Scolytus quadrispinosus* Say (Hopkins 1912, USDA Forest Service 1985b). Dieback and mortality occurred in elm, cottonwood, and willow over large areas of the Eastern United States during a serious drought in the 1950's (Toole 1959). Although hardwoods have suffered numerous declines, Hornbeck et al. (1987) found no prolonged periods of decreasing growth between 1900 and 1980 for northern red oak, sugar maple, red maple (*Acer rubrum* L.) and white ash in the New England States.

Beech bark disease is an introduced disease which has caused considerable mortality of American beech, *Fagus grandifolia* Ehrh., in the northeastern United States (Houston and O'Brien 1983). The primary fungi involved are *Nectria coccinea* var. *faginata* Lohman, Watson, and Ayers, and occasionally *N. galligena* Bres. (Houston and O'Brien 1983) which infect the bark following attacks by the introduced scale insect, *Cryptococcus fagisuga* Lind. Abiotic factors may enhance or restrict the initiation of the disease (Houston and O'Brien 1983). The disease is currently found throughout New England and south to West Virginia (USDA Forest Service 1986). The disease is continuing to spread from these areas. Prior to the spread of beech bark disease, widespread beech mortality occurred in 1934 in New York due to the combined effects of drought and winter injury (Spaulding 1935), and again in New York in the 1950's in association with attacks of the oystershell scale, *Lepidosaphes ulmi* L. (Buzzard and Risley 1970).

4. IN CONCLUSION

During this century, periods of widespread decline have occurred in most of the major forest types of the Eastern United States. The declines have varied in duration, severity, geographic location, and species affected.

Explanations for most of the declines are incomplete. Insect defoliation, drought and root diseases have been found to be important in several declines, but more investigations are needed to determine the exact role of these and other natural factors.

Further investigations are also needed to determine whether regional air pollution, including acid precipitation, may be a contributing factor in the declines. Hepting (1964) recognized the need for study of high oxidant levels and other regional atmospheric impacts in relation to declines of sugar maple, ash, and other hardwoods in the northeastern United States. More recently, Smith (1981) identified the pollutants of concern in the major forest ecosystems of the Eastern United States as including the secondary products of sulfur pollution, heavy metal particles and photochemical oxidants, and he suggested further studies to determine their effects. The possible relationship of regional pollution to tree declines in the Eastern United States is now being intensively investigated. Several forest types are being considered, but the largest research efforts at present are in the spruce-fir and southern pine types. To date, there is no conclusive evidence that any of the various forms of regional air pollution have contributed to the general tree declines. Air pollution is only known to have caused significant tree mortality in the vicinity of a few point sources. These few cases were reviewed by Hepting (1964, 1968).

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5.3 THE DISTRIBUTION OF FOREST DECLINES IN EASTERN CANADA*

A.N.D. Auclair[1]
Federal LRTAP Liaison Office
Atmospheric Environment Service
Downsview, Ontario, CANADA

1. INTRODUCTION

This paper presents a very preliminary account of forest decline over eastern Canada. Canadian concerns over the role of "acid rain" in the recent surge of forest decline has prompted research on the effects of air pollution on tree health and tree growth. This paper will not discuss this research. Rather it will emphasize the geographic incidence of forest declines that may provide a valuable basis for further studies on environmental correlation and etiology.

In contrast to impressions that forest declines are well- documented in eastern North America, it has proven difficult to assemble complete information on the nature and extent of tree declines over species ranges in eastern Canada (and the United States). Maps and a description of symptoms are available in some provinces and some states on some species but a coherent overall picture is lacking. Several projects currently in progress are attempting to achieve this.

Several tree declines over the 1925-1955 period in eastern Canada showed a well-defined pattern. Dieback on ash was first recorded in 1925 and by the early 1930's was extensive over southern Quebec (Pomerleau 1953). That same year (1925), the radial increment of birch and of several other species in Nova Scotia reportedly commenced a downward trend, becoming pronounced and persistent around 1937 (Hawboldt and Skolko 1948). Crown dieback on sugar maple in southern Quebec (Pomerleau 1944) and on white and yellow birch in New Brunswick (Balch and Prebble 1940) were first observed in 1932, the severity increasing greatly over the 1937-1949 period. "It is important to add that during this period, but more especially in 1946, 1947, 1948 and 1949, beech, maple, elm (Ulmus spp), cherry (Prunus spp) and poplar (Populus spp) were similarly damaged to a more or less intense degree. Even conifers such as balsam fir, spruces, pines and hemlock (Tsuga canadensis (L.) Carr.) were affected, although to a lesser degree, by the same conditions in some stands." (Pomerleau 1953).

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[1] The author is Manager of the Forest Environment Program on assignment from the Canadian Forestry Service, Headquarters, Ottawa, Canada.

Some recovery was reported at the time of the Birch Dieback Symposium in 1952 (Canada Department of Agriculture 1953) but the causes of these diebacks remained poorly understood.

In the late 1970's forest decline was again obvious over eastern Canada. Between 1977 and 1983, dieback and blight of unknown etiology were observed widespread on sugar maple (Canada Department of Environment 1987), white birch (Magasi 1985), white pine (Magasi 1985), ash, beech, and red oak (Canadian Forestry Service 1978-1985). The Forest Decline Workshop (Canada Department of Environment 1987) listed nine hardwood species and seven conifers affected by decline in Quebec. Noteworthy, these recent declines occupy more or less the same geographic area as diebacks of the 1925-1955 period and include many major hardwood and some conifer tree species in common.

2. THE CONCEPT OF FOREST DECLINE

Manion (1981) defines forest decline as a complex disease caused by the interaction of a number of interchangeable, specifically ordered abiotic and biotic factors to produce a gradual general deterioration, often ending in the death of trees. He distinguishes decline from single-causal-factor diseases of biotic and abiotic origin. He points out that decline as a distinct disease category is not universally accepted by forest pathologists; some view declines as a collection of unexplained diseases that may be shown in further studies to have specific single causal agents. Examples include ash dieback, birch dieback, maple decline, pole blight of western white pine (*Pinus monticola* Dougl.) and little leaf disease on shortleaf pine (*Pinus echinata* Mill.). In addition, Houston (1981) cites beech bark disease and oak decline as being widespread in some eastern states.

Typically the forest declines above have a number of common characteristics (Manion 1981): (1) involve at least three factors - one from each predisposing, inciting, contributing categories; (2) many interchangeable factors; (3) climate or site almost always predisposing or inciting factors; (4) weak non-agressive fungus pathogens and insects involved as contributing factor (esp. *Armillaria mellea* Vahl: FR. Kummer); (5) viruses typically a contributing factor; (6) serious depletion of storage-reserve carbohydrates; (7) feeder roots and mycorrhiza degenerate (prior to onset of symptoms above ground); (8) generally occur in mature trees; (9) wide range of symptoms; symptoms progressive on individual trees and between trees and random distribution within a given location; decline is host-specific but symptoms (dieback, blight) are not unique or exclusive; (10) lack of agreement on cause and importance of specific factors; Koch's rules applied only with difficulty.

Diebacks and blights are conditions commonly but not exclusively associated with tree declines. They are caused by any of several bacteria, fungi, or viruses or by certain environmental conditions. For the purposes of this paper, they are defined as follows: blight - a disease of plants characterized by withering, cessation of growth, and a more or less general death of leaf, flower, or stem parts without rotting; dieback - a condition in a plant in which the branches or shoots die from the tip inward.

The central hypothesis in forest decline is that stress of biotic or abiotic origin alters tree health and renders it susceptible to further loss of vigor. Disease organisms ultimately attack the weaken trees and result in their demise (Houston 1981):

Healthy Tree	+ Stress	⟶	Altered Tree
Altered Tree	+ Stress	⟶	Weakened Tree
Weakened Tree	+ 2° action organisms	⟶	Tree decline ending in death

3. DATA AND METHODS

Information on the distribution of tree declines in eastern Canada was obtained from four principal sources: (1) Forest Decline Workshop, Ottawa, 1986 (Canada Department of Enviroment 1987), (2) Birch Dieback Symposium, Ottawa, 1952 (Canada Department of Agriculture 1953), (3) Canadian Forestry Service (CFS) Annual Reports of the Forest Insect and Disease Survey (1978-1985), and (4) commentary of the Head, CFS Forest Insect and Disease Survey, Great Lakes Forestry Centre (Howse 1986, 1987).

Distributions were mapped on a 1:5,000,000 scale base-map (Canada Department of Transport 1964). Severity classes consisting of empirical estimates of the level of foliage loss or tree mortality were available for sugar maple dieback, yellow birch dieback, white birch deterioration and beech bark disease. In the case of ash dieback, red oak decline and white pine blight, only approximate descriptions of severity were available. Range limits of the tree species (Hosie 1979) were superimposed on each map.

4. RESULTS AND DISCUSSION

Forest declines in eastern Canada were currently evident on six widely occurring deciduous tree species. Only one conifer showed unexplained decline symptoms. This contrasted with the eastern United States. There, at least seven conifer species showed decline (Weiss and Rizzo 1987). The principal conifers dominating the eastern Canadian boreal forest (white spruce (*Picea glauca* (Moench.) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* L. Mill), jack pine (*Pinus banksiana* Lamb.) have been severely and frequently defoliated by insects. As a group, however, these boreal species were not known to show decline (*sensu* Manion 1981).

The predominance of deciduous species was apparent in the "unexplained decadence" of the 1930's and 1940's (Canada Department of Agriculture 1953). This suggested a predisposition by these northern hardwoods towards periodic episodes of widespread disease and mortality. However, whereas sugar maple dieback was currently widespread, dieback on white and yellow birch dominated the 1925-1955 decline. A description of the geographic incidence of each tree decline follows:

4.1 Sugar Maple Dieback

The first report of sugar maple dieback was made on ornamental trees in Pennsylvania and New Jersey in 1913 (Hartly and Merrill 1915). Since then the incidence of dieback on sugar maple (*Acer saccharum* Marsh.) has been sporadic but general throughout eastern Canada and the United States.

Prior to 1977 it occurred in the Beauce region of southern Quebec in 1932 (Pomerleau 1944) and again in the same area in 1962 and 1972 (Canadian Forestry Service 1962, 1972). It was observed concurrent with dieback on birch and other hardwoods in Quebec over the 1937-1949 interval, decline being especially intense from 1946-1949 (Pomerleau 1953). In Ontario early reports of dieback date to 1947; the degree of damage throughout Ontario since then has been highly variable with the heaviest concentrations of decline reports originating from counties surrounding the Georgian Bay, namely Sudbury-Parry Sound-Muskoka-Simcoe-Grey districts (McIlveen et al, 1986). McIlveen et al's (1986) review of the incidence of sugar maple dieback indicated that, although frequent in the adjacent New England States, the disease was not reported in Atlantic Canada.

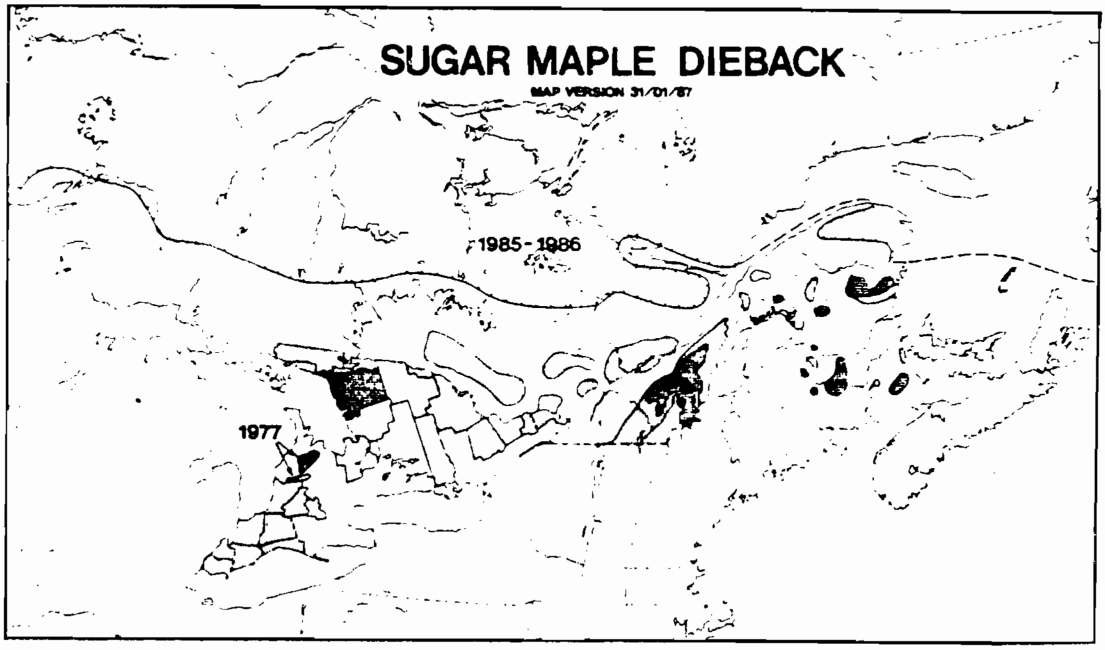

FIGURE 1. Integrated map of sugar maple dieback in eastern Canada by serverity class: light (dots), moderate (vertical lines), heavy (cross hatch) and severe (black); based on the Forest Decline Workshop (Canada Department of Environment 1987) and Gross (1978).

Recent reports indicated sugar maple dieback was widespread in New Brunswick, Quebec, and Ontario (Fig. 1). The percent of trees with dieback exceeded 30% in parts of northern, southeastern and southwestern New Brunswick (Canada Department of Environment 1987). A systematic aerial survey over maple forest types in southern Quebec revealed especially severe decline around Thetford Mines in the Beauce region (Bordeleau 1986). Foliage loss exceeding 26% was evident in 30% of maple forests over this region and in 20% of maple forests over the adjacent Appalachian region to the northeast (Canada Department of Environment 1987). The average severity over all maple forest types in southern Quebec increased from 22% in 1983 to 32% in 1985 (Gagnon et al 1986). In Ontario a province wide questionnaire to maple sugar producers indicated one-third of respondents felt tree decline was a current problem in their woodlots. Of the 20 respondents in the Parry Sound region 15 or 75% indicated decline was a problem. This suggested that, as in early accounts, this area was currently one of the most seriously affected in Ontario (Butler and McLaughlin 1987). Compared to Quebec the progression of sugar maple dieback in Ontario was thought to be relatively stable (Canada Department of Environment 1987).

4.2 Beech Bark Disease

This disease in eastern Canada was centered in the Maritime region. In 1944, the beech scale insect (*Crytococcus fagisuga* Lind.) was reported to have destroyed most of the mature beech (*Fagus grandifolia* Ehrh.) in Nova Scotia and Prince Edward Island and to be spreading throughout New Brunswick (Balch 1944). Recent observations indicated beech bark disease had reached severe levels throughout the range of beech in Atlantic Canada. Between 1969 and 1980, the serverity of crown dieback had increased four-fold (Canadian Forestry Service 1980). Nine of 11 counties in 1985 had an 80-100% incidence of affected trees. (Magasi 1985).

The disease has been reported in eastern Quebec at least since 1966 (Lachance 1987). A special survey in 1980 indicated the beech scale had extended its range 80 km westward from the Rimouski region to the Eastern Townships. By 1985 the disease itself had spread 60-75 km west of its 1980 locus at Rimouski. In 1984 severe damage was reported near Rimouski with 32-80% of trees affected (Canadian Forestry Service 1980, 1984, 1985). The beech scale insect but not beech bark disease was reported in central Ontario in 1984 and 1985 (Canadian Forestry Service 1984, 1985). The insect has been in Ontario since 1966 (Howse 1987).

4.3 Yellow Birch Dieback

Yellow birch (*Betula alleghaniensis* Britton) was a focus of the 1952 Birch Dieback Symposium (Canada Department of Agriculture 1953). Dieback symptoms were well-developed in this species and less related to over-maturity that in other birch species. Three features were noteworthy. First, the dieback was invariably preceded by a general reduction radial increment (Barter 1953b). In Nova Scotia this was first apparent around 1925 with a steady growth decline after 1937. In New Brunswick reduced growth began about 1932 and reached its lowest level in 1938. Dieback symptoms were first evident in 1932 and had become general over south and central areas of the province by 1935. By 1940 dying was widespread reaching 70-85% in trees greater than 30 cm dbh and 85-100% in trees greater than 60 cm dbh. Pomerleau (1949) noted a general growth decline in

Quebec yellow birch in 1931 and also after 1940. He first noted the crown dieback symptoms on birch in 1937 at St. Donat north of Montreal. These subsequently increased in intensity, particularly over the 1940-1949 period (Pomerleau 1953) and from 1948 to 1951 (Daviault 1953).

Second, a pronounced east-west gradient existed in the intensity of the dieback. It first appeared in Nova Scotia and was most severe in New Brunswick, decreasing in importance from east to west (Fig. 2). Daviault (1953) indicated it was first seen in eastern Quebec and spread west. By 1948, 16 years after its discovery in New Brunswick, dieback covered the range of yellow birch in Canada east of Ontario. Sinclair (1952) indicated the condition in Ontario was not uniform; only 13 percent of yellow birch showed decline, the decline was light to moderate, and only 5 percent of trees had died. An equivalent gradient existed in the northeast United States. Mortality was especially severe in Maine. At upper elevations in New Hampshire, all birch had died by 1949 and a high percentage were dead or dying elsewhere in the northern part of the state. In northern New York deterioration was moderate; in the Catskill region the intensity was considerably lighter. There was no evidence of dieback in 1947 or afterwards in Michigan or Wisconsin or elsewhere in the Lake States (Hansbrough 1953).

Thirdly, recovery was apparent; by 1952 dieback had practically ceased in Nova Scotia and New Brunswick (Barter 1953a); Daviault (1953) noted the severity had slowed in the Gaspé by 1946 and trees were recovering in restricted areas; a general recovery was noted in Quebec after 1950 (Pomerleau 1953).

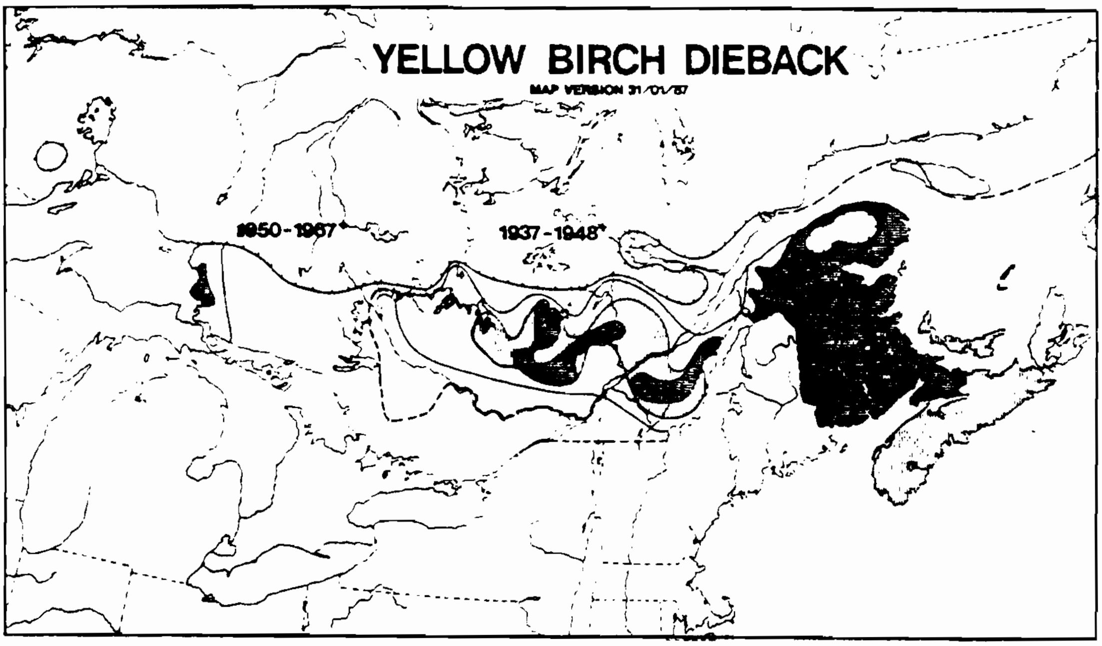

FIGURE 2. Integrated map of yellow birch dieback in eastern Canada by severity class: light (dots), moderate (vertical lines) and heavy (cross hatch); based on reports by Barter (1953b) and Rose et al (1969).

There was no general dieback on yellow birch indicated in recent survey reports (Canadian Forestry Service 1978-1985). Dieback had been observed in the 1966-1970 period over much of Ontario; severity was especially high on the east shore of Lake Superior (Fig. 2). Gross (1972) distinguished the crown deterioration over this interval from birch dieback disease of the 1940's as abrupt rather than progressive. He related it to especially heavy seed production in 1967 (average 70.6 million seeds/ha (Gross and Harnden 1968) and in 1970. This was preceded by intense defoliation on yellow birch by the sawfly (Dimorphopteryx melanognathus Rohwer.). This species had recurred on yellow birch three times over a 10-year period; with few exceptions it was confined to sites near water, on islands, and around lake and river shorelines. (Rose et al 1969).

4.4 White Birch Deterioration

White birch dieback over the 1925 to 1952 period was concurrent in all respects with dieback in yellow birch. Although yellow birch was often selected as the species on which detailed observations were made, the incidence in Betula species including yellow birch, white birch (Betula papyrifera Marsh.), and grey birch (Betula populifolia Marsh.) over its range (Barter 1953c), were substantially similar. Descriptions in Section 4.3 and the 1937-1948 map of yellow birch dieback (Fig. 2) applied equally to white birch with minor exceptions: (1) in young stands 50-75 years old, mortality of white birch was less than half (12-25%) of that in yellow birch (55%), (2) in mature stands (greater than 30cm dbh) white birch mortality was as severe if not more so than in yellow birch, perhaps due to the shorter life span of white birch species; (3) overall the yellow birch appeared more susceptible to injury and the progress and degree of damage related to age, growth rate, and degree of exposure from cutting or other causes (Barter 1953b); (4) in Ontario, infestations of the Dimorphopteryx sawfly on white birch were less intense but more persistent than on yellow birch (Rose et al 1969).

Crown deterioration observed currently in white birch along the east and northeast shore of Lake Superior (Fig. 3) had changed little since 1967 (Howse 1986). Along the Bay of Fundy, crown deterioration (early leaf browning and premature leaf drop) in white birch, associated among other pathogens with Septoria betulina (Pass.) leafspot blight, was first reported in 1979 (Canadian Forestry Service 1985). Since then the condition was observed widespread in 1980, 1981, 1983, 1984, and 1985 but was much less evident in 1982 and 1986 (Canada Department of Environment 1987). Both the Lake Superior and Bay of Fundy areas with affected white birch (Fig. 3) had high fog frequencies.

Weiss and Rizzo (1987) cited evidence of an apparently new decline of birch in New York, Vermont and the Lake States.

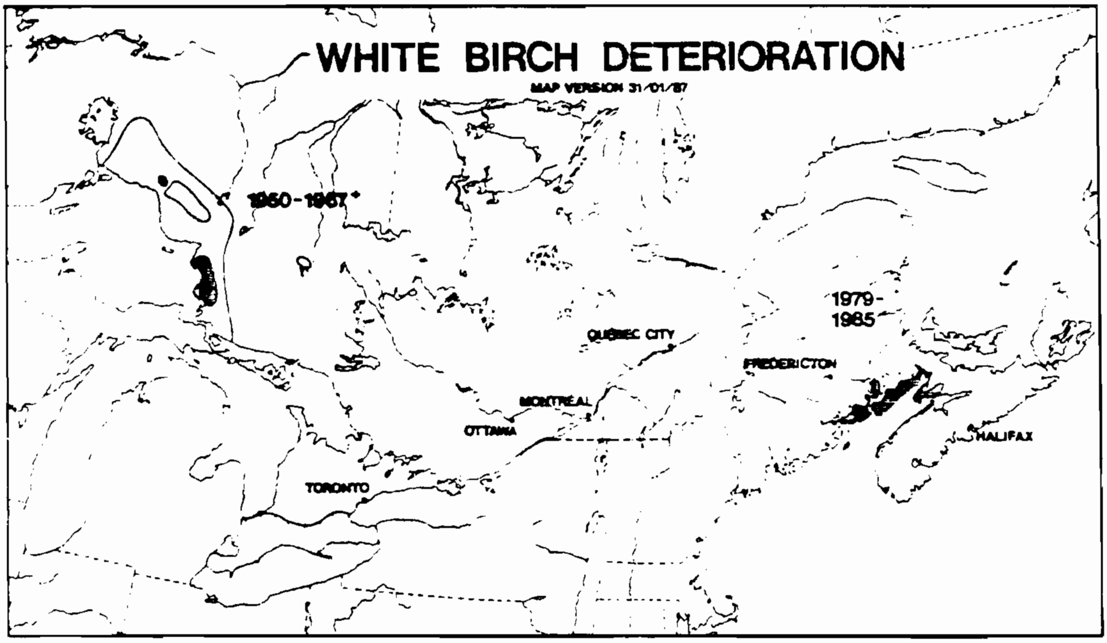

FIGURE 3. Integrated map of white birch dieback in eastern Canada by severity class: light (dots), moderate (vertical lines) and heavy (cross hatch); based on reports by Canadian Forestry Service (1983, 1984, 1985) and Rose et al (1969).

4.5 White Pine Blight

White pine blight was a foliar discoloration of unknown etiology found on all age classes of white pine (Pinus strobus L.)in Atlantic Canada. It was reported in New Brunswick and western Nova Scotia in 1978 and 1979 and more recently (1983-85) over a more extended area in New Brunswick, Nova Scotia and Prince Edward Island (Canadian Forestry Service 1978, 1979, 1983, 1984, 1985). It has not been reported recently in Quebec or Ontario but was widespread over Vermont in 1983-1985 (Teillon et al 1985). This disease was not described by either Houston (1981) or Manion (1981) as having characteristics typical of forest decline. Rather, in the United States it has been associated with ozone exposure combined with certain weather conditions during needle elongation (Berry and Ripperton 1963).

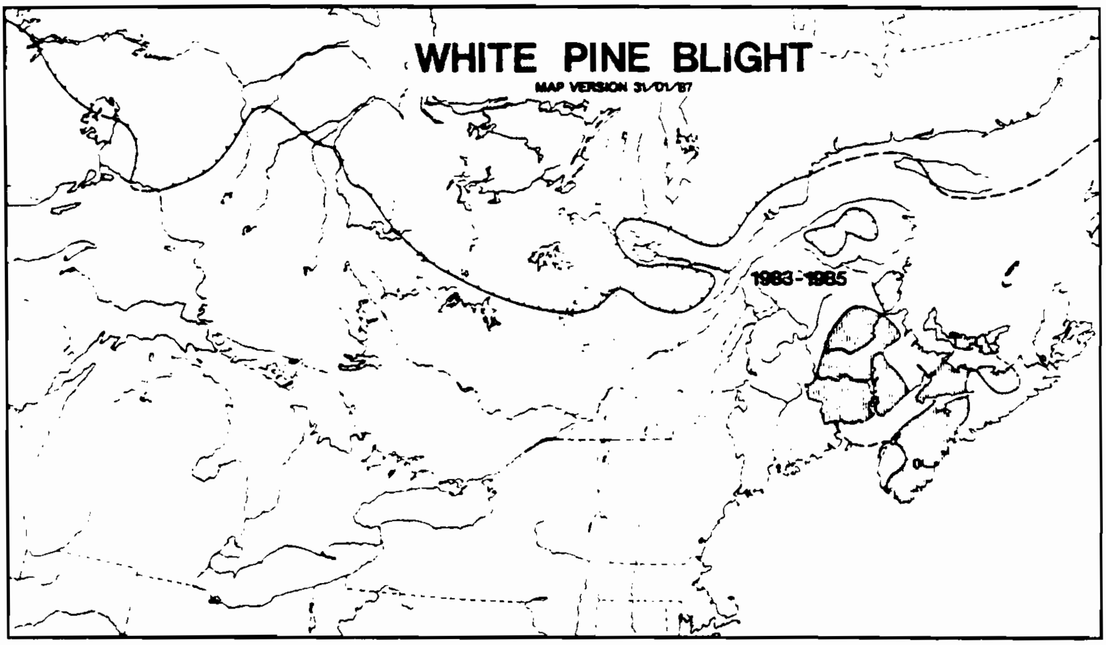

FIGURE 4. Distribution of white pine blight in eastern Canada based on reports by Canadian Forestry Service (1978, 1979, 1983, 1984, 1985).

4.6 Ash Dieback

The first signs of dying in hardwood stands with typical dieback symptoms were noticed as early as 1925. In that year Pomerleau (1953) noted the rapid decline in ash in several areas of southern Quebec and by the early 1930's ash species (mostly black ash (*Fraxinus nigra* Marsh.) and probably some red ash (*F. pennysIvanica* Marsh.) and white ash (*F. americana* L.)) were largely destroyed in the St. Lawrence Valley from the vicinity of Quebec City to the United States border, especially in the Eastern Townships (Fig. 4). The Forest Decline Workshop (Canada Department of Environment 1987) reported ash dieback was extensive in southern Ontario along Lake Erie. The disease was also present along the north shore of Lake Ontario east to Kingston and along Georgian Bay to Owen Sound (Howse 1987). The Forest Insect and Disease Survey reported recent ash dieback in small isolated locations in northern New Brunswick (1.5 ha) (Canadian Forestry Service 1984, 1985), in Quebec along the Cascapedia River (black ash, almost all trees along the river affected) and at Maple in southern Ontario (0.1 ha) (Canadian Forestry Service 1984).

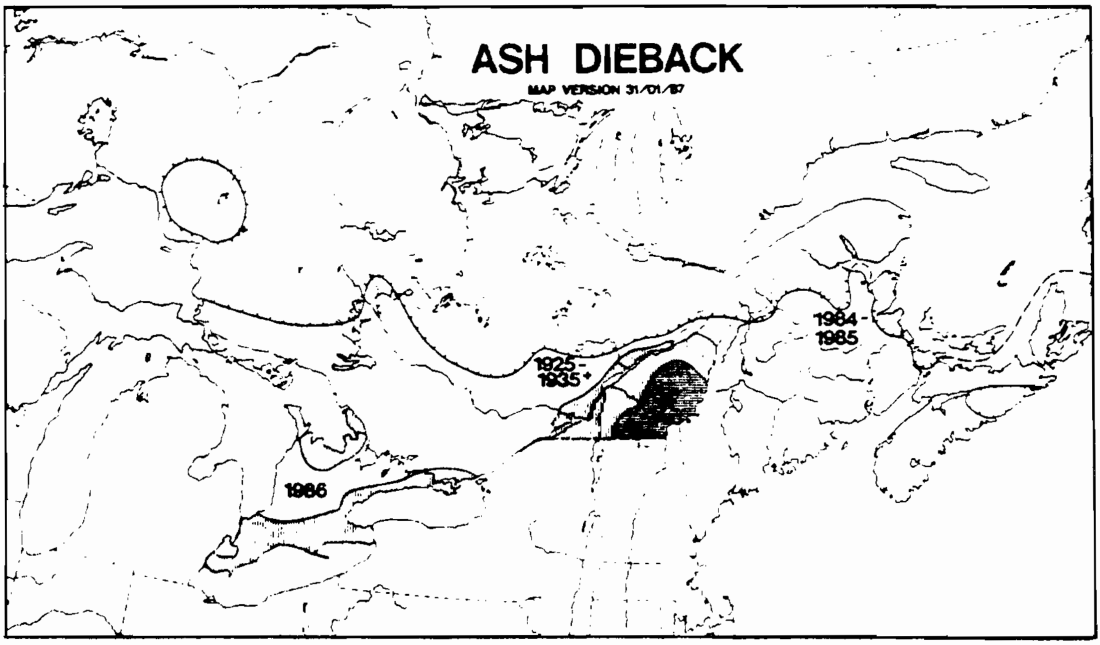

FIGURE 5. Integrated map of ash dieback in eastern Canada; based on reports of the Forest Decline Workshop (Canada Department of Environment 1987), Canadian Forestry Service (1984, 1985), Howse (1987) and Pomerleau (1953).

4.7 Red Oak Decline

In the mid and late 1970's decline in red oak (Quercus rubra L.) had been recorded in several areas of southern Ontario, particularly in the central region. Since 1977 10% of 1300 monitored trees had died but the overall condition of surviving trees had improved steadily over the past several years (Canadian Forestry Service 1984).

In 1983, mortality and dieback among oaks (predominantly red oak) were reported in isolated locations in the Ottawa and St. Lawrence valleys. Of 24 stands surveyed in a special 1984 study of red oak decline, five had no symptoms, and 15 showed light to moderate dieback. Four stands (7%) along the southern Quebec border with Ontario and New York State showed severe dieback. Two of these had 10-11% mortality (Canadian Forestry Service 1984).

5. ACKNOWLEDGEMENTS

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Mr. David McLaughlin (Ontario Ministry of Environment, Toronto, Ontario) for their individual data contributions to the integrated map on distribution of sugar maple dieback at the Forest Decline Workshop, Ottawa, 1986. Mr. David McLaughlin also provided observations on ash dieback in southern Ontario as did Mr. Gordon Howse (Great Lakes Forestry Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario). Mr. Howse added references and commentary on ash, beech, birch, oak, and sugar maple declines in Ontario that were incorporated on the distribution maps.

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5.4 THE SIGNIFICANCE OF AIR POLLUTION TO FOREST DECLINE IN CANADA*

P.J. Rennie
Canadian Forestry Service
Ottawa, Ontario, CANADA

1. INTRODUCTION

At first sight the Canadian forest might appear to form an almost inexhaustible part of the vast circumpolar belt of natural vegetation that straddles the Continents of America, Europe and Asia. Annual roundwood harvests, for example, have risen fairly steadily over the 1960 to 1985 period from about 90 to 160 million cubic metres and for pulp and paper production the overall trend during the 1975 to 1985 decade has been from 30 to 35 million tonnes.

No other single industry is as important, the export of Canadian forest products earning $14.5 billion in 1984, amounting to 13% of the total export figure of $109.5 billion. In comparison, the net contributions of metal ores were $7.8 billion, food products $3.4 billion and fisheries $1.1 billion (Anon. 1986). In addition, the forest has inestimable indirect values. It provides habitat and shelter for numerous species of wildlife, it stabilizes soil against erosion, it preserves the quality of water bodies, and it provides considerable recreational and aesthetic opportunities.

In contrast to this reassuring picture, less optimistic reports are heard. It is said the forest is not as large as supposed, a more difficult and expensive management stage is now being entered with the passing of the first-growth forest, allowable annual cuts are approaching their theoretical maximum, and air pollution is causing widespread declines and dieback in both North America and Europe. Indeed, the Central European experience of forest decline combined with the acknowledged difficulty of quickly implementing costly pollutant-abatement measures are sometimes extrapolated to North America to suggest a very pessimistic future.

Is this justified? What are the characteristics of the Canadian forest? What are the air-pollution threats? What declines might be expected? And what courses of action are open through research and innovative practices? This paper explores these questions.

2. THE CANADIAN FOREST

Table 1 shows clearly that potentially productive forest covers only a little over one third of the land area of Canada and that overall only about one fifth is economically accessible. Over 130 tree species are represented but only about 30 are of commercial significance. On inventoried productive forest land there is by volume 79% coniferous and 21% broadleaf species. Important softwood species making up the 79% are

*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

spruces, 30.2%; pines, 14.4%; fir, 14.0%; hemlocks, 9.8%; cedars, 5.4%; and Douglas fir, 2.8%. The 21% of hardwoods comprise poplar, 7.5%; white birch, 5.4%; aspen, 3.8%; maples, 1.9% and yellow birch, 1.5%.

TABLE 1 Candian land areas.(a)

Type	million hectares	%
Total land area	909	100
Wildland(b)	519	57
Productive forest	323	36
Accessible productive forest	161	18
Agriculture	67	7

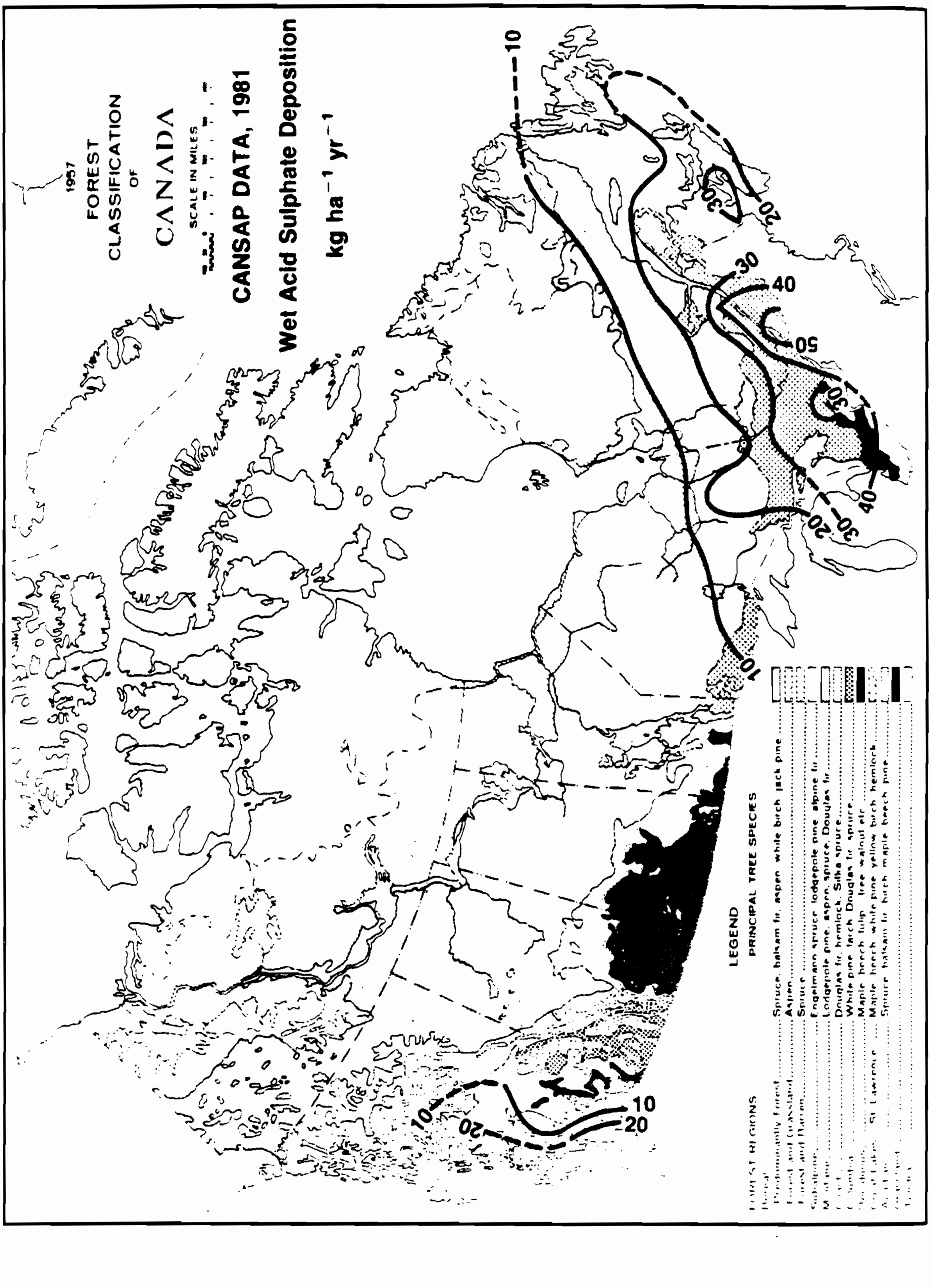
(a)Rennie, P.J. (1978)
(b)Defined as having a woody productivity of less than $30 m^3 ha^{-1}$

There are ten major forest-vegetation regions in Canada, distributed as in Figure 1. They are fully described by Rowe (1972), but for the purposes of the present paper it may be noted that in eastern Canada purely deciduous cover is restricted to the southernmost parts of Ontario. North of this in Ontario and throughout southern Quebec is the Great Lakes-St. Lawrence mixedwood forest and north of this again stretching as an arc is the main Boreal coniferous forest. In 1980, a harvest of 145 million cubic metres was obtained from 760,000 hectares, representing an average productivity of 1.9 cubic metres per hectare per year, assuming a 100-year rotation.

Except for the West Coast, an adverse climate and nutrient-poor soils combine to explain this low average biological productivity, the latter aspect taking on a special significance when the effects of certain management practices and environmental stresses are considered. Canadian forests are supported predominantly by soils of the Podzolic Order, with those the Luvisolic, Brunisolic, Gleysolic and Organic Orders playing relatively smaller roles. Soils are usually acidic, pH values ranging from 4 or less in the surface organic horizons to 5.5 or more in the subsoil. Except in the surface horizons exchange-capacities are low, as well as base-saturation. Soils are mainly young, having been formed from surficial deposits after glacial retreat. Many forest soils respond to nitrogen fertilizer, but responses to potassium and occasionally phosphorus occur on outwash sands but not tills.

The forest is semi-natural and unlike many intensively managed European forests is self-thinning. The periodic and regular removal of weaker, suppressed and diseased stems has never been practised, and there are widespread natural hazards and difficulties not met in intensively managed forests. Thus, annual fire losses amount to 2.1 million hectares - three times the area harvested. Pests and diseases cause annual losses of 107 million cubic metres - 74% of the size of the annual harvest. In 1982 there were 25 million hectares of forest dead or dying from one pest alone - spruce budworm. Through inadequate restocking after clearcutting, there had accumulated a total of 18 million hectares of prime forest-land in need of rehabilitation. An important feature of the Canadian forest is, therefore, that abundant examples exist throughout of declines, diebacks and unthriftiness. They are mostly part of the natural scene and many have been present since the glaciers retreated.

FIGURE 1 Forest classification of Canada with acid sulphate deposition contours



A fundamental difficulty arises associated with our enhanced concern with air pollution. Air-pollution damage is well known to the Canadian forestry sector, some one to three million hectares of forest having been seriously affected near strong point sources, such as smelters. The difficulty arises when considering regional air pollution, because disorders arising from the traditional problems somewhat resemble those arising from air pollution. The challenge is to separate the two. First, though, it must be asked: Which Canadian forests are exposed and to what?

3. AIR POLLUTION SCENARIO

Recent annual emissions for Canada and the United States are shown in Table 2. It is necessary to consider emissions from both countries because emissions are transported both ways across the international border. The prevalent direction of the winds in the eastern part of the North American Continent cause many emissions to be carried in a north-easterly direction out over the Atlantic Ocean. They also cause about one half of Canadian depositions not to have originated in Canada. As is now well known, some of the gaseous oxides are converted in the atmosphere into dilute sulphuric and nitric acids to be deposited in precipitation,

TABLE 2 Canadian and United States air-pollutant emissions.

Pollutant	Millions of tonnes per year	
	Canada (1980)	United States (1983)
Sulphur dioxide (SO_2)	4.5	20.8
Nitogen oxides (NOx)	1.7	19.4
Volatile organic compounds (VOC)	2.0	19.9

mist or fog. Some of the nitrogen oxides and volatile organics assist in the formation of ozone, which is not emitted as such from industrial processes. In eastern Canada, precipitation can be as acid as pH 4 to 4.5, with individual rain showers going down to pH 3. The acidity arises from a sulphate to nitrate ratio that varies from 65:35 to 55:45. The forestry sector is concerned not only with the acid deposition component of air pollution - but also with the ozone component, which very adversely affects tree tissues, and with the volatile organics the composition of which is poorly known (Nikolaou et al. 1984).

From the chemical analysis of a network of precipitation gauges (Summers et al. 1986; Barrie and Sirois 1986) it has been possible to build up a picture of the extent to which Canadian forests are impacted by wet acid sulphate and nitrate. This is summarized in Table 3. Of the 161 million hectares (83 in Manitoba westwards plus 32 in Ontario eastwards), or 72% overall, are not exposed to significant levels of air pollution. This takes the 20 kg level as a threshold and assumes it is a rough guide for other air pollutants. However, the remaining 28% or 46 million hectares that are so exposed in British Columbia and in the east is important forest near mills and markets. The 39 million hectares of the total of 71 million hectares significantly exposed in the east are distributed across southern Ontario and Quebec, the three Maritime Provinces, and about half of Newfoundland. This 39 million hectares takes in all of the mixedwood forest, most of the Acadian forest south of the St. Lawrence river and appreciable areas of the Boreal forest (Figure 1).

TABLE 3 Acid sulphate deposition and Canadian forests.

Productive and accessible forest, millions of hectares			
Deposition rate	Canada	Manitoba westwards	Ontario eastwards
all rates	161	90(56%)	71(44%)
<20 kg $SO_4ha^{-1}yr^{-1}$	115	83	32
>20 kg $SO_4ha^{-}yr^{-1}$	46	7	39
% of forest polluted by acid SO_4	28	8	55

In southwest Ontario and in southeast Quebec deposition levels exceed 20 kg and to all "wet" values must be added another 25% for so-called "dry" deposition entrapped by a forest canopy. In western Canada about seven million hectares based on Vancouver Island and on part of the Coast Range receive a similar deposition. It has to be emphasized, however, that the 20 kg level is a threshold for forest ecosystem change and for lake acidification on moderately sensitive terrain: it is not necessarily a threshold for forest injury.

With regard to the distribution of injurious ambient concentrations of air pollutants in Canadian forests, the situation today appears to be that apart from essentially local problems with mainly sulphur dioxide near strong point-emitters, the most serious regional problem centres on ozone and perhaps on poorly characterized mixtures of air pollutants. For ozone, rural monitors have been lacking, but it is known that episodes of phytotoxic concentrations occur in southern Ontario, in the Windsor to Quebec City corridor of southern Canada, in New Brunswick, in the greater Vancouver area and possibly elsewhere. It is thought that the more southerly mixedwood Canadian forests may be experiencing from time to time adverse concentrations of ozone combined with a fairly continuous deposition of acid precipitation. As since 1980 these forests have also shown very serious decline, there is much debate on possible relationships. There are also cases in the same area where conifers show a chlorosis somewhat reminiscent of that seen in Central Europe. This raises particular concern because whereas sulphur dioxide emissions have been dropping appreciably in both Canada and the United States, there is less downward movement for nitrogen oxides and volatile organics - the precursors of ozone (Table 4).

TABLE 4 Reductions in air-pollutant emissions, United States(a)

Pollutant	Annual emissions millions of tonnes 1977	1983	% Reduction
SO_2	26.3	20.8	20.9
NOx	20.9	19.4	7.2
VOC	23.6	19.9	15.7

(a)Anon, (1985)

4. FOREST DECLINES AND AIR POLLUTION

The term "forest decline" is leading to confusion. There are instances where a falling off in annual incremental growth has been recorded and attributed to regional air pollution. More critical examination of the situations has demonstrated the "decline" to be due to the normal decrease in annual increment that occurs with advancing age, to changes in stocking, nutrient status, or other conventional causes (Hornbeck, Smith and Federer, 1986; Sheffield and Cost, 1987). Sometimes high-elevation situations are cited without taking into account the generally adverse and highly variable ecological characteristics of such marginal sites (Hansen-Bristow, 1986).

Fortunately in Canada, there has been a nation-wide Forest Insect and Disease Survey Organization that has regularly monitored forests for over 50 years. Through this Organization, its expertise and uniform standards, very specific figures on losses can be provided for important pests and diseases and the necessary pest-management measures priorized. A special report prepared in 1984 showed the following principal pests and losses:

Spruce budworm (Choristoneura fumiferana): Damaged areas exceed 24 million hectares. Over the 1977-81 period, annual wood losses were 44 million cubic metres. Balsam fir is the species most damaged, but black and white spruces are also significantly affected.
Damage results in severe mortality, growth reduction and tree mutilation. Control measures have used chemical insecticides and increasingly, biological methods.

Spruce beetle (Dendroctonus rufipennis): Causes significant spruce mortality in several parts of western Canada. In British Columbia alone, over 99,000 hectares have been damaged, containing a wood volume of 4.4 million cubic metres. Control measures include sanitation logging and traps.

Mountain pine beetle (Dendroctonus ponderosa): A serious problem in western Canada, especially in British Columbia. Over 290,000 hectares of forest were affected in 1983.

Forest tent caterpillar (Malacosoma disstria): Has caused moderate to severe defoliation of several hardwood species, including aspen, in New Brunswick, Quebec, Ontario, and the Prairie Provinces. Some outbreaks are spectacular leading to appreciable mortality, growth reduction, and weakening.

Douglas-fir tussock moth (Orgyia pseudotsugata): A major pest in British Columbia, damaging about 12,000 hectares.

Scleroderris canker (Cremmiella abietina): Has been detected in almost all Provinces and is regarded as the most destructive pathogen of pines, particularly red, jack and Scots pines. The North American race continues to be a serious problem in nurseries and in young plantations in eastern Canada. The European race damages natural stands, plantations and urban trees in Quebec, New Brunswick and Newfoundland.

Dwarf mistletoes (Arceuthobium spp.): The parasite continues to be a perennial problem in western Canada and in some eastern Provinces, causing extensive mortality of mature and overmature trees. In British Columbia and the Prairie Provinces, its effect has been particularly serious, causing mortality of about 65% of the larger trees attacked by mountain pine beetle. It also has affected 15% of regeneration. In the Prairie Provinces jack pine and spruces are affected.

As may be expected, the Annual Reports of the Forest Insect and Disease Survey Organization provide detailed accounts of forest disorders arising from a variety of causes. These can often be attributable to readily identifiable organisms or to abiotic factors, such as drought, frost or strong-point sources of air pollution. There are, in addition, declines and diebacks not so readily attributable, perhaps the most serious and challenging being the widespread dieback of yellow birch and other hardwoods occuring in eastern Canada in the 1930 to 1950 period (Anon. 1953). Recently, an examination of the above Annual Reports for the 1951 to 1985 period for just Ontario generated the following occurrences of declines, diebacks and deteriorations. Organisms associated with the disorders were sometimes identified but in numerous cases these were only secondary pests, the primary triggering agent remaining obscure:

Deterioration of birch: 1951, 52, 53, 54, 67 and 68.
Maple dieback: 1958, 59, 60, 61, 84 and 85.
Deterioration of roadside maples: 1962, 63, 64, 65, 66, 67 and 68.
Maple decline: 1977, 80, 83 and 84.
Maple mortality: 1977.
Branch mortality of maple: 1969, 71 and 72.
Oak decline: 1977, 83, 84 and 85.
Branch dieback of oak: 1969, 70, 71, 74, 76 and 78.
Oak mortality: 1970, 71, 74, 78, 79, 80 and 84.
Hardwood decline: 1978, 79 and 85.
Ash dieback: 1984 and 85.
Beech bark cankers: 1963 and 85.
Beech decline: 1967.
Basswood branch cankers: 1963 and 67.
Branch mortality of poplars: 1972.
Branch mortality of mountain ash: 1971.
Dothichiza canker of Lombardy poplar: 1962, 66 and 74.
Drought: 1964, 76, 83 and 84.
Abiotic damage: 1969, 71 and 83.
Heavy seed crop: 1984.

It is interesting that none of these occurrences implicates regional air pollution, yet it is reasonable to suppose from the historical pattern of emissions in the northeast that some episodes of elevated sulphur dioxide and ozone concentrations did occur during the 25-year period (Gschwandtner et al. 1986). One might reasonably speculate that over this period widespread ambient concentrations of sulphur dioxide have increased then decreased, but may never have been high enough to generate strikingly visual foliar symptoms. The precursors of ozone, in contrast, have maintained their levels, but again concentrations may never have been high enough to generate symptoms that would be strikingly obvious and distinct from other symptoms, especially if observers were not familiar with ozone symptoms and had no information on rural ambient concentrations. What cannot be dismissed, in the light of our understanding of multiple-stress and the results of the National Crop Loss Assessment Network (NCLAN) (Adams et al. 1985), is the possibiliy that air pollution contributed to the phenomena of decline, dieback and deterioration reported without there being seen foliar symptoms obviously indicative of air pollution. Such a hypothesis is by no means new - hidden physiological damage - and is one of the hypotheses invoked to explain the malaise in the central European forest (Rennie and Halstead 1977; Schütt and Cowling 1985).

Indeed, it is this more elusive yet significant effect of regional air pollution that is so difficult to detect. Strong ambient concentrations of air pollutants are readily measured, their effects upon foliage are often characteristic, and there are usually well-established threshold air-quality standards developed from much prior fumigation experimentation. Of intermediate complexity are air-pollution effects upon soils. Ambient thresholds are inappropriate, long-term deposition processes are difficult to simulate using short-term lysimetric tests, so it becomes very difficult to develop acid-deposition ceilings for forest soils as have been done for water bodies on sensitive terrain.

The wealth of observational experience available from the main essentially coniferous forest regions of Canada does not so far indicate the occurrence of decline phenomena that cannot be explained by conventional causes. In this regard the Canadian coniferous forest environment much resembles that of central Sweden (Andersson 1986), pollution levels, soils, climate and forest type all being rather similar.

For the more southerly parts of Canada, which again are more comparable to the southern parts of Sweden, the picture is not so bright. Very serious dieback has been occurring in the sugar maple (Acer saccharum Marsh) forests of Quebec and Ontario, and comparisons have been made to the central European situation. As might be expected, viewpoints on cause vary widely, as is reflected in recent publications on the subject (Carrier 1986; Maple Producers 1986; McIlveen et al. 1986). Ontario sees the problem dating back to the 1900s, Quebec only to 1982, but both Provinces agree on its present seriousness. Aerial surveys conducted in Quebec show that of 533,600 hectares examined in 1985, 317,600 hectares (or 60%) were healthy or little affected. Some 189,200 hectares (35%) were lightly affected, 22,300 hectares (4%) were moderately affected, and 4,500 hectares (1%) were seriously affected. The worst affected area is centred on Thetford Mines, east of Montreal. In terms of economic and social significance, the problem is profound. There are 10,000 maple-syrup producers in Quebec deriving much of their livelihood from 7.3 to 13.5 million litres of syrup produced per year (1979 to 1983 period). The annual value averages $40-milion and Quebec production amounts to 89% of the Canadian total. The decline phenomenon not only reduces sap yield, but eliminates trees for future tapping and kills them in such a way as to render their wood unsuitable for saw-lumber or fuelwood. There is no proof that air pollution causes maple dieback, but Carrier (1986) eliminates a number of possible factors as single causes of dieback in favour of air pollution as the main suspect. McIlveen et al. (1986) believe that no single cause can be identified but point to a possible combination of several factors, such as defoliating insects, drought, other extreme climatic events, nutritional deficiencies, improper management, secondary root organisms and air pollution. Indeed, one of the Ontario investigators, D. McLaughlin, has pointed out that the combination of certain extreme events experienced within the recent eight-year period, 1976-1983, is likely to occur only once every 250 years. Why many scientists find it difficult to select air pollution as the main culprit is because an almost identical widespread dieback occurred in much the same region in the 1930 to 1950 period for yellow birch (Betula alleghaniensis Britton) and other hardwoods (Anon. 1953). The careful descriptions of the symptoms at the time bear a striking similarity to the present-day symptoms and to those described for beech (Fagus sylvatica) in West Germany (Schütt and Summerer 1983). The problem is being very actively researched and the imbalanced foliar nutrient levels recorded in some maple stands has suggested fertilization might be able to arrest dieback. It is impossible at this stage to predict the course of the epidemic, but during 1930 to 1950 there was a very considerable mortaility of yellow birch, with surviving trees appearing to grow out of the problem.

5. ABATEMENT ACTION

The federal Canadian government, in collaboration with Provincial governments and the United States government, is implementing several important measures designed to reduce regional air-pollution. The first of these focuses on sulphur dioxide, the principal precursor of acid rain. By 1994, Canadian emissions will be reduced 50% from 1980 levels. To assist industry there are federal grants of $150-million, with an additonal $25-million for demonstrations of smelter modernization.

A second major step is the implementation of tighter automobile emission standards. From 1988 onwards new cars will emit only 1.0, 0.4 and 3.4 grams per mile of nitrogen oxides, hydrocarbons and carbon monoxide respectively, representing major reductions from existing values of 3.1, 2.0 and 25.0 grams per mile. These new standards parallel those stipulated in the United States and are among the most stringent in the world, being for nitrogen oxides for example from 1.5 to 3.0 times more stringent than the new European Economic Community (EEC) standards. It is expected the new standards will not only reduce acid deposition but also the frequency of occurrence of injurious ozone concentrations.

The third major achievement was the initiation with the United States government of the bilateral Envoys' Study of acid rain. This led to the publication of the Envoys' Joint Report on 8 January 1986 and to the subsequent acceptance by both countries of the Report's Recommendations. The implementation of the proposed $5-billion U.S. emission-control program is expected to lead to further reductions in sulphur dioxide emissions. From the nature of transboundary air pollutant movements, Canadian abatement cannot alone reduce acid deposition to desirable levels (Manson 1985).

A fourth activity is the Canadian Forestry Service's continuing contributions to the United Nations' International Convention on Long-Range Transboundary Air Pollution. From the Conventon, signed by over 30 countries, came the international agreement to cut sulphur dioxide emissions 30% by 1993. In addition, a global system has been developed for assessing and monitoring forest dieback. Through FAO's Timber Committee and a Special Task Force, Canadian scientists have been closely associated with the development and application of the system. It is now being used by 15 countries and should play an important role in evaluating the success of pollution abatement.

6. CANADIAN RESEARCH

The Canadian Forestry Service has researched air pollution problems since the 1930s, but from the late 1970s the Program has expanded very considerably. It now forms part of a collaborative federal, provincial and international endeavour involving meteorological, aquatic, fisheries, wildlife and agricultural interests. Special links exist with forest industry and university expertise contributes in key areas.

A particular difficulty with regional air pollution, as distinct from strong point-source problems, is that the dimensions and seriousness of the threat is difficult to judge. Framework research-policy questions for a Program have to be based more on an understanding of ecological principles and processes than on grappling with an obvious dramatic problem. A good example of this is the well-founded suspicion that acid deposition over the long-term will accelerate the loss of bases from acid forest soils and increase their acidity (Glass et al. 1980). Only recently have two Swedish investigators found an older study of sufficient quality to confirm this suspicion (Hallbäcken and Tamm 1986). A very important component of an air-pollution program, therefore, is to be able to quantify the temporal aspects of this added leaching stress. Is it so mild that normal mineral-weathering can replenish soil nutrients or is there an upper depositional limit where normal replenishment canot keep pace with the accelerated leaching? And how is this limit affected by more demanding harvesting practices or by those incorporating fertilizers? What can the scientist tell the regulatory authority?

Complex problems are also faced by the scientist dealing with the direct effects of air pollutants upon tissues. Threshold concentrations or depositional rates may be quantified for single pollutants, but what about the complex mixtures met in real life? Especially when forests may not be growing at optimum nutrition or may experience a drought or other climatic stress. Should the acceptable upper pollutant level be designed in isolation from other stresses or should it accommodate them? And if the latter how extreme a stress and how frequent?

Against this background of at first no obvious air-pollution problem in the Canadian coniferous forest followed by an accelerating dieback problem with sugar maple, five main approaches were selected.

First, a focusing upon the need to give guidance to regulatory authorities on pollutant deposition levels or concentrations that must not be exceeded if the continued productivity and well-being of forests are to be assured. (The 20 kg acid sulphate level is such a guide developed for aquatic resources).

Secondly, the elaboration of the above guidance through the quantification of dose/response relationships developed for different tree species, soils, climatic conditons and pollutants.

Thirdly, the regular monitoring of forests to detect disorders or incipient stress, especially in the context of changing pollutant levels.

Fourthly, to establish adequate baselines for future reference.

Fifthly, to analyze trends in past annual increments to see if air pollution effects can be detected and isolated from other influences.

Space does not permit here more than an outline of this $2-million per year Program described in greater detail elsewhere (Rennie 1986). Studies are conducted in both the field and laboratory from six research centres across Canada. In three main forested catchments distributed across eastern Canada, hydrologic and element budgets are being prepared (Foster et al. 1986). These provide a framework understanding of the movement of elements into and out of the systems. Such information is essential to follow the fate of added sulphate, nitrate and potentially toxic metals. Laboratory studies include testing the effects of simulated acid rain on tree seedling growth (Percy 1983), plant reproductive processes (Cox 1983), root-mycorrhizae development (Fortin 1983), rootlet mortality (Hutchinson et al. 1986) and cuticle integrity (Percy and Baker 1986).

Indirect studies with soils are testing the effects of acidification on nutrient drainage (Arp 1983; Rutherford et al. 1985), on the mobilization of aluminum (Arp and Ouimet 1986a) and on the speciation and relative toxicities of different complex aluminum ions to tree seedlings (Arp and Ouimet 1986b). Soil-nitrogen and soil-sulphur transformations are the focus of other studies (Mahendrappa 1982: Maynard et al. 1984). A novel study is testing the effect of soil acidification and aluminum mobilization on balsam fir rootlet resistance to pathogens.

The third main area described above utilizes over 100 permanent sample plots established in representative Canadian forests. In addition to the regular monitoring by entomologists and pathologists of the Forest Insect and Disease Survey, foliar samples are being taken annually and soil samples at five-yearly intervals to characterize status and to detect changes. There is a special interest in the collaborative European study which is attempting to identify foliar physiological and biochemical parameters indicative of early pollution effects. At present, a symptomology text provides guidance (Malhotra and Blauel 1980).

7. SYNTHESIS

From the above treatment it may now be asked what significance do the constraints identified have on Canadian forest productivity? What do the declines mean? What can be said to answer the broad questions providing the rationale for the Workshop?

Three types of problems can be identified. First, well known and well understood ones. Secondly, well known ones where there is some divergence of view as to their future dimensions. Thirdly, new problems or unrecognized ones that require more attention.

As a background to these problems is the 1982 Framework for Forest Renewal Policy statement (Anon. 1983) that envisages an increase in forest productivity of 40% by the year 2000. Not everyone shares such optimism (Hohol 1985) but very constructive changes are occurring in the transition from the mostly natural first-growth forests to planned and managed second and third-growth stands of far shorter rotation length (Handley 1985). Over $1250 million of federal, provincial and industry funding is now being devoted to forest management and a rehabilitation strategy is being implemented to reforest insufficiently stocked land. Annual seedling production has risen from 200 to 600 million in the past 10 years (Anon. 1986) and site preparation, planting and weeding are increasingly practised (Barron 1985). Interest is being re-expressed in large-scale forest fertilization. There is still much to do in this area (Pearse et al. 1986a, 1986b), but substantial research programs are in place assisting with site rehabilitation and with such problems as fire and pests. The opportunity is being exploited of improved genetic stock. It seems unlikely that well-known conventional problems will curtail reasonable estimates of increased productivity. They are being accommodated.

In the second category of problems are ones that are understood in principle only and may be viewed by some as remote. The elimination of fire and the repeated harvesting of short-rotation stands are such, for ecological principles dictate that if fundamenal changes are made in expectations from nutrient-poor northern forest soils much understanding is called for to the specify the inputs required to sustain productivity. These are not immediate problems, but rather difficult ones that require recognition and attention if site impoverishment and lower biological productivity are not to become widespread (Mahendrappa et al. 1986; Kimmins 1987). Again no imminent declines are expected, but long-term ones could if new cultural practices are not developed.

In the third category are problems of unknown cause, such as the widespead yellow birch dieback of the 1930 to 1950 period and the present-day widespread dieback of sugar maple in eastern Canada. Also included are threats of unknown dimensions, such as air pollution. For both the yellow birch and sugar maple diebacks their significance in national or global terms is relatively small but regionally quite the reverse. Considerable concern was expressed in 1944 at the demise of yellow birch (Balch 1944) and there is the same concern being expressed today at the loss of sugar maple (Maple Producers 1986). A substantial loss of quality hardwood is occurring, aside from a reduction in maple-syrup production. No cause of the problem was identified for yellow birch and the epidemic ran its course. The same could happen for maple dieback, and it has to be recognized that even if regional air pollution could be eliminated tomorrow, maples might continue to die through an as yet unidentified cause.

On the other hand, the possibility exists that air pollution is contributing to maple decline. If this is so then the rather modest levels of regional air pollution being experienced in eastern Canada are a much more serious threat than might be supposed. Coniferous forests might also succumb, because although substantial abatement measures are being implemented, air-polluton levels are decreasing only slowly. With this scenario, much larger forest losses could occur, with irreversible soil impoverishment. Indeed, some scientists claim this has already happened.

A further possibility is that air pollution is harmful, but only significantly so in an unusual and infrequent mix of adverse factors that includes drought, other exceptional climatic events and insect attack - an explanation favoured by many.

It is, therefore, very difficult to predict the course of the current decline but one thing is very clear. It is that if one is managing a resource as economically, socially and environmentally important as the Canadian forest, one has to have a much better idea of the ecological processes determining and threatening productivity than hitherto. No longer in our increasingly industrialized landscapes can the forest be taken for granted.

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5.5 STUDIES ON TREE DAMAGE IN CANADA*

S.N. Linzon
Phytotoxicology Section
Air Resources Branch
Ontario Ministry of the Environment
Toronto, Ontario, CANADA

Studies on tree damage have been conducted in various parts of Canada. Most recently, sugar maple decline in regional areas has been the focus of attention in the provinces of Quebec and Ontario. Tree damage caused by atmospheric sulphur dioxide and fluorides emitted by point sources has been studied from coast to coast. In British Columbia and Newfoundland, fluorides emitted from aluminum and phosphorus manufacturers, respectively, have caused severe damage to nearby forests. In Ontario a number of fluoride emitting industries has caused tree damage in their immediate vicinity, but the greatest extent of forest damage occurred in the Sudbury area in the vicinity of nickel and copper smelters emitting sulphur dioxide.

STUDIES NEAR POINT SOURCES

In the Sudbury area of Ontario, three large nickel smelters had discharged prior to 1972 approximately 7000 tonne of SO_2 per day into the surrounding atmosphere. Forest effects in the area were excessive with severe injury on trees occurring up to 40 km northeast of Sudbury. Based on studies of over 6000 eastern white pine trees on 42 sample plots during a 10-yr period, (1953-1963) the Sudbury area was segregated into three fume zones: Inner, Intermediate and Outer (Linzon, 1966). In the Inner Fume Zone, an area of about 1860 km^2, eastern white pine trees displayed both acute and chronic foliar injuries which resulted in reduced radial and volume growth and in excessive tree mortality. In the Intermediate Fume Zone, an area of about 4140 km^2, chronic SO_2 injury was present, while in the Outer Fume Zone, atmospheric contamination was too dilute to cause visible injuries.

The greatest increase in chronic foliar injuries during the growing season was found to occur on the one-year-old needles of eastern white pine trees. The continuous development of injuries on the older needles was reflected in early abscission of the oldest foliage, reduced radial and volume growth and premature death of the trees. Over three times as many eastern white pine trees died annually in the Inner Fume Zone than in a control area located at a distance from Sudbury. The eastern white pine forests in the Inner Fume Zone were found to exhibit a net average annual negative growth in volume, since the trees that died during the investigation period exceeded the volume added by the surviving trees (Linzon, 1971). Radial increment growth for the period 1940 to 1960 as measured on cores

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extracted in 1963 from 20 dominant living eastern white pine trees on each of 42 sample plots showed a gradual decline in the Inner Fume Zone, whereas a constant pattern was maintained in the other areas (Linzon, 1973).

It was observed that chronic effects on eastern white pine trees in the forests near Sudbury were prominent where SO_2 air concentrations for the growing season averaged 44 ug m^{-3} (0.017 ppm), the arithmetic mean for the 10-yr (1954-1963) measurement period, and chronic effects were slight where SO_2 concentrations averaged 21 ug m^{-3} (0.008 ppm) (Linzon, 1971). It is important to note that the forest damage which occurred in the Sudbury area prior to 1972 was primarily the result of exposure to atmospheric SO_2. Other pollutants, such as O_3 are extremely low in the area, and the SO_2 monitoring stations were located sufficiently close to the forest plots under observation so that both were often subjected to the same SO_2 fumigations emanating from the Sudbury smelters. In addition, substantial reductions in the emissions of SO_2 from the Sudbury smelters after 1972 resulted in concomitant reductions in injury to forests in the area.

Starting in 1972, several abatement activities were undertaken by the Ni-producing industries in the Sudbury area. The existing three smoke-stacks at the Copper Cliff smelter were replaced with one tall stack (380m) in 1972 which reduced the concentrations of SO_2 in the vicinity of Sudbury, but contributed further to long range transported pollutants. The smelter at Coniston and the pyrrhotite plant at Falconbridge were shut down permanently in 1972. Other abatement activities included the operation of sulphuric acid manufacturing plants at both Copper Cliff and Falconbridge and the construction of a new smelter at Falconbridge in 1978. Emissions of SO_2 from the smelters in the Sudbury area were reduced from over 7000 tonne day^{-1} in the 1960s to about 2400 tonne day^{-1} in 1985 (a 66% reduction). In December 1985, the Ontario government approved a regulation requiring the two existing smelters in the Sudbury area to reduce their SO_2 emissions by a further 56.5% from an average of 2300 tonne day^{-1} in 1986 to 1000 tonne day^{-1} in 1994. The reductions in emissions of SO_2 in the Sudbury area have resulted in little or no acute damage occurring on vegetation in recent years. The fact that the drastic reductions in SO_2 emissions resulted in dramatic improvements in forest conditions in the Sudbury area demonstrate that SO_2 was the prime pollutant responsible for the severe forest damage observed earlier. Starting in 1978 the Regional Municipality of Sudbury became engaged in reclaiming the damaged land (Lautenbach, 1985). By the end of 1984, over 2,636 ha of land had been limed and fertilized, and grass and 387,580 trees had been planted.

A major study of fluoride effects on forests has been conducted in the vicinity of a P manufacturing plant at Long Harbour, Newfoundland (Sidhu, 1979). Foliage of balsam fir, black spruce, larch, and white birch displayed severe symptoms of fluoride injury up to a distance of 8 km from the source, moderate symptoms between 8 to 9 km, light symptoms from 9 to 12 km, and no symptoms beyond 13 km. At the end of the growing season of 1976, maximum fluoride conentrations in foliage of balsam fir, black spruce, larch and white birch were 265, 96, 411 and 357 ug g^{-1}. Beyond 12 km the fluoride concentrations in foliage of the same tree species were less than 20 ug g^{-1}. Air monitoring was conducted using Na - formate plates and the calculated maximum fluoride level in the air was about 5 ug m^{-3} (6.10 ppb) at a distance of 0.7 km from the source. Beyond 12 km the calculated level of fluoride in the air was 0.20 ug m^{-3} (0.24 ppb) or less.

Studies were started in 1969 on Cornwall Island, Ontario to document the effects of fluorides emitted from an Al reduction plant located immediately to the south in New York State (Linzon, 1970). At a sampling station on Cornwall Island about 1.6 km northeast of the Al plant, eastern white pine needles accumulated 135 ug g^{-1} fluoride and displayed severe injury. Many dead eastern white pine trees were present in the forest stand at this sampling station. Trembling aspen trees had 495 ug g^{-1} fluoride in injured foliage. The eastern white pines displayed an orange-red terminal necrosis on needles; the trembling aspen foliage displayed black necrotic marginal injury on leaves; and choke cherry leaves displayed reddish-brown marginal lesions. At a control location about 6.4 km northeast of the source, eastern white pine and trembling aspen foliage displayed no injury and contained less than 20 ug g^{-1} fluoride content. Lime candle measurments showed over 4000 ug F/100 cm^2 in the air near the eastern white pine stands located 1.6 km from the source. A control order to reduce fluoride emissions was served to the Al company by New York State. The Al company began operations in 1959 and emitted 139 kg F hr^{-1} until 1972 when abatement measures reduced the emissions to about 34 kg F hr^{-1}. In the years following 1972 little or no fluoride injury occurred on the current year's needles of the eastern white pine trees (Linzon, 1978).

The eastern white pine stands on Cornwall Island located 1.6 km from the source demonstrated a remarkable recovery in the radial growth of the trees following the abatement measures taken by the Al company in New York State (McLaughlin and Emerson, 1984). Three stands of eastern white pine were sampled and analyzed using dendrochronological methods. Two stands (identified in Figure 1 as West Bridge and East Bridge) were located downwind of the Al company. The third stand was located 22 km NW as a control. All three stands were similar in age, stocking, species composition, forest site classification and shared the same meteorological regime. Two increment cores were collected from 10 dominant, healthy trees at each site. The annual growth rings were measured to the nearest 1/100 mm on a Bannister Incremental Measuring Machine which was interfaced with an Apple IIe microprocessor. Software programs were prepared to facilitate data interpretation, compilation and display. During the period of high fluoride emissions (1959 to 1972) the growth rings of the white pine at the two Bridge stands were 52% narrower than the rings of control trees. Subsequent to 1972 the trees appeared to respond to the reduced fluoride emissions with wider growth rings. From 1976 to 1981 the mean ring widths for trees downwind of the source were not significantly different from the control trees.

An investigation was conducted in the vicinity of an oil refinery in Ontario regarding the sudden appearance of injury on Scots pine trees to a distance of 5 km from the refinery (Linzon and Tung, 1976). In addition to Scots pine, eastern white pine, spruce, larch, plum, and Manitoba maple trees displayed foliar injury. On the broadleaf trees, the foliage displayed both marginal necrosis and bifacial lesions in the central portions of the leaves. Chemical analysis showed higher levels of fluoride in foliage close to the source compared to control non-injured trees. A histopathological study was conducted on the injured Scots pine needles. Cellular damage was found to include collapsed mesophyll cells, hypertrophied transfusion parenchyma cells in the stele, a compressed phloem and collapse of the endodermal ring of cells surrounding the stele. The combination of symptomatology, resistance and sensitivity of different tree species, the chemical analysis results, and the histopathological findings confirmed that the injuries had been caused by an acute HF fumigation.

A study of the effects of atmospheric fluorides on tree growth in the vicinity of an Al manufacturer at Kitimat, British Columbia was started in 1973 (Bunce, 1985). A grid pattern containing 64 permanent sample plot was established. The trees in the plots were measured and recorded by species, diameter, height and condition. Increment cores were taken from the trees to measure tree growth, and foliage was collected to be chemically analyzed for fluoride content. The forest area surrounding the smelter was segregated into an inner zone (high effect), an outer zone (low effect) and a surround zone (no effect). Hemlock forests were severely damaged in the inner zone to a distance of about 8 km from the smelter, whereas the outer zone extended to about 17 km. The growth rate of the forests from 1954 to 1973 was reduced by 28% in the inner zone and by 19% in the outer zone compared to growth rates before the smelter began operation in 1954. Fluoride in hemlock foliage in 1974 measured 271 ppm in the inner zone and 163 ppm in the outer zone. Abatement measures were instituted at the smelter in 1974 and during the period 1974 to 1979, the rate of fluoride emission was reduced by 64%

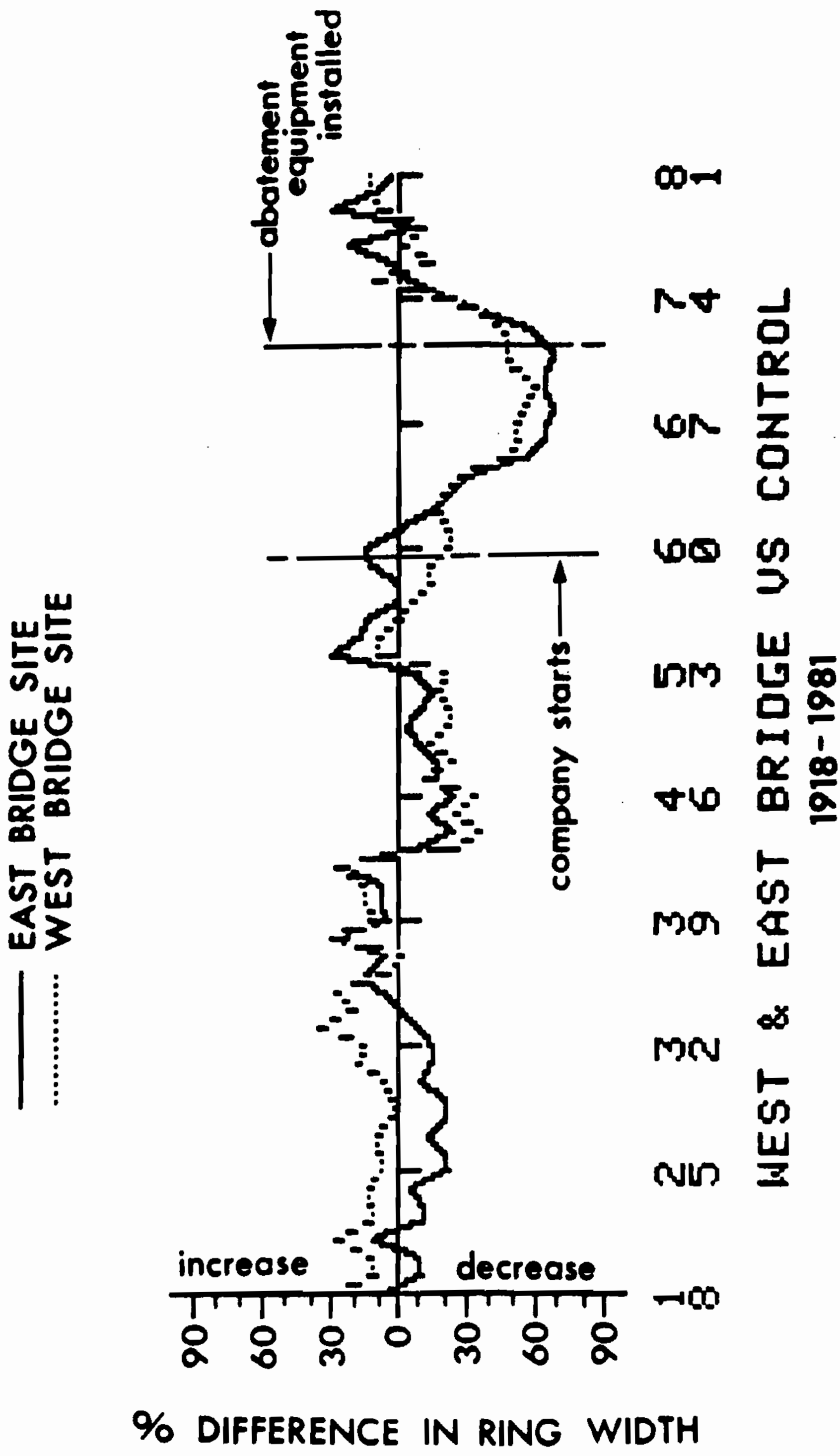
EAST BRIDGE SITE
WEST BRIDGE SITE
abatement equipment installed
company starts
increase
decrease
90 60 30 0 30 60 90
18 25 32 39 46 53 60 67 74 81
WEST & EAST BRIDGE VS CONTROL
1918-1981
% DIFFERENCE IN RING WIDTH

FIGURE 1

of what it had been previously. The fluoride content of hemlock foliage in the inner zone decreased to 87 ppm in 1979 and in the outer zone it decreased to 29 ppm. The basal area decrease in forest growth for the period 1974 to 1979 remained high in the inner zone but a small positive increase in forest growth occurred in the outer zone.

REGIONAL STUDIES

The above case histories dealt with tree damage in the vicinity of point sources. The closest situation in eastern Canada to the forest declines occurring on a regional scale in Europe and in the eastern United States is the decline of sugar maple in Quebec and Ontario. Maple syrup producers in the eastern Townships of Quebec first expressed concern in the autumn of 1978. Scientists made visits to the area in 1980, 1981 and 1982 and observed that the decline increased in intensity each year (Gagnon et al., 1985). The symptoms of damage included small leaves which tend to colour earlier than usual in the fall, loss of foliage from ends of branches, branch dieback, bark flaking off main branches, trunk tap holes taking longer to heal, reduced rate of radial increment growth and tree death. A number of hypotheses have been suggested for the cause of the sugar maple decline in Quebec which included long-term factors such as harvesting accompanying tree species, tree age, tapping, livestock grazing, and air and soil pollution. Short-term factors included adverse weather and insect infestations. Secondary factors included Armillaria mellea root rot. Acid rain and air pollution has been suggested as the most likely cause since the affected region receives the highest loadings of acid deposits, with the annual total being 40kg of wet sulfate ha^{-1} yr^{-1}.

In Ontario, in the spring of 1984, a number of maple syrup producers from the Muskoka area complained about the increase in dieback and mortality of sugar maple trees in the last six years. The producers felt that acidic precipitation may be involved and that continued sugar maple decline could jeopardize the local maple syrup industry.

A field study was designed by the Ontario Ministry of Environment to examine the etiology of the declining sugar maple trees. Permanent observation plots were established in seven woodlots in the Muskoka area of south-central Ontario and in one woodlot near Thunder Bay in northwestern Ontario. Soil from the woodlots, and foliage, twigs and roots from sugar maple trees exhibiting a gradient of decline symptoms were collected for chemical analysis. Increment cores were collected from sampled trees and discs were taken from felled trees to examine chronological growth patterns. In addition, atmospheric acidic deposition rates, forest management practices, site disturbances, tree age, site quality, the presence of diseases and the history of insect defoliation and weather records were investigated at each study site location (McLaughlin et al., 1985).

A summary of the 1984 study results indicated that the current outbreak of sugar maple decline in Muskoka first became evident abut 1978. When the data from the seven Muskoka study sites were combined, using a numerical decline index, 58% of the trees were considered healthy, 20% had light to moderate decline symptoms, and 22% exhibited severe maple decline. Although some degree of tree decline was observed on maples in all age classes it was most pronounced on older trees and on trees which had been tapped for maple syrup production or otherwise wounded. Site nutrient deficiencies were not implicated in the decline of sugar maple.

The soil at the Muskoka sites was acidic with a mean pH of 4.8 and contained high amounts of exchangeable Al, ranging from 5 mg to a high of 33 mg kg^{-1} in mineral soil ($CaCl_2$ extracts). Declining trees in Muskoka suffered extensive root death and the fine roots had significantly higher Al concentrations than fine roots of healthy trees. The Al levels averaged 47% higher in fine roots from declining trees (4000 mg kg^{-1}) versus healthy trees (2730 mg kg^{-1}) which was statistically significant, ($p \leq 0.05$).

Two increment cores were taken at breast height from each of six sample trees at each of the seven study sites in Muskoka. The cores were mounted, sanded and stained with phluoroglucinol to highlight the annual growth rings. The ring widths were observed through a microscope and measured to an accuracy of 0.01 mm on a Bannister Incremental Measuring Machine interfaced with an Apple II microprocessor. Accompanying software modelled after Fayle et al., (1983) provided on-line ring-series graphics to continuously compare the measured cores and ensure accurate ring dating. Additional software programs transformed the actual ring width measurements into tree-ring indices as described by Fritts (1966). This is accomplished by fitting a regression line curve to each ring width series and dividing the actual ring width by each yearly value of the fitted curve. The resultant tree-ring index has a mean of approximately 1.00 and a variance which is independent of tree age, position within the stem and mean growth of the tree. The individual tree ring indices were averaged to generate a sugar maple chronology for each study site, a chronology for healthy and declining tree populations and a Muskoka regional maple chronology.

Annual growth rings for both healthy and declining trees were vey narrow during the two years of forest tent caterpillar defoliation in 1976 and 1977. Subsequent to the collapse of the insect epidemic, growth recovered in the healthy trees but not in the declining trees. Incremental growth in the declining tree population appeared to be falling relative to the healthy trees for 20 years prior to the caterpillar infestation suggesting that this group of trees may have been predisposed to decline perhaps by physiological, genetic or environmental factors.

A foliar chemical gradient was detected with reduced elemental concentrations in the tops of the tree crowns at Muskoka. Early season droughts during the two years of defoliation by insects (1976 and 1977) and again in 1983 and root infections by Armillarea mellea were some of the factors in the tree decline.

The etiology of sugar maple decline is probably site specific, and may vary between individual trees and regions. At Muskoka the soils are acidic and are classified as sensitive; Al is freely available to trees and therefore the potential for indirect effects to trees exists. Higher amounts of Al were found in the fine roots of declining trees in Muskoka compared to healthy trees. Foliar tissue leaching and reductions in incremental growth on some trees may be environmentally related. Sugar maple decline is widespread throughout the Muskoka area and the region receives high loadings of acidic deposition (about 35 kg SO_4 in wet precipitation/ha/yr). These data suggest that acid precipitation, as an environmental stress, may be an additional factor to the complex maple decline syndrome.

From the above, it may be tentatively concluded from the initial study of sugar maple decline at Muskoka, that the severe epidemic of forest tent caterpillar in the late 1970's combined with spring droughts in 1976, 1977 and 1983 were prime inciting factors. Armillaria mellea root rot, tree age and site management were contributing factors. Some data from the study suggested that acidic precipitation is an additional environmental stress in the Muskoka area.

In Ontario, a province-wide survey is being conducted by the Ministry of the Environment to determine the degree and extent of hardwood decline (sugar, maple, ash, beech, and birch) in order to document trends over time which could be related to regional atmospheric deposition loadings. A total of 110 plots have been established by the Ontario government. In addition, a detailed stem analysis and dendrochronology study is being conducted in different Forest Sections of Ontario to develop regional tree growth chronologies which can be related to different soil buffering capacities, and different loadings of atmospheric pollutants.

A major effort has been undertaken by the Canadian Forestry Service in the establishment of an Acid Rain National Early Warning System (ARNEWS). Over 100 plots will be established across Canada in stands of major commercial tree species. The main objective of this program is to detect the possible damage to forest trees and soil caused by acid rain or to identify the damage sustained by Canadian forests (trees and soil) which is not attributable to natural causes or management practices (Rennie, 1986).

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5.6 THE IMPACT OF AIR POLLUTION ON FOREST ECOSYSTEMS OF THE LITHUANIAN SSR*

M. Vaichys, K. Armolaitis, V. Oniūnas, A. Raguotis, L. Skuodiene and L. Slavénienė
Lithuanian Research Institute of Forestry
Girionys, Kaunas, Lithuanian SSR, USSR

1. INTRODUCTION

After world war II industry, energetics and mechanical transport began rapidly to develop in the Lithuanian SSR. Currently, in the republic air pollution due to mechanical transport comprises 50 %, while due to energetics and industry 30 and 20 %, correspondingly.

Near intensive highways natural environment is contaminated over distances of 150-200 m. In this zone lead, chrome, strontium and nickel accumulate to the greatest extent. In winter chlorides and sulphates are noted too. So far only the latter two substances affect the viability of trees adversely.

As to power stations and industrial enterprises, currently, about 15 % of the area covered with wood are already under the influence of their emission. The forests have suffered most of all near the factories of nitric fertilizers.

Subsequently, these problems have developed into a major national concern for the republic.

2. THE OBJECT OF INVESTIGATIONS

The investigations were carried out on the zone of the influence of toxic emission (SO_2, NO_x, NH_3, HF etc) from the factory of nitric fertilizers. Near it a large forest grows in which pine, spruce, birch and black alder stands prevail Oak, grey alder and larch (European, Polish) occur rarer.

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podzol, sod-podzol (gleyed variants in the lower parts of the relief) and sandy soils (with morainic loams in some places) are widespread.

3. RESULTS

3.1. The state of forest stands

Pine (Pinus sylvestris) and spruce (Picea abies K.) are damaged to the greatest extent. In the direction of the predominating winds the stands of these evergreen species are destroyed over distances of 8-12 and even 20-25 km from the pollution source. Deviduous stands mainly suffer in the zone of 3-5 km. The conifers are damaged most of all. They begin to dry in at the age of 50-70 years. The most significant negative impact of toxic emission was noted during extremely cold winter in 1978-79 when air temperature was repeatedly -29-30°C.

Stand resistance is stipulated not only by the distance from the pollution source. At the same distance the stands on very moist soils are more sensitive than on these with normal moisture. Moreover, their viability decreases with age and, consequently, with height too. The highest trees in stands and the highest stands in large forests are damaged frist. In massive forests stand resistance reduces considerably the presence of large openings. The relief has a great influence too. On steep slopes facing the pollution source the extent of stand damage increases upwards.

To study the accumulation and distribution of toxic substances under the conditions of air pollution we applied air-dry organic substances-sorbents (in this case - Sphagnum magellanicum). They were placed in nylon meshes and hung out at the height of 1,5 - 3 m from the ground at different distances from the contamination source. In 1983-1984 we carried out an experiment on catching of macro- and microelements with the aid of sphagnum in the surroundings of Enterprise Amalgamation "Nitrogen". In sphagnum increase in the content of total manganese, titanium, vanadium, nickel, zirconium, yttrium, lanthanum, cerium and strontium was established. It must be noted that with increasing distance from the factory these elements diminish considerably. It shows their technogenic origin. At the distance of 0.1 - 0.5 km from the factory the oserved chemical elements exceed the control as follows: manganese by 2.9 times, titanium by 1.8 times, vanadium and lanthanum by 2.5 times, nickel and zirconium by 2 times, yttrium and cerium by 5 times and strontium by 5 times and strontium by 25 times. However, at the distance of 2-3 km the content of manganese and vanadium is 1.9 times more than the control, while that of lanthanum, nickel and strontium 2.3, 1.2, 6 times, correspondingly. Increase in the content of yttrium and cerium comprises 3.5-4 times. The accumulation of macroelements and change of the reaction in the direction of alkaliing were noted in sphagnum too. The maximum content of phosphorus, nitrogen, fluorine and sulphates were found at the distance of 2 km from the factory.

3.2. Changes in physiological functions of trees

The investigations on the physiological state of trees of the main species (pine, spruce, birch, asp and oak) growing in the contaminated zone revealed that toxic emission causes disorder of the major physiological functions. At frist, the disorder of the metastable balance of ions in a cell is noted. The determination of K^+ ions in the deionized environment indicated that the concentration of K^+ ions getting out via cell membranes depends on the species and tree distribution with respect to emission source. Under the given conditions the trees growing in the nearest zone from the source of contamination have the most permeable membranes. In the zone of up to 3 km the concentration of K^+ ions (in mkg/100 ml of deionized water - deionized environment) for oak, birch and pine is 1.9, 1.7 and 1.5 times , correspondingly, more comparing with the control, whilst for pine and spruce even 2.5 and 2.2 times, correspondingly.

It is common knowledge that fluorine and its combinations are not indispensable elements for substance of a plant cell. Therefore, no detoxication of it is caused in the organism. According to our data the greatest quantity of fluorine was found in the needles of pine and spruce during intensive growth and phytomass accumulation (from 0.004 to 0.007 mkg/50 ml of deionized environment or 10^{-5} m concentration). It is supposed that fluorine accumulating in the chloroplasts of the green mass of trees (which grow in a contaminated zone) causes significant disorder in the photosynthetic apparatus.

In a growing cell continuous albumin renewal occurs. However, constant impact of emission on tree weakens albumin synthesis and simultaneously intensifies the process of albuminolysis. It is established that industrial emission causes essential changes in the content and state of albumins. For deciduous trees growing in the nearest zone from emission source the albumins which are functionally important for growth comprise from 41.7 to 55.6 % comparing with the control. For conifers the synthesis of functional albumins of a cell occurs in a lower level: for spruce from 32.4 to 46.3 % and for pine from 27.0 to 30.3 %. The quantity of simple albumins increase from 8 to 15 % for deciduous trees and from 24 to 42 % for conifers.

Moreover, we determined essential changes in the chemism of the photosynthesis due to industrial emission. Hence, the accumulation of reserve substances and their conversion into sugar becomes slower. This phenomenon has a direct dependency on frost-resistance of trees. The given function is disturbed to the greatest extent in the zone of 3 km from the emission source. In shoots of conifers the quantity of sugar is from 21 to 32 % less than the control, which in these of deciduous trees - from 11 to 20 %.

3.3. Chemical composition of forest vegetation

The investigations revealed that the maximum content of the total and nitrate nitrogen accumulate in considerably damaged leaves of birch and oak as well as in the thicket of raspberry and elder. It was ascertained that nearer the source of emission in the assimilation organs of plants increase was noted in the content of sulphur and sulphates (from 2 to 3 times), total R_2O (from 1.5 to 2 times), total fluorine (from 2 to 4 times as well as in the content of some microelements (strontium, vanadium, manganese, zirconium, barium, lanthanum, yttrium etc.).

Thus, due to the impact of different toxic substances of technogenic origin essential chemical changes occur in forest biogeocoenoses. The visbility of trees is effected adversely.

3.4. Contamination of snow cover and soil

The data of the investigations on physically-chemical properties of snow cover (1981-1986) indicated that the most significant contamination was in the territory of the factory and at the distance of 0.5 km from it. The greatest quantity of mineral dust accumulated there comprises from 0.03 to 0.06 g/l, whilst at the distance of 3-5 km - approximately 0.01 g/l. In snow cover different ions with industrial emission occur: SO_4, Cl, NH_4, NO_3, F, K, PO_4. Their concentration diminishes with increasing distance from the factory. However, at the distance of 5 km ion content exceeds the control by 2-3 times. The index PH of snow water near the factory amounts to 6.0-6.9. It decreases up to 5.4 - 6.2 with increasing distance. Obviously, increase in potassium cations by 6 times, in calcium by 5 times, in ammonium by 4 times causes alkaliing of snow water near the factory in spite of the fact that acidifying anion content increases too. In the control samples of snow the values of pH ranged from 5.4 up to 6.2.

In the same samples of snow the content of microelements (Sr, Ce, Zn, Mn, Cu, Pb) was determined. Of them only strontium content increased several times, whilst the quantity of the rest microelements in all objects practically did not change.

The obtained results of the investigations enable us to conclude that according to physically - chemical properties it is feasible to establish the extent and boundaries of local air pollution.

It is ascertained that forest litter is a good accumulator of macro-and microelements getting there with industrial emission. Nearer the factory the content of nitrogen, phosphorus and potassium as well as strontium, lanthanum,cerium, vanadium, manganese, yttrium, ytterbium and barium increased. However, increase in other investigated microelements such as cobalt, lead, boron, molybdenum, zinc, chrome, zirconium, silver, lithium, titanium, niobium, scandium and gallium was very slight and therefore, practically it may be ignored. The maximum of macro- and microelements was determined on the territory of the factory and at the distance of 500 m from it. Comparatively many described elements accumulated in the litter at the distance of 2.5 km from the source of air pollution. Some increase was found even at the distance of 10 km.

In the mineral part of the forest soil increase in some macro- and microelements was observed only near the factory (up to 250 m from it). We can infer that forest litter accumulates industrial emission and thus, isolates the upper mineral soil horizons from air pollution. Also forest litter is a perfect index of the extent of the environment contamination by industrial emission.

3.5. The state of soil microflora

The character of the impact of separate industrial objects on the development of soil microflora differs considerably. The emission of metallurgical and chemical factories, as a rule, suppress microorganism development in the ecosystems of the environment. This does not hold, however, for the surroundings of the factories of mineral fertilizers, at least during the first decades of their influence.

The objects of our investigations (pine, pine-birch stands and their cutovers) are situated at different distances from the contamination source. In the litter of these forests we found increased content of the main elements of mineral nutrition. It included abundant fall off of nitrophylum grass. Hence, the number of microorganisms in the litter is approximately 2-4 times more than usually. In pine stands it amounts to 10-60 million in 1 g of dry substance, while in pine-birch stands up to 60-100 million. There prevail ammonifier non-spore forming bacteria, however, the number of bacilli, actinomyces and micromycetes is considerably less. Stimulation of the development of microorganisms and other physiological groups (nitrificators, denitrificators, anaerobic fixatives, cellulose-decomposing microorganisms) is insignificant.

The most abundant microflora is noted in the litter of the forests situated at the distance of 12 km from the factory, whilst the poorest one (below the control) at the distance of 2-3 km. Due to emission in the upper horizons of the mineral soil microflora slight changes occur after 10-15 years.

The abundance and composition of the microflora in the forest litter is conditioned to a great extent by epyphyte microorganisms which live on needles and leaves of trees. After dying off they fall on the litter. Calculation of the microflora indicated that it is extremely rich in the contaminated zone of the factory of nitric fertilizers. The number of epyphytes on the needles of pine and on the leaves of birch is almost the same. It amounts to tens of millions per 1 g of dry substance, i.e. approximately 10 times more than in undamaged forests. The majority of epyphyte microorganisms are ammonificators among which there are many bacteria with brightly coloured cells. Micromycetes have dark-coloured mycellium. Among them there are comparatively many yeast like fungi and yeast. Actinomyces are entirely absent.

We can conclude that microbiological control of forest ecosystem contamination first must rely on the calculation of epyphyte microflora as most responsive to industrial emission.

3.6. Regeneration of dead forests

Currently, not only carrying out of ecological monitoring is actual. A complex problem of regeneration of dead forests must be solved. It is implemented as follows:

- near contamination sources experimental mixed forest plantations from the most gas resistant species of trees and bushes are raised. Measures are taken which promote natural regeneration of deciduous trees.

- additionally, over distances of 6-8 km from emission source on the poorest soils less resistant trees and bushes but which have adapted well to the local site conditions (even some evergreen conifers) are planted. The aim is to achieve a shorter exploitation period.

- at the same distance but on fertile soils willow plantations and these from fast growing trees (poplar, larch) are raised.

- planting material is grown in the same plances of local contamination (at some distance from emission source). It results in adaptation of plantings. Only the weak ones die.

4. CONCLUSION

Industrial emission in forest phytocoenoses has an integrating and unvafourable influence on the main physiological functions and chemical composition of vegetation and soil. It is reflected in growth and surviving of trees. The boundaries of local air pollution are readily determined according to physically - chemical properties of water, snow cover and forest litter as well as on the basis of epyphyte microflora calculation and with the aid of organiz adsorbents of emission. Forest litter accumulating macro - and microelements prevent the contamination of the upper layers of soil to a great extent.

In regenerating the dead stands great attention must be focused on natural regeneration of deciduous trees, on raising of willow plantations and mixed plantations from the most resistant species.

5.7 THE IMPACT OF AIR POLLUTION ON FOREST ECOSYSTEMS AND MEASURES TO ENHANCE THEIR RESISTANCE*

N.P. Kalinichenko, V.D. Kasimov, A.A. Martynuk, L.L. Kozhenkov, S.M. Petrov and E.V. Romashkevich

All-Union Institute of Forestry and Mechanization (VNIILN)
Moscow, USSR

Forests, being a potent environment-forming factor in biosphere and a renewable source of valuable organic raw materials at the same time, acquire a particular importance under the progress in science and technology that has aggravated the relations between the natural environment and socity. The problem of the decline of forests exposed to industrial and traffic emissions has become acute in the last few decades. As a result, according to the UNO ECE data, the total area of affected stands in Europe alone at present exceeds 7 mln. ha.

The USSR is one of the largest forest countries with about 20% the world forested area and the total standing volume of 80 bln.m^3.

The natural diversity determines the USSR forest stand composition and yield as well as the division into several forest-growing zones: forest - tundra; forest with taiga and mixed coniferous - broadleaved stands included; forest - steppe and steppe. Mountainous forests are characterized by vertical zonality.

The environment pollution within the country has local character with separate areas having higher contents of contaminants caused by the activities of industrial enterprises and transboundary atmospheric transfer (Vasilenko et al.1985). According to estimations done, S emissions at the territory of the USSR make up approximately 16 mln. ton/year, including 4 mln. ton due to the transfer from Western and Eastern Europe (Vasilenko et al. 1985; Fourth..., 1982). The highest sulfate concentrations in snow are recorded in the European part of the Soviet Union (Vasilenko et al. 1985), where 24% forested area is located with pine (30%), spruce (32%), birch (20%) and aspen (6%) prevailing (Lositsky and Chuenkov 1980).

It is known that local (impact) pollution of the environment is characterized by the close relation between the factors reflecting disturbances in the environment constituents depending on the distance from emission sources. The same regularities are inherent in forest ecosystems, with the charac-

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ter, size and territorial distribution of the damage depending on the power of a source, composition of emitted contaminants, meteorological conditions, topographic features of a terrain, forest stand composition and age, site features and other factors. Emission impact may considerably change ecological conditions for forest ecosystem existance, upset their natural structure and functions and cause their deterioration. The main elements are always technological factors - they determine the level of emission loading on ecosystems.

The characteristic feature of technogenic pollution is an excessive accumulation of pollutants in various components of ecosystems. Emissions from chemical plant complexes and central heat power plants generally do not cause the acidification of melt and rain water. The snow cover in the vicinity of mineral fertilizer production and cement plants is characterized by a weak alkaline reaction, induced by the presence of Ca, Mg, AM and partially K and Na cations in technogenic pollutants. In spite of the neutral weak alkaline reaction in the zone within 4-5 km from emission sources sulfate, nitrate, bicarbonate and chlorine concentrations in snow are recorded to be higher compared to the background concentrations of the above; these substances may later accumulate in forest ecosystems or be removed outside the systems. More pollutants are accumulated in the soils under forest stands than on sites with no forest. Thus, for 30-year old pine forests of lichen and Hylocomium, Dicranum,... spp. type, the excess value of SO_2 near industrial plants may be up to 20 kg/ha/year.

In addition to the pollutant supply with atmospheric precipitation there observed direct absorption of gases by plant assimilative organs through stomae or sedimentation on leaf surfaces. S content in the needles of young pines growing close to industrial plants may be as great as 0.20 - 0.25% dry weight and the absorption of sulfurous gas with young pine crowns over a growing season is about 25 kg/ha. The major portion of S is absorbed during the first year of needle life, but in spite of this, necroses in needle apices appear in May-June of the second year of life. The variation in S absorption by needles from different portions of pine tree crowns is not significant and does not depend on site and age. There has been traced a tendency toward an increased S content in needles of trees in Craft classes 3 and 4 compared to 1 and 2.

Pollutant flow to an ecosystem causes, first of all, disturbances in the life functions of its most susceptible components: lichens, soil microbial fauna, etc. But those are the vitality weakening and dieback of tree and shrub canopy, primarily of its idificators, i.e. standing trees, that result in fundamental changes in the whole ecosystem structure and functions.

Stand response integrates specific changes in all ecosystem components that arise, caused by emissions. Technogenic factors, creating stress situations and causing early senescence, ultimately result in decreasing woody plant life duration. Tree canopy dieback occurs over a relatively short period of time when the doses of pollutants are high. As a result of the injury of the bulk of the assimilative organs and disturbances in shoot formation, progressive crown drying with subsequent dieback takes place. The process of decline goes on more intensively in conifer stands than in hardwoods, because the latter have higher tolerance to emissions. The inflow of big amounts of toxicants decreases the possibilities of adaptation of the main forest-forming species within a species. In case of acute injuries the resistance of a phytocenosis shows especially well the advantages of multistoried tree stands with a complex composition, capable of an effective change ("readaptatuon") in the technogenic environment. The age of the stand where trees are exposed to pollution still more intensifies the character of an injury. For example, Scots pine trees at the age up to 30-40 years may preserve the vitality of the leader, replacing it with a lateral branch, capable of orthotropic growth. Along with it, under the influence of emissions crown drying and dieback of aspen trees occur at the age of 120-140 years.

With local atmospheric pollution, acute damage of stands exposed to high concentrations of pollutants is observed mainly on edges near emission sources, on leeward slopes and range tops. The major portion of the injured forest area includes forest stands, exposed to chronic injuries by medium and low concentrations of emissions, at which ecosystem decline persists long and has a latent character at the beginning that can be detected with the help of sensitive biological and physiologo-biochemical tests. Gradually the changes acquire an irreversible character and involve the whole system. Stand response to chronic exposure has a number of specific features.

Under the condition of chronic atmospheric pollution shortening of pine and spruce needle life duration as a result of early shedding may be observed. Three-year observations on the dynamics of needle growth and shedding in weakened pine stands indicate a certain "balance" of these processes: increased older needle shedding during a growing season is accompanied by an earlier beginning and enhanced intensity of current needle growth. The developed needles have larger sizes and higher dry weight compared to control trees. Eventually, in spite of the decreased amount of needles in a stand, the needle mass of severely weakened trees of the same diameter is larger compared to controls.

As a result of a long exposure to pollution the aboveground biomass of a stand decreases, the portion of stem wood becomes less, though simultaneously the portion of branches and needles increases (Table 1). The analysis of the production per year shows that a decrease in wood increment is attributed to a decrease of the economic productivity of the assimilative organs (ratio of annual wood production to needle mass) as a consequence of the need to compensate for the recovery of too early shed needles and the reduction of photosynthetic surface due to necroses, pigmentation and chlorophyll degradation. According to estimations the chlorophyll content in severely affected 30-year old pine stands (lichen - Hylocomium type) appears to be reduced almost twice.

Table 1. Indices of productivity of 30-year old pine plantations with different levels of weakening by industrial emissions (pine stands of lichen - Hylocomium type, site index III - IV)

No sample plot	Damage index	Standing volume m^3/ha	Aboveground biomass centner/ha				Needle prod.	Chlor. store kg/ha
			total	stem	branch	needle		
1	3.0	83	474	348	76	55	0.40	30
4	2.8	61	452	281	94	77	0.28	-
5	2.8	96	568	392	102	74	0.40	-
3	2.1	136	754	592	95	67	0.70	34
27	1.9	180	815	637	104	74	0.76	-
29	1.3	160	935	814	67	54	1.06	-
26	1.4	194	1090	885	116	89	0.69	59

Unlike in acute cases, yield losses attributed to chronic exposure to emissions and expressed as standing volume, average and current increment values, are caused by the deterioration of growth and gradual dieback of a portion of trees. Reorientation of metabolism in woody plants is responsible for the decrease in radial increment, height increment, with the character of the change in the above factors depending on the age when the stands started to be exposed to emissions. The young pine stands, age class 2, having formed under pollutant exposure,respond, first of all, by decreasing their height increment. Exposure to pollutants at the age of 35 results in simultaneous reduction of both radial and linear increments, however, at the end of maturity stage, when the height increment is depressed due to the natural reasons, diameter increment decrease is prevailing. In maturing pine stands of cowberry - Hylocomium ... type the average reduction in current radial increment over 50-year period of exposure is 40, 30 and 20% compared to controls at the distances of 1-3, 5-7 and 19-20 km respectively from pollution sources.

Prolong exposure to low pollution concentrations reorganizes the course of natural differentiation in a stand, including the dieback of dominant and subdominant individuals the same as the trees of lower Craft classes. As a result of depressing the crowns of larger diameter trees and better light admittance under a canopy we may expect changes in the mortality level of supressed trees as well.

Disrupting the fundamental life functions of trees, emissions help certain species of entomological pests and phytopathogens to injure them. The population of pine-tip moths (Evetria) goes up and a number of stems, damaged by blister rust canker increases in pine stands, weakened by toxicants.

The discussion of the impact in forest ecosystems, caused by industrial emissions, would not be complete without considering certain aspects of adverse changes in soils exposed to pollutants. Their accumulation in soils is potentially dangerous for the plants due both to toxicity and possible disruption of mineral nutrition balance and changes in some physical characteristics. The buffering power of soils is determined, first of all, by their types and depends on an organic matter content, exchangeable cation composition, mechanical composition, water regime, etc.

The studies, carried out on soddy podzolic medium loamy soils near industrial production, emitting N and S oxides, show the acidification of top soil horizons to pH=3.3-3.7 in the close vicinity to industrial enterprises. The soils are characterized by extremely low saturation with exchangeable forms of Ca and Mg, also by high hydrolytic and exchange acidity that can be explained by the removal of exchange bases from the soil profile as a result of their replacement with H ions. The removal of exchangeable cations may be enhanced by the supply of surplus heavy metals, replacing K in the soil uptake complex. Due to Ca cation removal, breaking of soil structure occurs with subsequent erosion development and loss of upper fertile horizons. Owing to higher solubility of primary minerals, the content of exchangeable Al, that disturbs Ca, Mg, and P transport and use along with the direct toxic effect on the root system, appears to increase 2 - 2.5 times.

In concealed brown podzolic soils exposed to F emissions pH does not decrease, due to a higher content of humus and Ca. But an increase in exchange acidity as a cosequence of Al mobile form accumulation appears to occur instead.

Eolian immature sandy soils also do not change pH values when exposed to SO_2 NO_x and Cl emissions. Small amounts of humus in the above soils facilitate decreasing Ca and Mg contents and the degree of soil saturation with bases.

The role of soil conditions in the stability of eco - systems to emissions cannot be evaluated in any predetermined unique manner. In case of high emission doses the soil and hydrological conditions, apparently, do not considerably affect the character of a succession. After the decline and at the moment of forming a secondary association the soil conditions may be extremely important for they determine the composition and trends in natural regeneration. On sandy soils lacking nutrients and moisture a declined pine stand actually cannot be replaced with anything else. On rich soils there exists a possibility of regeneration and successful growing of hardwoods and mixed conifer - hardwood stands. But an excessive accumulation of technogenic pollutants or disturbances in soil physiochemical properties, that is enhanced after the tree canopy decline, may considerably limit natural regeneration and reforestation. Greenhouse experiments with conifer seed germination and evaluation of the seedling vigour on the samples of heavily contaminated soils, show that soil toxicity does not adversely affect germination. The experiments demonstrate an increased seedling mortality and poor growth because of root damage at later stages.

Table 2. The effect of soil toxicity on seedling survival (numerator in %) and growth (denominator in cm)

No site	Distance from pollution source in km	Species	Experiment date 10	20	30	40
1	0.5	pine	70/-	60/0.67	57/0.68	0/-
		spruce	63/-	60/0.82	67/0.80	33/0.90
2	5	pine	93/-	93/1.59	90/1.65	80/1.82
		spruce	100/-	100/1.27	90/1.33	67/1.50
3 (control)	15	pine	93/-	100/2.38	97/2.41	97/2.62
		spruce	97/-	93/2.13	97/2.15	97/2.36

In certain cases the feasibility of successful reforestation is limited by a combined effect of considerable atmospheric air pollution and soil pollution. Under F emissions at the distance of 0.5-1 km from a pollution source only some Salix species and herbaceous species survive. Surviving individual birch and aspen trees often have dwarf or bush-like forms, drying crowns and then die back. At longer distances (up to 3-4 km) from pollution sources the condition of the above species appears to be better and they form fairly productive stands. 30-35 year old pines in such stands have symptoms of initial decline.

Under the chronic air pollution the optimal soil conditions favour forest stand vitality. For example, pines on soddy cryptopodzolic loamy sands are more resistant to SO_2 emissions compared to pines on sandy soils with the deficit of nutrients and moisture.

Fairly large damaged forest areas and the threat of their further increase in the future require an active search of methods for lowering economic losses and ecological damage. It goes without saying, a cardinal decision of the problem is feasible only in case of decreasing emissions down to the levels that are not harmful for woody vegetation. Along with this, the proper application of the existing and specific methods of forest management gives a beneficial effect on the condition, growth and yield of forest stands exposed to toxicants.

Two main tasks are generally solved in forest management on exposed sites:

1. Increase of resistance and life duration of stands
2. Decrease of timber and other forest benefit losses after the decline of stands.

Simultaneously, some other management problems of minor importance may be solved in the zones of emissions.

Management decisions and planning are based on the data on stand damage levels and prediction of possible changes in stand condition for the future. The information about the nature of stand weakening is obtained through surveying the exposed areas and identifying zones of damage. Zoning within the exposed areas is done judging by the most sensitive tree species as often as at least once in 5 years. If a more particular decision on measures is needed, damage levels are assessed for individual compartments.

The long-term planning of forest management in stands exposed to emissions is based on the prediction of stand condition that takes into accout emission dynamics, pollutant concentrations in the air and thresholds of forest - forming species resistance. To obtain data on stand condition dynamics for making timely decisions, it is reasonable to carry out observations on permanent sample plots, established in stands of different age, having different species compo - sitions in the zones of damage in the process of forest inventories.

Management measures are assigned to fit specific zones of damage. In the zone of severe injury, characterized by the prevalence of died stands, clear sanitation cutting with subsequent reforestation by natural regeneration or by forest plantations established with pollution resistant tree and shrub species, are recommended. In the zones of severe or moderate damage a complex of measures is applied that is aimed at establishing and growing emission resistant stands, capable of fulfilling functions of sanitation and hygiene, recreation and soil protection at appropriate sites to the full. This is achieved by purposeful improvement and sanitation cutting, proper choice of species for plantations, by taking into consideration the specific features of technologies for their establishing and growing. Mineral fertilizer application in the zones of moderate and low damage improves nutrient availability and increases tree radial and linear increment. Increased doses of N as well as N in combination with P and K (Table 3) give a good effect on poor sandy soils.

In the zones of severe damage fertilizer application, as a rule, is ineffective, as the fertilization provides neither forest ecosystem conservation, nor their productivity levels.

Improvement cutting in mixed stands may be used for forming a composition, ensuring resistance to pollution. Improvement cutting in conifer stands, providing better nutrition regimes and more potent crowns, facilitates their higher resistance to toxicants. Nevertheless, one should be careful with improvement cutting in the zones of severe damage. In weakened stands a beneficial effect has been noted when mineral fertilizers were applied in combination with cutting of moderate intensity.

Table 3. The effect of mineral fertilizer application on 30-year old pine plantations

No sample plot	Treatments	N-content in needles %	Radial increm. mm	Heght inc. cm	Lateral branch inc., cm
1.	Control	1.23	0.84	27.2	20.6
2.	N_{90}	1.40	1.12	30.8	22.5
3.	N_{150}	1.55	1.42	34.5	25.8
4.	N_{200}	1.60	1.55	42.2	25.6
5.	$N_{90}P_{90}K_{90}$	1.44	1.08	34.6	24.6
6.	N_{150} $P_{90}K_{90}$	1.53	1.55	40.9	28.9
7.	$N_{200}P_{90}K_{90}$	1.51	1.50	46.0	30.8

Much attention should be given to phytophagous organism monitoring as their populations may appear to be subjected to unexpected changes.

Measures on lowering forest stand damage are developed as applied to specific forest-growing zones, with their typology and industrial production types as well as the diversity of natural and climatic conditions taken into account.

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5.8 EFFECT OF TECHNOGENIC AIR POLLUTION OF FOREST STANDS OF THE UKRAINE AND MEASURE OF FOREST OPERATIONS TO INCREASE THEIR RESISTANCE*

P.S. Pasternak and V.P. Voron

Ukranian Scientific Research Institute
of Forestry and Forestry Protection
Kharkov, Ukranian SSR, USSR

Problem of pollution of atmospheric air - the most important biosphere component - is one of the problems of the present. Despite of the great efforts to control & to prevent emissions, the level of pollution owing to the intensive development of industrial enterprises & of the number of transportation facilities continues to grow. Negative effects of air pollution on forest was discovered more than hundred years ago,however the greatest enlargement of the scale of forest injury caused by this factor was reported during the last decades.

The problem of atmospheric air cleanliness,considering high concentration of industrial enterprises,arose in some industrial regions of the Ukraine as well.Advantages of socialism,planned economy system in the first turn,secured adoption of modern measures of air pollution control.Concentrations of phytotoxicants in air do not exceed top permissible concentrations (TPC) for a human being set in the USSR.As investigations by many authors show (Илькун Г.М.1978,Николаевский В.С.1983,Сергейчик С.А.1984, Wentzel K.F. 1982) TPC normals for a human being,however,can't be used when the ecological norms are set for carrying capacities of industrial air pollution for woody vegetations,as their value is several times more than TPC normals for plants.Therefore,despite of the fact that air pollution is not of such expressed catastrophic character as is in the countries of Central Europe,the decision of the problem of reduction of forest stands injury is actual for the Ukraine as well.

In the Ukrainian scientific research institute of the "Znak Pochyota" order of Forestry & Forestry Protection named after G.N.Vysotsky,integrated research of forest stands situated at various distances from cement & potassic enterprises & from enterprises producing nitrogenous fertilisers,is carried out in various climatic zones of the republic in order to study the effect of technogenic pollution of atmosphere on forest ecosystems & in order to work out methods of their resistance.

Materials & methods

Experimental material includes data on 65 permanent sample plots situated in forest,steppe(enterprises of nitrogenous fertilizers),forest steppe & foothill(cement & potassic enterprises)zones of the republic, 7 stationary plots for selection of assortment of air pollution resistant species &

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for investigation of effect of mineral fertilizers & improvement cuttings on the state of stands under the prolonged influence of phytotoxicants.

Natural conditions of investigated regions greatly differ one from the other. Climate of forest & forest steppe zones is temperate continental with mild winter & warm moist summer, meanwhile in steppe it is continental with hot summer & expressed droughty - dry wind phenomena. In steppe zone average annual temperature is + 7,8° C, mean temperature of the most warm month (July) is + 21,5° C, of the most cold one (January) it is - 6,6° C & average annual amount of precipitation is 480 mm; for the forest zone these climatic indices are + 6,9° C, - 5,4° C & 620 mm respectively.

Forest growing conditions of forest zone are fresh complex subors (C_2), of forest steppe zone - moist hornbeam beech forest & moist abietic oak - grove (D_3), of steppe zone - dry & fresh subors (B_1 - B_2). As for the objects of investigation in forest zone these were 30-60 year old pure pine & oak - pine stands on soddy podzolic sandy loam soils, in steppe zone these were 20-70 year old pure pine stands on soddy immature sandy soils, in forest steppe zone - in the region with cement enterprise - these were hornbeam-beech & beech-pine stands on grey forest soil; in the region with potassic enterprise these were stands of various composition, oak, common silver fir, common spruce, Austrian pine & Scotch pine on soddy podzolic loamy soils.

Sample plots were established in accordance with the procedures generally accepted in timber inventory & in silviculture. Tree injury was determined in accordance with "Sanitary rules in the USSR forests" (1970). Index of the state of stands was determined as a quotient of the division of the sum of products of the state category value & number of trees in this state category by the total number of investigated trees. We evaluated as sound stands those ones whose state index was 1,00 - 1,50; as weakened stands - those with 1,51 - 2,50; as greatly weakened stands - those with 2,51 - 3,50; as dying stands - those with 3,51 - 4,50; as dead stands - those with 4,50.

Collection and analysis of sediments were made by V.M. Drozdova's et al procedure (1964). Soil was selected by composite sample procedure (not less than from 10 points). Various soil indices were determined by generally accepted in the USSR procedures.

Choice of species assortment that is tolerant to pollution for green planting was made by investigation of the state of available green planting & of man - made experimental plantations in the zone with the enterprises, which are studied.

Investigation of the opportunity to increase resistance to technogenic air pollution by means of mineral fertilizing & also by setting optimal regime for improvement cuttings in forest stands under the influence of this negative factor was made on specially created stationary plots.

Composition & reaction of precipitation are greatly changed under the influence of emissions. As it is known, we consider precipitation pH 5,5-6,0 as normal, in the zone with enterprises producing nitrogenous fertilizers (data by V.G.Mazepa & M.L.Zyat'kov) in both forest & steppe zones great alcalization was reported. Normal reaction of precipitation in forest zone was reported only at the distance of 40 km from the enterprise, if the radius is less than 10 km, snow pH is varied from 6,30 to 7,58, the radius being less than 1km snow pH is varied from 8,61 to 8,86. The reason is great amount of ammoniacions in emissions. Great amount of sulfates in precipitation was also reported (up to 19 mg/l). However they donot greatly influence on the precipitation reaction, may be because of neutralization by NH_4^+ ion.

Alkalization of precipitation was reported in the region of cement enterprise:snow pH within the radius less than 7km exceeds 7,0.However the reason of alkalization in this case is different - increase of calcium, magnesium, potassium & sodium base contents. In precipitation that fell when wind blew from cement plant potassium base content was 1,3 times greater, magnesium base content was 3,1 times greater & calcium base content was 9,2 times greater as compared to precipitation that fell when wind direction was different.

Precipitation reaction in the zone of potassic enterprise is normal. Chlorine anion content, however is 8-21 mg/l, that is 4-13 times greater than their mean content in precipitation of European territory of the USSR(Дроздова В.М. и др.)

Soil changes in the region with enterprises under study is not equal. Both qualitative & quantitative characteristics of emissions as well as characteristics of the soils themselves cause these changes.

In the region with enterprises producing nitrogenous fertilizers & with potassic enterprise, i.e. with enterprises contaminating environment by gas toxicants soil contamination is poor for the present. Soil pH in forest zone within the radius of 15 km is varied from 3,8 to 4,1, but the less is the distance from the source of contamination the greater is pH value. Contamination of soils with sulfates was not reported there was no marked difference in content of ammonia & nitrate nitrogen. Such soil indices as the biologic activity are changed at the same time,complete absence of mushrooms in these forests within the radius of 15 km from the enterprise is the evidence of this.

In the zone with cement enterprise the situation is quite different. Cement dust sedimentation on the ground surface & its following illuviation by precipitation into soil caused its great alkalization. Upper soil horizon reaction was changed from subacid (check pH is 5,47) to weakly alkaline & even alkaline (up to pH 8,42).Soil alkalization is of superficial character, up to 85 per cent of the entering amount of contamination is kept in a 50 cm soil layer. The higher is the level of dust sedimentation, the deeper is the alkalization. Alkalization of light grey soils whose mechanical composition is more light was considerably deeper as compared to clay loamy grey & dark grey soils. Maximum level of contamination of the upper soil horizon was reported at the period of small precipitation quantity & high air & soil temperature.

Forest can clean polluted air streams. 1,47 t/ha of dust is settled in the canopy of 35-year-old beech stand at a 3km distance from cement enterprise every day, in addition 0,37t are kept by foliage & total amount of sedimentation is more than 1,7 times greater as compared to open terrain. However opportunity to use woodly vegetation as a biofilter is limited when environment is contaminated by strongly toxicant ingredients.Accumulation of sulfur in needles of 15-20-year old stands in the region with enterprises producing nitrogenous fertilizers in the steppe zone is, for example, only 7-9 kg/ha.

Limited opportunity to use forest biocoenoses as biofilters is explained by negative effect of emissions. Chronic type injuries, that are the result of prolonged action of low concentrations of phytotoxicants & of their accumulation in assimilation apparatus are characteristic for the stands in the the region with the above mentioned enterprises. We found out that necrosis & premature cast of Scotch pine needles in the steppe zone of the Ukrainian SSR was noted after accumulation of 0,2-0,3 per cent of sulfur of oven-dry basis in needles.

These are chemical & aggregate compositions of phytotoxicants in the first turn that stipulate for the degree of vegetation damage.The greatest stand decline was reported in the region with enterprises producing nitrogenous fertilizers & potassic enterprises (Tables 1,2). Effect of cement dust-state index of pinetum does not exceed 2,15, state index of beech stands being 1,65 - is considerably less hazardous.

Consequences of effect of emissions from enterprises producing nitrogenous fertilizers are far worse in the forest zone than in the steppe zone. In steppe in 40-year-old pure pinetum at 4 km distance from the enterprise producing mineral fertilizers state index was II,42, dieback was about 30 per cent and 5 per cent of dead wood.Meanwhile in the forest zone these indices are much greater and are IV,40;52 & 27. Radius of pineta damage in the forest zone is almost two times greater.

Table 1

Pure pineta state in the region with enterprises producing nitrogenous fertilizers

Distance from the source of emissions, km	Age, years	Density of stocking	Bonitet	Distribution of the trees by the state categories, per cent: I	II	III	IV	V-VI	State index
Steppe zone									
0,5	35	0,3	V	-	38	36	13	3	3,04
3,0	35	0,8	IV	10	56	26	3	5	2,50
4,0	40	0,7	III	9	57	26	3	5	2,42
7,0	40	0,8	II	85	10	3	1	1	1,24
15,0	35	0,9	II	92	6	-	-	2	1,16
Forest zone									
4,0	60	0,9	I	0	12	31	4	52	4,40
5,0	55	0,7	I	0	37	39	3	21	3,10
7,0	55	0,7	I	0	53	28	1	17	3,00
9,0	50	0,6	I	0	57	28	0	15	2,90

11,0	50	0,62	I	27	54	13	2	5	2,00
15,0	60	0,8	I	61	29	6	1	2	1,45

Spacial regularity of the change in stands state allow one to distinguish zones of forest stands damage in the region of air pollution, that is of great importance for both successful planning and planting and carrying out measures of forest operations to increase forest stands resistance to emissions.

Ecological stability of forest stands, their ability to resist effect of environment pollution are considerably determined by the stands structure,i.e. by their composition and age.

It is the border's density that considerably predetermines the degree of damage of stands, situated within the forest area, by technogenic emissions. It was found out that the state of forest stands in the zone with potassic enterprise in the forest area with dense border was improving as the distance from the forest wall increased. It is 0-20m part of the border from the forest wall that is damaged by emissions most of all.

Forest stands productivity is depressed as a result of negative effect of air pollution. Minimum ptytomass amount,f for example, in 15-year-old young pineta was reported in the great hazardous zone (Table 3).It is trunk wood mass that is decreased especially perceptible,it is 2,2 times less than the check one. As the distance from the source of emissions increases, the state improves and specific weight of needles grows both total phytomass of yuong stands & its separate components increase.

A 30-year period of effect of cement enterprise emissions on forest stands caused considerable decrease of productivity in both beech-pine and hornbeam-beech stands. Thus the bonitet of a 35-year beech stand is one class lower at a 3 km distance from cement plant as compared to the check one,mean H is 27 per cent lower & dbh is 40 per cent lower. Stand phytomass was lowered from 184,8 to 90,8 t/ha & assimilation surface area is 50,7 thousand cu.m/ha i.e.1,4 times less than the check one.

Downfall of trees increment is the reason of productivity decrease. Current accretion in heighto of a 100-year old pure stand before starting cement enterprise being 35 per cent more than the control one, 12 per cent more in diameter and 21 per cent more in volume, after starting the enterprise current accretion in height, diameter and volume decreased 59,35 and 15 per cent respectively.

In forest stands growing in conditions of permanent air pollution pressure favourable conditions are created,as a result of permanent weakening and drying of trees, for colonization of trees by secondary insects and for their infection by fungous pathogens. Colonization of pineta by bark beetles, for example (Blastophagus piniperda L.,Blastophagus minor L., Ips acuminatus Gill.,Ips sexdentatus Boern.,Acanthocinus aedilis L.,were revealed) runs up to 65 per cent in the region of enterprises producing nitrogenous fertilizers in the fo-

Table 2. State of forest stands in the zone of distribution of emissions from potassic enterprise

Distance, km from the source of emissions	Repetition of winds, per cent	Composition of stand	Age, years	Density of stocking	Species	I	II	III	IV-VI	State index
3,5	11	10 0	100	0,5	0	12	20	24	44	3,60
3,0	11	10 0	100	0,8	0	39	16	12	33	3,02
2,0	6	10 0	100	0,9	0	56	22	3	19	2,19
3,0	15	10 0	100-120	0,8	0	37	37	4	22	2,47
1,5	13	3Ap302P2S	100	0,7	Ap	76	24	-	-	1,24
					0	38	3	-	7	1,40
					P	38	35	4	23	2,38
					S	48	16	1	35	2,56
2,5	11	4S302L1F	40	0,8	S	54	11	11	24	2,37
					0	68	26	2	4	1,49
					F	75	10	10	5	1,48
					L	91	9	-	-	1,09

Columns I, II, III, IV-VI: Distribution of trees by the states, per cent

Notes. O-oak;AP-Austrian pine; P-Scotch pine;S-common spruce;L-European larch; F-common silver fir

Table 3

Productivity of 15-year-old pineta the steppe zone of emissions from enterprises producing mineral fertilizers

Number of sample plots	Mean: H m	dbh cm	Degree of damage	Phytomass of the abcveground part, centner/ha: needles	branches	trunk wood	total
1	3,9	4,8	heavy	36,73	59,04	125,77	221,54
18	5,5	5,9	medium	40,89	51,76	152,41	245,24
11	6,1	5,7	small	44,43	63,51	192,75	300,69
14	7,7	6,7	check	49,14	55,62	285,39	390,15

rest zone, infestation by Armillariella mellea (Fr.ex.Vahl) Karst. runs up to 46 per cent.

18-32 per cent of trees were infested by Armillariella mellea in pure 100-year-old oak groves in the zone with potassic plant, that is 2-3 times more than the check, and up to 31 per cent of trees (with 7 per cent as the check) were infested by Scolytus intricatus Ratz. There was higher infestation of trees by Nectria ditissima Tull. in 35-year-old beech stand in the zone of maximum level of cement dust sedimentation.

Great changes also take place in a lower stories of forest biocoenosis, in a living soil mantle in particular.These changes were the result of both direct and indirect effect of pollution.Disappearance of lichens in the zone with all four enterprises and also great decline,lowering of grass layer continuum and of species satiation of herbage consisting of acidophilous and neutral species in the zone of cement dust sedimentation is a result of direct phytotoxic effect. As for indirect effect it consists in that alternation of forest species by steppe species takes place (steppization) in steppe zone as a result of change of light status in lower stories and disturbance of forest situation;alternation of forest species by meadow species,mainly by herbaceous species (sprigging,turfing) in forest zone. There was abrupt increase of representation,abundance and cover according to project by undesirable and ruderal species in both climatic zones.

The most effective method of increasing tolerance to gas of green planting is the alteration of species sensitive to pollution by tolerant ones.

On the basis of the complex of investigations we can suggest the assortment of tolerant species.In the steppe zone they are:Robinia pseudoacacia L.,Ulmus pinato-ramossa Dieck.,Ligustrum vulgare L.,Cerasus pomentosa (Thunb)Wall., Fraxinus viridis Michx.,Hippophae rhamnoides L.,Rosa canina L.,Morus alba L.,Elaegnus angustifolia L.,Caragana arborescens cens Lam.,Syringa vulgaris L.,Physocarpus opulifolia(L)Maxim.,Betula verrucosa Ehrh.,Acer negundo L.,Acer saccharinum L., in the forest zone these are:Robinia pseudoacacia L Viburnum opulus L.,Acer negundo L.,Acer pseudoplatanus L., Rhus typhyna L.,Quercus robur L.,Quercus rubra L.,Padus racemosa(Lam.)Gilib.,Lonicera tatarica L.,Amorpha fruticosa L., Ulmus carpinifolia Rupp. et Suckow.,Carpinus betulus L.,Pinus nigra Arn.,Juglans mandshurica Maxim.,Morus alba L.

Populus alba L.,Populus berolinensis Dipp.,Populus simonii Carr.,Syringa vulgaris L.,Evonymus europaea L.,Ligustrum vulgare L.,Robinia pseudoacacia L.,Caragana arborescens Lam.,Populus tremula L.,Amorpha fruticosa L.,Fraxinus excelsior L.are tolerant to cement enterprise emissions; Robinia pseudoacacia L.,Acer pseudoplatanus L.,Caragana arborescens Lam.,Salix fragilis L.,Populus nigra L.,Crataegus oxyacantha L., are tolerant to potassic enterprise emissions.

Mineral fertilizing is an important method of tolerance to gas increase of pineta in the zone with enterprises producing nitrogenous fertilizers.Contents of nitrogen,phosphorus and potassium in soil and needles increase owing to this procedure,assimilative activity is also intensified and stabilized and even stand state is improved.$N_{100}P_{60}K_{60}$ is the optimum dose of mineral fertilizing in steppe, in forest zone the optimum dise is $N_{60}P_{60}K_{60}$ plus micronutrient elements.

Conclusions

1.These are chemical and aggregate compositions and disposition of the stand as regards the source of pollution that stipulate for the degree of forest damage by industrial emissions.

2.Type of atmosphere pollution by industrial emissions being the same greater damage of woody plants takes place in the regions where the climate is more humid.

3.It is the structure of the stand,i.e. its composition and age that greatly predetermines resistance of forest stands to the action of technogenic emissions.

4.Infestation of trees by entomopests and phytopathogens is increased in forest stands damaged by emissions.

5.Direct effect of phytotoxicants and change of light status in lower stories of forest stands cause great change in a living soil mantle.

6.Increase of resistance of forest stands is possible due to correct application of improvement cuttings,sanitation cuttings and due to creation of stands of timber species.

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5.9 THREAT TO FORESTS IN POLAND, ESPECIALLY TO FORESTS IN MOUNTAINOUS REGIONS*

R. Dzialuk
State Forests Enterprise
Warsaw, POLAND

1. General characteristic of forests in Poland

The forests in Poland cover 8.641 millions of hectares i.e. about 27.6 % of the country's geographical surface. The share of forest surface per 1 inhabitant ranges to 0.23 ha. As to the property structure, the state-owned forests dominate with 7.106 millions of hectars, what amounts to 82.2 % of the total forest surface.

Forests in national parks occupy 83 thousands of hectars what constitutes 1.2 % of the total forest surface.

The private-owned forests take 1.535 millions of hectares i.e. about 17.8 per cent of the total area of forest land.

Forests in this country are considerably dispersed, and the State Forests Enterprise manages over 23 thousands of separate forest complexes. The average surface of a private forest farm exceeds 1.07 ha while the number of forest owners attains 1.431 millions.

Within the state-owned forests - 66 % grow on the conifer forest sites while 31 % are the broadleaf forest sites and wet sites constitute only 3 %. Most of the forest surface is covered by the coniferous species such as common pine and Norway spruce.

*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

2. Threat to forests in Poland

Threat to the forest environment increases rapidly in all industrialized countries including Poland as a result of harmful effect of byproducts of economical development. In this country, forests are under a permanent stress as far as their health state and sustained productivity of timber are concerned. This is the result of the unfavorable site pattern and of the adverse climatic conditions. Furthermore, a poor species composition of forests and their age structure, with younger stands predominating, also add to aggravate the situation.

Under the above described conditions, all egzogenic negative effects lead to conflict situations which are considered as important both economic and ecological threats to the forests.

Ambient air pollution is frequently regarded as the main causing factor, especially such pollutants as SO_2, NO_x, fluoride compounds, heavy metal and alkaline dusts.

The first and fundamental link in the "chain disease" that degrades our forests is the air pollution for it affects negatively the forest biological resistance and ultimately makes them vulnerable to biotic and abiotic diseases.

The air pollution level is very high in some regions in this country, e.g. in Sudety Mts. the SO_2 and fluoride concentrations exceed considerably the admissible 24-hours standard. In 1980, the maximal 24-hours concentration there was 0.23 to 0.28 mg/m^3 at the IUFRO standard being determined at the level of 0.05 mg/m^3.

The synergism of different pollutants in the air may be of equal importance when considering the phenomenon of forest decline.

According to estimates made in 1985, visible symptoms of damage occur on 700 thousands hectares and 40 thousands of hectares are considered to be badly damaged by industrial imission. Physiological injuries are already encountered on about half of the forest area in Poland. The damage due to industrial imission shows an exponential growth and has increased from 180 thousands of hectares in 1967 to more than 700 thousands of hectares in 1985. The increment losses alone were assessed to be about 3 millions of m^3 annually, what is equivalent to approximately 25 milliards of zlotys.

Industrial imission acting together with other harmful factors such as noxious insects, particularly secondary pests, pathogenic fungi, adverse atmospheric conditions and the like lead to a permanent deterioration of the state of forests, especially in the mountainous regions. Such a phenomenon we can observe in Sudety Mts. where acute damage and decline of forest in the western part of the Mountains occurred earlier and now the same can be seen in the central and eastern parts of these Mountains, on a greater scale, particularly in the massif of Śnieżnik. In this massif, in the portions close to the ridge top the decline of spruce stands has a disastrous character; dead and dying-off trees constitute 60-80 % of growing stock.

3. Counteracting the air pollution damage

The scope of activities of the foresters aiming at reduction of damage due to air pollution is rather limited as there is no possibility to effectively increase the resistance of tree species against the pollutants.

There is only a limited possibility to select more tolerant species to some levels of imission. In such circumstances the foresters try to alleviate the situation but it should be stressed that the only effective mean of counteracting the air pollution damage to forest is to reduce the amount of imission, and particularly the gaseous one at its source.

Among the measures taken by the state in order to diminish the damage are:

1. counteracting insect pests, especially secondary pest of spruce - lineate bark beetle, bark beetle which attack spruce stands weakened by the imission and adverse climatic conditions /wind-falls/. Counteracting the pest outbreaks is harmonized with the maximal utilisation of timber.

2. reforestation of extense deforested areas in the upper portions of Sudety Mts. involves stand rebuild with new species in conformity with new conditions of forest production and requires additional agro- and phytomelioration techniques. The latter are extremely labour and money consuming under mountainous circumstances. About 4.5 thousands of hectares have already been restored in Sudety Mts.

3. the early rebuild of spruce stands into broadleaf-mixed stands, to the advantage of such hardwood species as beech, mountain maple, birch, rowan tree and like. It should be added, however, that the rebuild stands will not produce as much timber as the previous spruce stands and their capability to protect soil and fulfil social function will be much lesser.

4. in order to gain information concerning the spatial distribution and dynamics of air pollution including SO_2, NO_x, fluorides and dust, a network of measurement system has been organized on 1800 of points over the whole forest area. At present a system of biomonitoring is to be organized in forests.

In addition, the forest areas severely endangered by the imission as well as those where the threat is likely to appear are subject to study in the complex research programmes. The studies aim to elucidate the mechanism of forest decline and to provide practical suggestions as to how such forest areas should be managed in future. But the efficiency of such activities is largely dependent upon the reduction of industrial imission for otherwise they will remain merely the time and money consuming half measures.

5.10 CONSERVATION OF FORESTS UNDER CONDITIONS OF GROWING THREATS TO THE ENVIRONMENT*

K. Rykowski
Forest Research Institute
Warsaw, POLAND

I. Introduction

Main features of the natural environment in Poland combining to explain the conditions of forest growth are defined by central location of the country in Europe as well as by its situation between the Baltic Sea and Tatra Mts, and involve:

- confrontation of two climates: the oceanic one from the West and the continental one from the East, with western winds predominating;
- natural range limits of such forest tree species as fir, spruce, beech and white oak;
- variety of forest community types contained between the upper timberline in Tatra Mts. and Sudety Mts. and the coastal dunes.

The variety of habitats and stand types is fairly vast: from the man-made, one-species, ecologically poor conifer stands in the western part of the country; such a stands being characteristic of the forests in Poland, to the most natural in the European scale, rich and multispecies forest associations in Białowieża Forest in the eastern part. The latter forest constitutes actually the natural relic.

Most of the forest tree species are affected by the extremal values of climatic factors, such as storms, excess snow fall, day-night and seasonal temperature amplitudes which constitute the permanent damage-causing agents. The above mentioned natural range limits mean for many forest tree species an early physiological senescence and more pronounced responses to the stress factors.

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

Even more than by the natural environmental factors, the character of the forest has been shaped by man's activity. Species composition of forests in Poland is already considerably altered: conifer stands occupy about 80 % of the wooded area, 70% whereof take the pine stands. This results from the historical management procedures of land: on the one hand forests were pushed away to the poorest grounds while, on the other, conifer species were propagated for economic reasons, i.e. spruce in the mountains and pine in lowlands. In this way there were shaped the features of forests on extense areas. These features include:

- geographic-climatic alienation /resulting from reduction of species diversity/;
- ecological alienation /resulting, on one hand, from afforestation of the postfarming and waste lands on about 1.5 million ha, on the other - from a simplified biocenotic structures/;
- provenance alienation /owing to "raw material"-type forestry widespread at the turning point of XIX and XX centuries/.

The above "alienation complex" is observed in a considerable portion of the managed forests in Europe.

At this stage of evolution of the forest, there emerged a new factor having the power unknown so far - industrial air pollution. From that time on man does not shape the character of forests any more, he set in motion the process of their decline.

II. Forests in mountainous regions

An illustration to the "Forest Decline" in this country are spruce stands in Sudety Mts, that is, actually, lack of these stands on the area of about 35.000 ha already. They have been removed by sanitation fellings during the last 5 years. One can easily find here a corroboration to a number of concepts of the dieback mechanisms, known from the literature, such as "from the top", from the roots", concept of "starvation death", incessant transpiration and the like.

A closer diagnosis points out to the action of various pollutants /SO_2, NO_x, F and ozone/ and to their synergistic activity among themselves and with adverse climatic and habitat conditions.

Under extreme mountainous conditions, at the upper timberline as well as in the poor habitats, the injuries to the forest occur already at low average concentrations of 15 - 20 µg SO_2 annually. The toxicity treshold for trees lies higher under more favourable growth conditions. The direction of injury occurrence has been characteristic of the area: at first in western part of Sudety Mts, then in their central part and now also in eastern part, i.e. along the direction of prevailing winds. Massive felling of dead trees results in lowering of the upper timberline and in the deforestation of landscape along with all consequences defined as ecological disaster.

A dramatic evidence is found here of the vitality of social- and soil-conservation functions of forests and particularly of their water-conservation properties.It is the forest in mountainous regions, endangered by erosion, on the watersheds and at the sources of rivers, that constitutes an irreplacable element for the water management. Forest play a decisive role in regulation of the amount and quality of surface waters, their outflows as well as in the formation of water resources. For Poland with its most deficient hydrological balance, among the European countries, this role is of the existential importance.

If the rate and direction of damage to the forest in southern Poland are to remain unchanged, the consequences in the regional scale will acquire the national character and, ultimately, will affect the country's economy.

III. Does stand or forest decline ?

There are as many hypotheses explaining the phenomenon of forest decline as numerous are specialists involved in the job.

The changes have been documented in the fundamental metabolic processes such photosynthesis, respiration, transpiration, physiological transport, injuries to cells and their organelles, and genetical consequences. The evidence is mounting of the chemical damage to soils and roots, of the damage to the most valuable and- at the same time - the most sensitive element of the pedosphere - to the microbiological factor, Changes recorded at the above level call special attention: in the moderately contaminated zone the reduction of live mycorrhizas attains about 30% while in the heavily contaminated zone - about 70%. Vitality of the mycorrhizas diminishes remarkably /the activity period amounts about 3 months/ their morphological-anatomical character undergoes a change - from classical ectotrophic to ectendotrophic.

Contamination of soils and a decrease in their biological activity lead to the elimination of woody species from the contaminated areas for a time longer that that of duration of the imission. The dieback of trees, even a massive one, is not what is called the forest dieback. The forest dies when its habitat dies and trees lose their reproductive capabilities. There is enough evidence to belive that in the zone with maximal contamination the habitat dies back and the chances of reestablishing the forest are reduced to minimum.

This creates a paradoxical problem for forestry - the problem of forests without stands. Moreover, this means the problem of reclamation of the forest grounds. In the same way as waste heaps are being reclaimed. Such a phenomenon occurrs in the extreme situation, e.g. around some industrial plants where industrial deserts have been formed. Similar problem arises in the deforested portion of Western Sudety Mts.

IV. Forests in lowlands

The image of Sudety Mts. gives a specific perspective in which one has to estimate the phenomena occurring in the forest in the country-wide scale.

In Poland forests occupy 8 645 000 ha what constitutes 27.6% of the geographical surface. 0,23 ha of forests falls on 1 inhabitant and the forestation rate varies considerably between regions from 11.8 to 47.1%. In the property structure the state forests predominate with 82.2%.

The age structure deviates from the normal one as average stand age is 51 years with prevailing 60-year-old stands and with a deficit of mature stands.

Timber resources amount to 1 348.6 millions of m^3 in the gross roundwood, while the average stand volume is 173 m^3 per ha. This is about 78% of the potential average stand volume.

Until 1980, timber resources showed a steady growing trend. In recent years, however, this growth is remarkably lower, and there is a tendency to record a stabilization or even reduction of resources in the regions affected by the industrial imission.

In the years 1950 - 1980, the effective timber harvest was usually higher than the allowable annual cut. This exceeding, resulting from the state demand for raw material, amounted jointly to 115 millions of m^3. The stand age structure has deteriorated thus deepening the deficit of older stands.

Forest areas free from the imission influence do not practically exist in Poland. Half of the forested surface is within the zone of physiological injuries. Visible morphological symptoms are recorded on the surface of about 700 000 ha. The forest area thus affected is still growing and this growth has an exponential nature.

The same character shows the growth of pollution emitted to the atmosphere from the home- and abroad sources, whereat "export" and "import" of the polluting substances is pretty well balanced. Estimates show that about 58% of the imission above the territory of Poland originate from the sources located abroad.

A lot of phenomena that were somewhat obliterated in the course of accelerated dieback of the mountainous spruce stands, are to be observed, at the slower pace, in many regions in this country. They occur less dynamically, constitute a prolonged intermediate phases, and their effect is not as immediate. Moreover, ill sanitary and health state of the forests is frequently attributed solely to the factors that constitute the ultimate link in the chain disease and are conspicuous.

The dimensions and frequency of the damage brought about by a massive outbreaks of primary pest insects as well as a proliferation of secondary pests and pathogenic fungi suggest that we face now a new, higher level of the forest disease vulnerability.

Tree root diseases due to pathogenic fungi such as Armillaria mellea and Fomes annosus constitute a permanent threat to the forest in Poland. The infested surface covers about 1.5 mln ha involving, in particular, pine and spruce stands growing on the abandoned farmland. Productivity losses coused by Fomes annosus observed on about 250 000 ha represent between 11 and 40% of mass increment. A part of these stands, at the age of 35 - 40 years are being prematurily removed what leads to the further productivity losses.

In the course of the last 5 years /1981 - 1986/, a steady increase is noted in the amount of soil borne diseases, especially in the regions within of industrial imission. The harmful effect of Armillaria mellea, known from Beskid Żywiecki Mts., recently finds new corroboration in spruce stands of the Western and Eastern Sudety Mts. The pathogen is accompanied by two other species of equal importance: Fomes annosu and Phomitopsis pinicola - a stem pathogen. Occurrence of these fungi has been multiplied as a result of storm and snow damages to stands.

The slowdown of pace of the metabolic processes and their biochemical impairment, which are difficult to discover before manifestation of the morphological symptoms, make the stands vulnerable to the other damaging factors . Physiological stress resulting from drought or defoliation by insects becomes more pronounced or even irreversible under such a conditions.

An increase is noted in the occurrence of fungi attacking shoots and foliage /causing the needle cast of pine needles/ in the stands of higher age classes. The scope of mycoflora composition has been characteristically widened on the prematurily falling pine needles to include: Lophodermium pinastri, L. seditiosum, Lophodermella sulcigena, Cyclaneusma minus, Sclerophoma pityophila, Alternaria alternata, Aureobasidium pullulans, Botritis cinerea, Cladosporium herbarum. The above species gain more and more importance both phytopathologically and ecologically in view of destabilization of the forest ecosystems.

In the Upper Silesia Industrial Region the following species cause stem necrosis in larch: Pezicula livida, Leucostoma kunzei, Phacidiopycnis pseudotsugae and Phomopsis occulta.

There is also an increase in number of the wood decomposing species such as Coriolellus sinuosus, Fibroporia vaillantii, Gloeophyllum sepiarium, G. trabeum, G. abietinum.

In the years 1982 - 1984, a severe damage to pine shoots by Gremmeniella abietina and Cenangium ferruginosum was observed. As a result of the above epiphytosis on the area of 200 000 ha, about 10 000 ha of 20 - 30 year-old pine stands were cut during the sanitation fellings.

In the years 1983 - 1984, a rapid decline of health status of the deciduous trees was observed and the dieback of oak, beech and birch stands has become a new problem for the forest management. Estimates show that about 290 000 m^3 of oak wood has died and about 473 000 m^3 is dying. The whole size of damage amounts to about 25% of mass of the oak stands. From the dead trees Armillaria mellea was most frequently isolated while from the dead shoots - Ceratocystis sp.

Damage to beech stands amounted to about 13% of mass of these stands. The decline of beech has been caused by set of harmful factors, known as the slime outflow that is accompanied by an insect Cryptococcus fagisuga and a fungus - Nectria coccinea.

The physiological weakness of trees releases the noxious potential of insects and fungi. The activation of pests and diseases is recorded which, until recently, were known to have only secondary- or tertiary importance or even organisms that were regarded as saprophytes. There accur qualitative and quantitative changes in the populations of mikroorganisms dwelling on the assimilatory organs and on shoots, and the activity is growing of the widely known root pathogens. The process of self thinning is accelerated and the disease etiology becomes more unclear.

The Polish forestry encounters the phenomena mentioned above throughout the whole country more and more frequently.

Synergistic effect of airborne biotoxic compounds, climatic factors and of noxious biotic potential innate to forests seems to present the basic source of destruction of the forest ecosystem. The proportions of individual, mutually co-operating factors, variy depending upon local situations and the changes have different dynamics.

V. Consequences

The dieback of stands involves primarily the consequences in raw material. At first there occurs an excess of raw material associated with its depreciation. In the years 1980 - 1986, about 120 millions of m^3 of timber were harvested as a result of compulsory sanitation fellings and removal of dead trees. This was due to the joint action of imission, climatic and biotic damage to the forest and involved certain changes in the assortment structure and in the proportions of the felling categories. Further on, there will follow a decrease in stand productivity, reduction of volume and, after a period of a relative meeting of needs, a profound deficit of timber.

The annual increment losses due to atmospheric pollution were estimated as 3 millions of m^3 of timber what constitutes about 15% of the allowable annual cut. The quantity of timber decreases including the large size wood, while there is an increase in logging of medium- and small sized wood of lower quality. This leads to the changes in wood utilization and processing.

During the years 1983 - 1985, a reduction of the average degree of crop density was observed, from 0.83 to 0.81, while the forest surface with average degree of crop density below 0.6 attained 25% of the forest area as a whole.

Until recently, changes in forest and in the forestry were never as profound and rapid as they are now. Recently, the basic documents regulating management procedures in the forest, such as: Forest Inventory Guidelines, Principles of Sylviculture and Forest Protection Instructions - elaboreted under normal conditions and intended for the normal course of production and management processes, lost a lot of their usefulness. A necessity arises of assessing the forest state at short time intervals, even every year. There is also a necessity of changes in the work style in the forestry since it has chiefly been occupied with the settlement of the forest state in this country for the last 5 years. Hence, the importance of new differentiated procedures is growing along with the demand for a new scientific categories, while the scope of necessary information becomes broader.

VI. Monitoring system

The forestry in Poland has developed a system of its own for the purpose of surveillance, estimation and prognosing the developments in the environment and in the forest ecosystem. This undertaking aimed at the assessment of the main pollutants spatial distribution, their dynamics in the forest as well as at the comprehension of the forest ecosystem response to pollutant concentrations of different quality and quantity.

The network of the forest environment monitoring in Poland embraces the following:

- technical service determining the dose of pollution reaching the forest /technical surveillance/;
- permanent research work on the selected permanent study plots;
- network of permanent observation plots distributed according to geodetic grid over the area of the whole country, serving for the purpose of periodical control of the state of forest.

Within the framework of technical monitoring a network of 1800 measurement points was organized to provide data concerning the spatial distribution and temporal variability of main pollutants /SO_2, NO_x and F/, determined by the contact method and of dust fall determined by the sedimentation method.

The permanent research work has been conducted in the forests located in three different contamination zones and involves mainly pine stands on the conifer forest habitats, i.e. the forest areas of greatest natural and economical importance in Poland.

The research programme for all the zones in question embraces the studies on:

- changes in species composition and forest community structure;
- dynamics of stand volume increment, changes in growing stock and its structure;
- biogenesis and anatomical analysis of wood;
- morphological changes in tree species;
- changes in species composition, number and structure of insect populations;
- intoxication of foliage;
- accumulation of main pollutants in plant bioindicators including vascular plants and bryophytes;
- soil environment with respect to its chemistry and to mycology;
- amount and quality of wet deposit in forest ecosystems.

Each of the above problems, of necessity only briefly identified here, employes a substantial research potential from many research centres and involves extended, specific methods. A lot of them constitute a continuation or extension of already existing studies.

The periodical surveys of the forest health and sanitary state have been performed by the specialized personnel in the field, these surveys being an integral part of monitoring system of the forest environment in Poland.

VII. Conservation of forests

Recording of injuries, observing the development of phenomena, defining the threats, prognosing - all this is attributable to the attitude of contest. Such an attitude is not always useful in practice, especially, as the conservation of forests calls for immediate action.

The sole and ultimate solution to the problem would be the practical and not declared reduction of emission in Europe. This statement, repeatedly cited, does not require any justification.

But the forestry cannot contend oneself with postulating the actions that are entirely independent of it. In a situation where there is a lack numerous data or consistent prognoses, the classical management methods acquire, quite unexpectedly, a great value in the endeavour after forest conservation. Evidently, only there where the forest is still growing and capable to respond positively. Neglecting or abandonning these methods might be erroneous even when prognoses are catastrophic.

1. The calassical principle is that a cultivated species should be in conformity with its habitat. This enables creating a situation of " dispersed risk" of stand growth - species enrichment at smallsize-surface mixing, taking advantage of habitat mosaic and of locally differentiated moisture conditions - at securing the optimal growth.

2. The principle of "dispersed risk" is also realized by the introduction of understory, what leads to biocenotic enrichment of poor stands and protects the soil.

3. Preferring the so called resistant species and abandonning the low-tolerance species would be a simplification. Resistant species do not exist at all and the selection made at present might have not significance considering the uninhibited growth of the environmental contamination.

4. It seems that one of the most important activities is to secure the genetical riches of forest trees, with all their possible diversity and ecotype variability as they constitute an invaluable material for the forestry, regardless the situation.

5. Natural regeneration should be reinstated where it is possible, particularly in the rarefied stands, even, if it seems that keeping them standing is economically unjustified but ecologically indispensable.

6. Forest thinning becomes increasingly important, particularly in the younger stands which are most sensitive to such a treatment. The classical selection-cut pattern with criteria shifted towards the vitality of trees can, to a certain degree,

inhibit the advancing degradation of forests.

7. The magnitude of timber harvest should be conditioned solely by the sylvicultural requirements.

As a matter of fact, the question is of application of the classical principles for the stand formation, in order to obtain a diversified species-, age- and height structures.

This results from a fundamental thesis, formulated long time ago, the present interest whereof is corroborated by the current state of forests, that every simplification of the management or cultivational procedures leads to a simplified structure of the forest and to the impairment of its biological resistance. Generally, the imprecise term: "biological resistance" is conceived as the capacity of resisting the action of "egzogenic factors" This is the question of the innate features of a forest ecosystem, the self defance ability that should be restored, reinforced or generated. Practically, this is the only instrument at the disposal of the foresters. It should be remembered, however, that this "biological resistance" of stands, like every "resistance", is limited. Its limits are conditioned by actions of the above "egzogenic factors".

The increase in the concentration of biotoxic compounds released to the atmosphere acquired the exponential character. If this character does not change the action of toxic compounds will trespass the tolerance tresholds and adaptation capabilities of any arganism. Even the best management practice principles may serve solely to sustain the forest existence but they will not reverse the course of events.

VIII. Final statements

In the course of rapid development of studies on the causes of forest decline, the forest itself has been divided into leaves, needles, shoots, roots, soil, insects, fungi, small and large animals and their parts. From all of the above "compartments", it is possible to derive a less or more consistent generalization and hypotheses, or even - though it is rather risky - to recommend the remedies. However, the knowledge of a simple cause-and-effect relationships at the level of the parts is not sufficient to explain the phenomena at the level of the whole.

Imission and other biotoxic products of civilization became a paranatural factors of the environment. They are present in their specific form, like other factors, in all biological structures that developed in a given environment. They penetrate into the structural elements of the ecosystem, changing their functions and ecological importance. Moreover, they also change the range of reaction of cells, tissues, organisms and whole populations. At all trophic levels there proceeds the elimination of some elements to the advantage of others. The cycling of matter and energy flow become modified. Thus the influences reach the very essence of the ecosystem functions.

The forest ecosystem becomes a new specific quality, different than a simple sum of sick organisms and impaired populations. Similarly, the sick plant constitutes a new quality, differing from those before infection.

The pathology of trees knows the methods of prophylaxis, therypy and counteracting the diseases. The pathology of ecosystem or just e c o p a t h o l o g y does not know such methods for it does not exist as a science so far. It seems it is in the making at present. However, there is a risk that it may remain a descriptive science only.

23.III. 1987

5.11 RESULTS OF THE SURVEY OF THE HEALTH CONDITIONS OF THE FRENCH FORESTS IN 1986*

P. Bazire
Forestry Department
Ministry of Agriculture
Paris, FRANCE

The network of observations plots for surveying the health of forest trees in 1986 covers about 2 500 000 hectares of forests, mainly in mountains and hills regions. There is one observation plot every 1 600 Km2. These plots are situated each kilometer along transects East-West ; the transects are separated by 16 kilometers in the direction North-South.

The 1986 survey includes 1416 observation plots, 959 (67,7%) in the forests managed by National Forest Office, and 457 (32,3%) in the forests managed by private owners.

In each observation plot, 24 trees are observed by two forest technicians. The trees observed are classified by reference to the level of damage affecting their foliage : percentage of needles/leaves loss and degree of yellowing of needles/leaves. The five damage classes are shown in the table below :

FRENCH classes	CEE classes	Needle/leaf loss %	Tree health
1	0	0 to 9	Healthy
2	1	10 to 24	Slight damage
3	2	25 to 59	Medium to serious damage
4	3	60 to 99	Dying
5	4	100	Dead

*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

All the tree species has been observed, but the results published concern only oak, beech, other broad-leaved trees, norway spruce, larch, silver fir, scots pine, and other coniferous trees. On the whole, about 17 900 broad-leaved trees and 18 000 coniferous trees ware observed in 1986.

TABLE I - Results by tree species and by administrative region

Table I furnishes the percentages of trees having lost ot least 25 % of their needles/leaves, and the percentage of trees having yellowed needles/leaves.

TABLE I bis - Comparison between results of 1986 with those of 1985

Compares the results of 1986 and those of 1985, for each administrative region.

We can see approximately an aggravation of the health of broad-leaved trees particularly oaks, and an improvement of the health of coniferous trees. Nevertheless, broad-leaved trees are healthier on the whole than coniferous trees.

TABLE II - Comparison between results of 1986 in dominant and co-dominant trees and supressed trees

Compares for each tree species, the levels of damage in dominant and co-dominant trees and those in supressed trees. On the whole, the dominant trees are healthier than the supressed ones for the percentage of needles/leaves loss, but their yellowing is more important.

The difference is more marked with the classes number 3 and 4 CEE (percentage of trees having lost at least 60 % of their needles/leaves), except the beech.

	Dominant and co-dominant trees	Supressed trees
Oak	0,34 %	4,9 %
Beech	3,3 %	1,4 %
All broad-leaved trees	0,6 %	2,4 %
Norway spruce	0,8 %	3,2 %
Silver fir	2,3 %	2,9 %
Scots Pine	2,4 %	6,4 %
All coniferous trees	1,7 %	3,5 %
All Species trees	1,1 %	2,8 %

TABLE III - Results by forest region and by geographic country

There are 309 forest regions in France and 75 are concerned here. Nevertheless, the west forest regions are very little damaged, only the North-East and East forest regions are really damaged. In order to simplify the results, they are grouped by geographic country which regroup some forest regions.

The tree species are regrouped in broad-leaved trees and coniferous trees. For each group, the damage classes are furnished : number of trees and percentage. The number of trees (and percentage) having yellowed needles/leaves are also given.

Some forest regions are hardly damaged. For example, in the Vosges mountain, the forest region "Basses Vosges gréseuses" : 53 % of Silver fir have lost at least 25 % of their needles ; in the Jura mountain, the percentage of the Silver fir of classes 2 to 4 CEE is 27,8 % in the "Haut-Jura" forest region. In the North-Alpes mountain, this percentage is 41,5 % in the "Chartreuse" forest region, and in the "Chablais" forest region, 42,9 % of Silver fir have yellowed needles. In the Pyrenées mountain, 60 % of the Silver fir of the "Haute-Chaîne" forest region have yellowed needles, but only 13,7 % have lost at least 25 % of needles.

TABLE I -

Each table furnishes by administrative region, for each tree species :

- the number of trees
- the percentage of trees having lost at least 25 % of their foliage { classes 2 to 4 CEE = french classes 3 to 5)
- the percentage of trees having yellowed needles/leaves = c.f. = color of foliage
- • : no significant

Chêne	= Oak
Hêtre	= Beech
Autres feuillus	= Other broad-leaved trees
Total	= All broad-leaved trees
Epicea	= Norway spruce
Mélèze	= Larch
Pin sylvestre	= Scots pine
Sapin	= Silver fir
Autres conifères	= Other conifers
Total	= All coniferous trees
Total toutes essences	= Total All tree species

TABLE I bis -

Comparison between results of 1986 with those of 1985

TABLE II -

Comparison between results of 1986 in dominant and co-dominant trees and supressed trees

TABLE III -

Results of 1986 by geographic region (group of forest regions)

All broad-leaved trees
All coniferous trees
All tree species

TABLEAU I

Cf = couleur anormale du feuillage

Chaque tableau établi par région administrative donne par essence :
- le nombre d'arbres
- le pourcentage des arbres ayant perdu au moins 25 % de leur feuillage = classes 3 à 5
- le pourcentage des arbres dont le feuillage a une couleur anormale (jaunissement) = Cf
- * non significatif

Régions / Essences	NORD-PAS-de-CALAIS Nb	% 3à5	Cf	ILE DE FRANCE Nb	% 3à5	Cf	HAUTE-NORMANDIE Nb	% 3à5	Cf	MIDI-PYRENEES Nb	% 3à5	Cf	CHAMPAGNE-ARDENNE Nb	% 3à5	Cf	LORRAINE Nb	% 3à5	Cf	ALSACE Nb	% 3à5	Cf	FRANCHE-COMTE Nb	% 3à5	Cf
Chêne	144	4	1	209	5	3	124	1	7	160	3	1	602	4	11	204	1	0	641	4	10	465	17	12
Hêtre	19	0*	0*	88	0	1	582	1	15	854	4	9	158	3	12	591	7	4	821	3	11	1023	2	10
Autres feuillus	211	3	2	357	7	10	223	0	5	134	6	22	1001	2	2	268	6	0	937	10	9	1294	4	2
Tous Feuillus	374	3	2	654	6	7	929	1	12	1148	4	9	1761	2	6	1063	5	3	2399	7	10	2782	6	7
Epicéa	13	16	38	-			1	0*	0*	21	0	0	164	1	2	954	13	9	662	8	12	938	11	8
Mélèze	-			-			14	0*	0*	24	0	4	-	-	-	-	-	-	22	0	5	1	0*	0*
Pin sylvestre	51	2	37	46	9	70	71	3	1	-	-	-	16	19	69	220	12	5	463	19	19	36	25	11
Sapin	-	-	-	-	-	-	42	2	2	569	8	50	-	-	-	1310	21	21	835	27	23	841	17	14
Autres conifères	18	0*	0*	20	0	5	47	6	2	110	5	15	3	0*	0*	29	14	10	83	3	5	82	5	10
Tous conifères	82	3	29	66	7	50	175	3	2	724	5	42	183	2	8	2513	17	15	2065	18	17	1898	13	11
TOUTES ESSENCES	456	3	7	720	6	11	1104	1	10	1872	5	22	1944	2	6	3576	13	11	4464	13	13	4680	9	8

Régions / Essences	BOURGOGNE Nb	% 3à5	Cf	AUVERGNE Nb	% 3à5	Cf	RHONE-ALPES Nb	% 3à5	Cf	LANGUEDOC-ROUSSILLON Nb	% 3à5	Cf	PROVENCE-ALPES-COTE D'AZUR Nb	% 3à5	Cf	TOTAL Nb	TOTAL 3 à 5 Nb	TOTAL 3 à 5 %	TOTAL Cf Nb	TOTAL Cf %
Chêne	235	3	1	364	7	12	368	6	4	21	24	0	0	-	-	3537	218	6,2	268	7,6
Hêtre	139	1	1	399	5	11	1284	2	6	149	0	2	237	5	5	6344	202	3,2	549	8,7
Autres feuillus	557	4	2	463	8	7	1362	4	4	32	6	0	270	21	0	7109	394	5,5	344	4,8
Tous Feuillus	931	3	2	1226	7	10	3014	1	5	202	3	1	507	13	8	16990	814	4,8	1161	6,8
Epicéa	24	0	0	427	6	9	1977	10	9	31	26	29	45	7	0	5257	522	9,9	473	9,0
Mélèze	-	-	-	-	-	-	21	0	0	17	0*	0*	175	6	5	274	11	4,0	10	3,6
Pin sylvestre	9	22*	22*	279	5	32	621	6	11	19	0	5*	311	34	4	2142	300	14,0	337	15,7
Sapin	-	-	-	783	4	17	1429	13	18	40	3	0	125	20	16	5974	917	15,3	1269	21,2
Autres conifères	116	2	39	187	3	8	426	2	3	51	0	12	205	31	16	1377	100	7,3	145	10,5
Tous conifères	149	3	32	[illegible]76	5	16	4474	9	12	158	6	10	861	25	8	15024	1850	12,3	2234	14,9
TOUTES ESSENCES	1080	3	6	2902	5	13	7488	7	9	360	4	5	1368	20	8	32014	2664	8,3	3395	10,6

TABLEAU 1 bis - COMPARAISON 1986-1985

POURCENTAGE D'ARBRES AYANT PERDU PLUS DE 25% de LEUR FEUILLAGE

Régions / Essences	NORD-PAS-de-CALAIS 1986	NORD-PAS-de-CALAIS 1985	ILE DE FRANCE 1986	ILE DE FRANCE 1985	HAUTE-NORMANDIE 1986	HAUTE-NORMANDIE 1985	MIDI-PYRENEES 1986	MIDI-PYRENEES 1985	CHAMPAGNE-ARDENNE 1986	CHAMPAGNE-ARDENNE 1985	LORRAINE 1986	LORRAINE 1985
Chêne	4	4,2	5	4,8	1	1,3	3	0,6	4	1,6	3	1,0
Hêtre	0	0	0	0	1	0,9	4	2,7	3	0	7	3,7
Autres feuillus	3	0,5	7	5,0	0	0,9	6	5,2	2	2,2	6	6,3
Total Feuillus	3	1,9	6	4,3	1	0,9	4	2,7	2	1,7	5	3,8
Epicéa	16	15,4	-	-	-	-	0	0	1	0	13	12,1
Mélèze	-	-	-	-	-	-	0	0	-	-	-	-
Pin sylvestre	2	0	9	4,3	3	4,5	-	-	19	16,7	12	32,0
Sapin	-	-	-	-	2	0	8	2,3	-	-	21	20,0
Autres conifères	0	0	0	0	6	10,0	5	0,9	0	0	14	0
Total Conifères	3	2,4	7	3,0	3	4,0	5	1,9	2	1,3	17	16,2
TOTAL TOUTES ESSENCES	3	2,0	6	4,2	1	1,4	5	2,4	2	1,6	13	12,5

Régions / Essences	ALSACE 1986	ALSACE 1985	FRANCHE-COMTE 1986	FRANCHE-COMTE 1985	BOURGOGNE 1986	BOURGOGNE 1985	RHONE-ALPES 1986	RHONE-ALPES 1985	TOTAL FRANCE 1986	TOTAL FRANCE 1985
Chêne	4	3,2	17	14,8	3	1,7	6	6,6	6,2	5,0
Hêtre	3	1,6	2	7,9	1	0	2	1,0	3,2	3,0
Autres feuillus	10	7,5	4	2,0	4	1,8	4	1,9	5,5	3,9
Total Feuillus	7	4,3	6	7,4	3	1,5	3	2,1	4,8	3,75
Epicéa	8	8,5	18	16,5	0	0	10	7,1	9,9	10,0
Mélèze	0	0	0	-	-	-	0	0	4,0	1,4
Pin sylvestre	19	29,0	25	13,9	22	22,2	6	10,0	14,0	17,7
Sapin	27	30,2	17	22,1	-	-	13	15,1	15,3	18,6
Autres conifères	3	6,2	5	0	2	9,5	2	3,6	7,3	4,4
Total Conifères	18	21,7	13	18,3	3	8,7	9	9,9	12,3	14,1
TOTAL TOUTES ESSENCES	13	12,4	9	11,8	3	2,5	7	6,5	8,3	8,4

TABLEAU II

Classes de dégâts	ARBRES DOMINANTS ET CODOMINANTS Nb d'arbres	1 (0	2 1	3 2	4 3	5 4)CEE	Cf	ARBRES DOMINES ET SURCIMES Nb d'arbres	1 (0	2 1	3 2	4 3	5 4)CEE	Cf
CHENE	2891	2158	577	133	7	3	235	645	464	98	43	17	15	33
%		74,6	20,0	4,6	0,24	0,10	8,1		71,9	15,2	6,7	2,6	2,3	5,1
HETRE	4102	3326	627	117	9	4	412	2242	1916	230	40	19	13	137
%		81,1	15,3	2,9	3,2	0,1	10,0		85,5	10,3	1,8	0,8	0,6	6,1
TOUS FEUILLUS	11323	8949	1837	423	45	18	873	5667	4630	624	190	76	62	288
%		79,0	16,2	3,7	0,4	0,2	7,7		81,7	11,0	3,4	1,3	1,1	5,1
EPICEA	4092	2787	950	304	22	14	388	1165	650	326	143	20	17	80
%		68,1	23,2	7,4	0,5	0,3	9,5		55,8	28,0	12,3	1,7	1,5	6,9
SAPIN	4046	2196	1158	563	83	8	978	1928	1147	494	206	43	14	291
%		54,3	28,6	13,9	2,1	0,2	24,2		59,5	25,6	10,7	2,2	0,7	15,1
PIN SYLVESTRE	1788	966	550	208	33	10	302	354	250	53	26	15	8	35
%		54,0	30,8	11,6	1,8	0,6	16,4		70,6	15,0	7,3	4,2	2,2	9,9
TOUS CONIFERES	11333	7035	2869	1140	155	33	1640	3691	2214	912	391	87	41	409
%		62,1	25,3	10,1	1,4	0,3	14,5		60,0	24,7	10,6	2,4	1,1	11,1
TOUTES ESSENCES	22656	15984	4706	1555	200	51	2682	9358	6884	1536	581	163	104	713
%		70,5	20,8	6,9	0,9	0,2	11,8		73,6	16,4	6,2	1,7	1,1	7,6

TABLEAU III

T A B L E A U X   P A R   M A S S I F S

Région NORD - *Bas-pays de Flandre, Ardenne, Argonne*

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	1346	1185	88,0	113	8,4	48	3,6	73	5,4	4 arbres secs 0,3%
Tous conifères	262	247	94,3	9	3,4	6	2,3	38	14,5	0 arbre sec
Toutes essences	1608	1432	89,1	122	7,6	54	3,3	111	69,0	4 arbres secs 0,25%

Région PLAINE D'ALSACE - *Hardt, Plaine de Haguenau, Plaine de l'Ill, Sundgau, Pays de Belfort*

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	1319	987	74,8	226	17,1	106	8,0	134	10,2	11 arbres secs
Tous conifères	287	174	60,6	79	27,5	34	11,9	42	14,6	2 arbres secs
Toutes essences	1606	1161	72,3	305	19,0	140	8,7	176	11	13 arbres secs

Région MASSIF VOSGIEN - *Collines sous-vosgiennes (Ouest, Est, Sud)*
Vosges gréseuses (Basses et Hautes)
Vosges cristallines

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	2675	2073	77,5	451	16,9	151	5,6	268	10,0	17 arbres secs 0,6%
Tous conifères	4364	2157	48,6	1475	33,3	802	18,1	720	16,2	33 arbres secs 0 7%
Toutes essences	6905	4086	59,2	1880	27,2	939	13,6	975	14,1	50 arbres secs 0,7%

Région PLATEAU LORRAIN + PLATEAU DE LANGRES et BASSIGNY

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	1019	868	85,2	138	13,5	13	1,3	51	5,0	1 arbre sec
Tous conifères	73	33	45,2	26	35,6	14	19,2	3	4,1	0 arbre sec
Toutes essences	1092	901	82,5	164	15,0	27	2,5	54	4,9	1 arbre sec

Région MASSIF JURASSIEN - *Petites montagnes, 1er Plateau, Pentes intermédiaires, 2ème Plateau, Haut-Jura, Bugey central et méridional*

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	2640	1956	74,1	555	21,0	129	4,9	80	3,0	8 arbres secs 0,3%
Tous conifères	2006	990	49,3	764	38,1	252	12,6	201	10,1	7 arbres secs 0,3%
Toutes essences	4646	2946	63,4	1319	28,4	381	8,2	281	6,1	15 arbres secs 0,3%

Région MASSIF ALPIN - Alpes du Nord

Essences	Nombre d'arbres total	Catégorie 1 Nb	Catégorie 1 %	Catégorie 2 Nb	Catégorie 2 %	Catégorie 3 à 5 Nb	Catégorie 3 à 5 %	Coloration du feuillage anormale Nb	Coloration du feuillage anormale %	
Tous feuillus	1743	1502	86,2	189	10,8	52	3,8	117	6,7	4 arbres secs 0,2%
Tous conifères	2443	1561	63,9	561	23,0	321	13,1	365	15,0	7 arbres secs 0,29%
Toutes essences	4186	3063	73,2	750	17,9	373	8,9	482	11,5	11 arbres secs 0,26%

Région MASSIF CENTRAL - Morvan + Auvergne

Essences	Nombre d'arbres total	Catégorie 1 Nb	Catégorie 1 %	Catégorie 2 Nb	Catégorie 2 %	Catégorie 3 à 5 Nb	Catégorie 3 à 5 %	Coloration du feuillage anormale Nb	Coloration du feuillage anormale %	
Tous feuillus	2662	2293	86,1	231	8,7	138	5,2	133	5,0	21 arbres secs 0,8%
Tous conifères	2826	2371	83,9	333	11,8	122	4,3	363	12,9	12 arbres secs 0,4%
Toutes essences	5488	4664	85,0	564	10,3	260	4,7	496	9,1	33 arbres secs 0,6%

Région BASSIN PARISIEN - Ile de France et Normandie

Essences	Nombre d'arbres total	Catégorie 1 Nb	Catégorie 1 %	Catégorie 2 Nb	Catégorie 2 %	Catégorie 3 à 5 Nb	Catégorie 3 à 5 %	Coloration du feuillage anormale Nb	Coloration du feuillage anormale %	
Tous feuillus	1581	1361	86,1	172	10,9	48	3,0	154	9,8	5 arbres secs 0,47%
Tous conifères	241	201	83,4	30	12,4	10	4,1	36	15,0	1 arbre sec 0,41%
Toutes essences	1822	1562	85,7%	202	11,1	58	3,2	190	10,5	6 arbres secs 0,33%

Région PYRENEES

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	1130	898	79,5	184	16,3	48	4,2	108	9,6	3 arbres secs 0,27%
Tous conifères	724	548	75,7	133	18,4	43	5,9	302	41,9	3 arbres secs 0,41%
Toutes essences	1854	1446	78,0	317	17,1	91	4,9	410	22,2	6 arbres secs 0,32%

Région ALPES du SUD

Essences	Nombre d'arbres total	Catégorie 1		Catégorie 2		Catégorie 3 à 5		Coloration du feuillage anormale		
		Nb	%	Nb	%	Nb	%	Nb	%	
Tous feuillus	889	599	67,4	212	23,8	78	8,8	47	5,3	0 arbre sec
Tous conifères	1654	998	60,3	397	24,0	259	15,7	166	10,1	3 arbres secs 0,18%
Toutes essences	2543	1597	62,8	609	23,9	337	13,3	213	8,4	3 arbres secs 0,12%

5.12 ATMOSPHERIC POLLUTION AND FOREST DECLINE IN FRANCE: THE STATE OF PROGRESS OF RESEARCH UNDERTAKEN IN THIS FIELD*

M. Bonneau[1], P. Joliot[2], G. Landmann[1], M. Muller[3] and R. Wunenburger[3]

[1]INRA Nancy, Champenoux, F-54280 Seichamps, FRANCE
[2]Institute of Physio-chemical Biology, 13, rue P. & M. Curie, F-75005 Paris, FRANCE
[3]Ministry of the Environment, Neuilly s/Seine, FRANCE

1. INTRODUCTION

Initiated in October 1983, the french research programme on "Forest Decline Attributed to Atmospheric Pollution" (DEFORPA) has the following organisation :

- The "Management Committee"
chaired by M. Lucien CHABASON, head of SRETIE(1) (Ministry of Environment), including representatives from various ministerial departments and the major research organisations involved. It is responsible for organisation, coordination and programme financing ;

- The scientific committee
chaired by M. Pierre JOLIOT, professor at "Collège de France". It proposes scientific orientations, expresses its opinions on research projects submitted to the management committee and carries out result assessment.

- Research work is managed by M. Maurice BONNEAU, research manager at INRA(2), assisted by an operational group of scientists specialised in the various scientific areas involved in the programme. The budget dedicated to the programme in 1986 amounts to FF 38 M. approximately, including salaries and overhead cost of people participating laboratories : INRA, CNRS(3), Universities, National Meteorological Office, Electricity Board (EDF), Atomic Energy Commission (CEA), Institute for Applied Chemical Research (IRCHA) ...

- The DEFORPA programme has a good position at the international level since on one side, it has the benefit of a financial support by EEC, and on the other side, a close cooperation has been established with similar programmes underway in Federal Republic of Germany and in Switzerland Exchanges will also be developped in the framework of French - Canadian and French - USEPA cooperations, and with Eastern Europe (mainly in the framework of I.I.A.S.A.).

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.**

(1) Service de la Recherche, des Etudes et du Traitement de l'Information sur l'Environnement
(2) Institut National de la Recherche Agronomique
(3) Centre National de la Recherche Scientifique.

2. THE RESEARCH TOPICS OF DEFORPA

Pursuant to Scientific Committee recommendations, the programme is being carried out until 1990 along the four main lines :

1°) Objective assessment of forest decline

Classification of symptoms as a function of ecological conditions in groves, follow-up of damages in times and in space (map of damages). This implies the strengthening of scientific observations in some clusters conveniently selected within the ONF (4) network, as well as the progress of remote sensing methods, in particular SPOT image processing.

2°) Assessment and follow-up of air pollution in forest

Permanent monitoring stations are being installed and operating in the middle altitudes mountains (Vosges, Jura, Alps, Pyrénées, Massif Central, Ardennes), in more or less damaged forest zones, so as to check whether the decline is connected with the level of acidic and/or photooxidation pollution.

By relaying on mobile monitoring equipment (laboratory vans or especially equiped aircrafts) during specific campaigns, it will be tried to determine the influence of mountainous profiles on physico-chemical composition of clouds, of fogs, of rains, of snow in contact with forests especially in the 700 m - 1200 m altitude zone where damages are generally the most important.

Finally, 45 m high tower with instruments will be installed in 1987 at Donon Pass ... The measurement of pollutants and physical atmospheric parameters at different levels, under, inside or above the tree foliage will permit estimates of pollutant amounts retained by tree foliage and depositing on the ground.

3°) Investigations on direct action of air pollutants on forest trees

On one side, we pursue experiments in "simulation" and "exclusion" chambers with a view to improve our knowledge of physiological effects of the various types of pollution and compare these effects with decline symptoms observed in the field.

On the other side, we endeavour to conceive new experimental equipment either for continous analysis of photo-synthesis in ipen top chambers, or for submitting various twigs of the same aduet tree to different sets of pollutants (soft wall minichambers).

Composite physiological effects due to pollutants and other stressing factors, chiefly the hydrix stress (drought), are also being investigated.

Let us notice that, for this programme to be fully efficient, it should ne able to lean on a fundamental knowledge of the tree physiology. But this research topic is too little investigated at present time, in Frabce as well as in foreign countries. It is the reason why the international symposium SILVA in Paris, February 1986, recommended a cooperative development of fundamental research in this field. In France, INRA and CNRS should devote themselves to it in coming years.

4°) Study of soil role in the decline progresse

Excessive deposits of air pollutants -in particular acidic ones- on forest soils can in the long range result in physico-chemical or biological desorders (both being tied most of the time).

(4) Office National des Forêts

These desorders, especially in the rhyzosphere, can in their turn trigger or aggravate the decline of forest trees through their root system.

Investigations are being pursued on these various aspects :

- by carrying on research on mycorhysation and root parasites ;
- by pursueing investigations on aluminium content of capillary or non capillary waters in the ground ;
- by initiating the active phase of experimentation on the AUBURE watershed (Southern Vosges), in comparison with experimental watershed of Mont-Lozère (Massif Central) located in a much less polluted area.

3. SUMMARY OF THE RESULTS OF RESEARCH UNDERTAKEN SO FAR

The aim of the research of the DEFORPA programme was to study the causes of forest decline, particularly in the Vosges, since 1983. The research has also been extended a little to include other regions. Obviously after only 2 years of work, when most of the teams had no prior experience of the subject, it is too soon to fulfill this objective. We can only try to demonstrate the main lignes of progress achieved in an extremely complex topic.

3.1 - Observations

The results of the 1986 survey campaign nearly show a steadiness of the damage level compared to the 1985 one. Broadleaves stands are less damaged than conifers but their damage level is a little higher than that of 1985 ; however the percentage of trees having more than 25 % of missing foliage is only 5 to 8 %. Conifers are more damaged that broadleaves trees, but their health seems to have mended a little from 1985, particularly in the fir stands. The most damaged region is the Vosges where 18 % of the needle trees have a percentage of needle trees have a percentage of needle lack greater than 25 %. As far as the degree of defoliation is concerned, the high-Jura and the Northern Alpes come just after the Vosges. It is the same for the intensity of yellowing, the Vosges being the most damaged and the Vercors and the Chartreuse being the most concerned regions in the Alpes. On a little area of the Central Pyrenees to, the white fir is strongly yellowing.

Manual interpretation of the infra-red photographs gives a good inventory of decline and allows one to draw a suitable map. At the moment that is the only possible means, apart from ground observations, as in spite of progress, automatic interpretation of the photographs seems to be a lon way off, and interest in the use of satellite images has only just begun.

3.2 - The relationships between ecological conditions and the decline

This consisted of several studies including an examination of past conditions, by observing the annual rings of the Vosgian firs which date from the second half of the 19th century. Many results were obtained from these studies :

- the growth curve for fir during the last century, which has been established rigorously by eliminating the age effect, does not show a decrease in production but only fluctuations which, o a century scale, are due to temperature variations in the Northern hemisphere, and in detail reflect climatic accidents. Severe droughts have given rise to very marked reductions in growth for a ten of years each time. For example there was a very great reduction between 1972 and 1982 which has probably falsely given the impression of being unprecedented. Paradoxically, decline, characterised by needle fall, only begins one or two years before growth returns to its normal level. Meanwhile, if one considers firs with different levels of defoliation (or better with different widths of sapwood) the growth curves diverge over several tens of years, the divergence often beginning to appear during one of the periods of depression mentioned above (1921-23 or 1947-49). For the fir, that could be just as much due to the great droughts in the past (1921-23, 1947-49). On the other hand, yellowing in spruce cannot be explained this way, particularly in the Vosges, for such a yellowing was not to be seen after the 1947-49 great drought ;

- decline generally increases with altitude, but there are exceptions ;
- there seems to be a fairly good relationship between nutritional conditions and the decline, but the relevant elements differ, depending on the area studied : magnesium and calcium in the Vosges, potassium in the Pyrénées ; this probably shows a direct effect of the acid pollution on the foliage ; in the Jura there is no relationship between decline and nutrients, although the declining stands show lower nutritional levels of N and P, elements which are clearly below the optimum for all the stands studied in the Jura. In the Vosges the magnesium deviciency as well as the yellowing of the fir and spruce seem to be related to the soil chemistry and the richness of the parent material ; it may be thought that the lack of exchangeable cations in the soil make easier the effect of the elements leaching from the leaves by acid deposition.

At the same time it cannot be denied that there is some contradiction of these results within the DEFORPA programme, probably due to different sampling techniques (the difference between random and stratified sampling). In the Jura, soil chemistry and type have no effect, but the decline is stronger on the shallowest soils.

- the decline depends on the age of the trees ; the oldest are the more damaged.

3.3 - Pollution conditions

The study of pollution in the Vosges is located in the "Col du Donon". SO_2 pollution is practically non-existant during most of the year (annual mean : 15 micrograms of SO_2 per m^3) but there are peak periods of 200-300 micrograms on certain days in winter when there are stable anticyclonic conditions with a light easterly wind. Ozone can reach very high levels in summer (200 micrograms during peak periods) with a small diurnal fluctuation. The mean during the growing season of 7 hours per day, could be about 100 micrograms per m^3 and is therefore likely to cause damage.

The rainfall is moderately acid, with a pH possibily falling to 3,8 at the beginning of a rain episod.

Specific measurements have been carried out on the particle size and chemical composition of the aerosol material, and analysis of falling snow. This work shows clear differences related to wind direction. Northerly or Easterly winds bring more acid snow, containing more sulphates and nitrates, and air with more fine aerosol material (0,1 µm diameter), than winds from the West or South. The amounts of aerosol material in the air remain low (3 000 - 15 000 particles per cm^3) compared with those of urban areas (300 000 particles per cm^3 at Fos for example).

Studies of the air mass trajectories passing over the Donon site, using a simple model, give results similar to that of Eliassen, and show that 38 % of the pollutants arriving over the site (at least for the SO_2) originate from within France. This rather high proportion may be surprising for some important emission sources, out of the French territory, are not very far from the Donon. But theses sources are in North or East direction and the dominant winds come from the South-west. A very interesting result of this study, is that a year like 1976 is not only characterised by its dryness, but also, due to the exceptional distribution of the air mass trajectories, coming more frequently from the East, by a greater input of pollutants.

Progress has been made on the modelling of SO_2 oxidation to H_2SO_4 in the atmosphere related to cloud type, and shows a difference between the continental clouds which contain fine drops, and the maritime clouds with larger drops.

When we consider the levels of all the pollutants together, it seems that photooxydants are more libely to cause trees declining than SO_2.

3.4 - Physiological research

Unfortunately the physiological studies were only begun just before the end of the contract, on spruce in open chambers at the Donon site (an exclusion chamber running since July 1985), and at Montardon (a simulation trial with O_3, SO_2, $O_3 + SO_2$, reproducing the conditions at the Donon and only running since the spring of 1986, and therefore lacking an SO_2 peak). Research has only been carried on *in situ* spruces, representing the range of different pollution), or on seedlings or plants subjected to SO_2 levels in the air of 200 micrograms (about the concentration levels at peak periods in the winter at the Donon, but in the growing phase).

Many results are clear, and the same results are found *in situ* as for the experimental conditions.

a) The soluble proteins are lowest in the needles of *in situ* spruce showing the greatest decline, and in the young plants subjected to controlled SO_2 pollution.

b) There are variations in the *in situ* enzyme activity, especially in second year needles : notably, a large reduction in the glutamate-dehydrogenase and malate-dehydrogenase potentials, and an increase in the phosphoenol-pyruvate-carboxilase and the isocitrate-dehydrogenase potentials ; the increase in the latter can be related to the increased respiration rate shown elsewhere.

c) A positive interaction (increase in damage) between SO_2 pollution and soil drought is clear in experimental conditions, especially in the water content of young plants or seedlings (needles and roots), and in the photosynthesis.

d) Declining trees contain more free sugars than healthy trees.

e) Decling trees contain more tryptophane.

f) *In situ* declining trees have less arginine and more putrescine than healthy trees. Conversely, seedlings under controlled pollution conditions (200 micrograms of SO_2) which do not show decline symptoms, contain more arginine and less putrescine than the controls.

g) The terpene content, which seems to be modified in declining trees, is a difficult criteria to use because of its great variability between trees.

h) The needles of the declining trees have a higher polyphenol content than that of the healthy ones.

3.5 - Research on biotic factors

This research has not succeeded in identifying a factor which is indisputably responsible for the decline. Armillaria (*Amillaria obscura*), which occurs in the final phase of decline in some stands which show a higher mortality than normal, cannot be held responsible as the initial factor without further proof, nor can it be completely discounted. Contrary to what was thought at one time, it is not certain that mycorhization is more deficient in declining stands than in healthy ones. It is certain that the fungal parasites, *Pythium* or *Fusarium* species, on fine roots, have no action ; this is less certain for the *Trichoderma* species.

Experiments on young plants show that unidentified soil micro-organisms seem to reduce mineral nutrition. This inhibition disappears when a calcium fertilizer is used. This line of research should be followed up, because if these phenomena were proved to have increased recently due to the soil acidification, they could contribute to the explanation of the yellowing in spruce, and more generally, to the degradation of the mineral nutrition which can be seen everywhere.

It is not intented at present to initiate in the DEFORPA programme studies dealing with other kind of pathogenic agents than these in the rooling zone. Concerning virus, which sometimes are thought in several countries to be responsible for the decline, if not as starting factor at least as predisposing factor, it was decided only to keep ourselves informated of the studies in the other countries.

4. WHAT CAN BE CONCLUDED ABOUT THE CAUSES OF DECLINE ?

In a multitude of papers from different countries on the synthesis of this subject, it has been written that the decline was a complex and many sided phenomenon, differing from region to region and sometimes in very small areas. On the basis of the actual facts we agree with this conclusion.

SO_2 pollution can certainly increase the decline and aggravate the consequences of drought. 1976 was particularly favourable for these conditions since, as the analysis of the trajectories shows, pollution increased that year. The spring was already dry when the easterly winds were able to bring noticeable pollution. Generally speaking the strain of the forest ecosystems during sometimes ten years long dryness spells, testified by ring width decrease during these periods, may have contributed to make the trees more sensitive to the pollution or, conversely, have been intensified by the pollution. Nevertheless one must remember that there are declining firs in the Luchon region in the Pyrénées, where SO_2 levels are low and where the 1976 drought was not severe. Ozone and the mists or acid clouds (although they have not yet been analysed in the Vosges) are probably the most plausible culprits. It is thought, following PRINZ's theory, that humid acid precipitation associated with ozone could bring about mineral impoverishment in the leaves, which in effect one observes in all the regions affected by decline, for one or more elements which differ from region to region. This geographic differenciation leads us to think that air pollution is not the only cause and that ecological conditions (soil, climate ...) strongly modulate its action. The rapidity of the nutrient deficiencies increase, well illustrated by the rather sudden spruce yellowing in the Vosges (new phenomen not noticed in the past, even after the strong 1947-49 dryness spell), still remains unexplained as the air pollution, either acid or photooxydant, probably increased progressively. It is possible that years long applied acid pollution have made the trees more sensitive to the increasing photooxydant air load, by way of soil improverishment and roots misfunctioning.

Could the intervention of an as yet unidentified microflora which seems to inhibit the absorption of nutrient elements, be an explanation ? Why would it develop in such a brutal fashion ? We cannot answer that at the moment.

It must also be emphasises that dendroecological studies show that some of the phenomena contributing to the decline syndrome, in particular the recent reduction of growth which is seen for the firs in the Vosges, are only the normal result of the drought of 1972-76, which this species seems to be recovering from. It is necessary to wait for a few more years to know, if we have propitious climate conditions, whether decline symptoms which were due to the dryness spell 1972-1976 and which acted by reducing growth until 1980, will disappear or not. In the first case we might conclude that pollution, even if it contributed to reinforce the dryness effect, is not able alone to cause or perpetuate forest decline. In the second case, it would have an own effect and we should have to determine whether the symptoms are indentical to, or different from those which had been observed from 1983 to 1986.

6. GENERAEASSESSMENTSOFWOODSUPPLY AND FOREST DECLINE

6.1 STATE-OF-THE-ART REPORT ON THE EXTENT OF FOREST DECLINE ATTRIBUTED TO AIR POLLUTANTS IN EUROPE – FALL 1986*

S. Nilsson
Biosphere Project
Environment Program
International Institute for
Applied Systems Analysis
A-2361 Laxenburg, Austria
and
College of Forestry
Swedish University of Agricultural u
Sciences
S-77073 Garpenberg, Sweden

1. INTRODUCTION

During the last 10 years concern about forest decline attributed to air pollution has increased dramatically. Already in the early days of industrialization, damage symptoms were identified on trees in the neighborhood of industries. However, the problem gained wide publicity first in the early 1980's. At this moment, the first quantitative estimates of the damage were presented in different countries in Europe. The estimates were carried out with different precision in different countries. The definition of damage varied from country to country. In some countries the reported figures were based on expert judgement rather than on a statistical survey. It is just during the mid 80's that the reported damage figures are based on sound statistical surveys.

The objective of this paper is to make a critical evaluation of existing quantitative reports about forest decline in Europe. Such a quantification will play an important role in assessing the effects of forest decline on the European society and forest sector.

2. REGISTRATION OF THE FOREST DECLINE

Methods used for monitoring forest decline on large areas must be highly simplified in comparison with experimental field studies. So far, for large-scale monitoring the dominating damage variables have been the density of canopy and yellowing of foliage. The indications are registered from the ground on sample plots in the field.

The density of canopy (defoliation) is assessed as the fraction of needles or leaves which have been shed in comparison to the norm. The principle for damage classification in large-scale monitoring is shown in Table 1:

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Table 1. Relationships among damage classes, defoliation classes, and discoloration classes in the registration of forest decline.

Defoliation		Discoloration		
Defoliation Class	Percent Defoliation	1	2	3
		< 25%	26–60%	> 60%
0	0–10%	0	I	II
1	11/20–25%	I	II	II
2	20/25–60%	II	III	III
3	> 60%	III	III	III
4	Dead	IV	IV	IV

Damage classes: 0 = Healthy; I = Light Damage; II = Moderate Damage; III = Severe Damage; IV = Dead.

Source: S. Nilsson (1987). "Extent of forest damage attributed to air pollutants with update for the situation 1986". Report to the ECE/FAC Timber Committee, Geneva (forthcoming)..

Many countries are only collecting information about the density of canopy (defoliation) and not on the degree of discoloration. Therefore, in this paper the degree of defoliation is employed as the main indicator of forest damage attributed to air pollutants.

The base year for evaluation of reported damage to forests attributed to air pollution (i.e., the first year in which the collected data were based on a sound statistical representation using systematic sample plots) is 1983 for France, G.F.R., and Poland. For the other countries, with existing monitoring of the forest decline, the base year is 1984 or 1985. This means that there are no possibilities to draw conclusions about the development of damage attributed to air pollutants over time based on available statistics.

3. EXTENT OF DAMAGE ATTRIBUTED TO AIR POLLUTANTS

In the presentation of the extent of damage, three levels will be discussed. The first level includes the extent of damage which, to a specified degree of probability and statistical uncertainty (due to the data collection), can be said to be generated by air pollutants. The second level of damage belongs to a group with a high probability that the damage should be attributed to air pollutants. But the estimated extent of damage has a high statistical uncertainty (due to the data collection) in reported data. The third level is the reported damage group "slight damage" of conifers in the reports from different countries (10–25% loss of foliage). This group cannot be regarded as damaged by air pollutants for sure today. But the group must be regarded as a risk group which can develop into the first level during future adverse climatic conditions, such as severe frost and drought and/or with increased emissions. The basic data collected in this group can be said to have a high statistical uncertainty.

The reported data on the actual damage are reported in different units in different countries (see Appendices I, II, and III for information sources). From the industrial point of view, it is important to try to translate the different units into volume. Such a translation must in the current situation be very rough. The author is aware of the many sources of errors in making this transformation.

The extent of the damage attributed to air pollutants is presented in the following tables.

Table 2. Volume of coniferous trees showing damage symptoms. The monitoring method is well-known and figures are expressed in million m^3 (Damage level 1).

COUNTRY	1983	1984	1985	1986
Central Europe				
Austria	—	36.4	29.7	38.4
Belgium	—	—	2.7	—
Denmark	—	1.2	1.1	—
France	—	—	82.3	74.4
Germany, Fed. Rep.	92.3	164.4	173.4	156.2
Hungary	—	—	0.2	—
Italy	—	4.6	9.9	—
Luxemburg	—	0.05	0.08	0.1
The Netherlands	—	1.9	2.3	3.2
Poland	25.1	—	161.4	—
Switzerland	—	20.2	18.9	33.6
United Kingdom	—	11.7	5.2	23.1
Nordic Countries				
Finland	—	—	158.7	—
Norway	—	62.0	62.0	—
Sweden	—	529.9	477.8	367.7

In Table 2, countries in Central Europe are separated from the Nordic Countries. The reason is that even if the same criteria for damage are used in the two regions, the Nordic countries stress that natural factors over-shadow the possible effects of air pollutants and the damage is not of the same kind as in Central Europe. Therefore the Nordic countries argue that it is not meaningful to compare the level of damage between different regions in Europe. The damaged trees in the moderate-damage level (see above) are also all concentrated into the lower part of this damage class in the Nordic countries.

By this rough calculation, about 500 million m^3 of conifers in this group seem to be damaged in Central Europe in 1984–85. The corresponding figure for trees with less vitality for the Nordic Countries is about 590 million m^3. In calculating the total figures of damage, the last year with available information about damaged volume has been employed.

Table 3. Volume of deciduous trees showing damage symptoms. The monitoring method is well-known and figures are expressed in million m^3 (Damage level 1).

COUNTRY	1983	1984	1985	1986
Austria	—	—	48.0	52.8
Belgium	—	—	0.5	—
Denmark	—	0	0	—
France	—	—	137.0	182.4
Germany, Fed. Rep.	65.5	136.7	147.9	163.5
Hungary	—	—	22.1	—
Italy	—	—	5.3	—
Luxemburg		2.4	2.6	3.3
The Netherlands		1.6	2.3	2.5
Poland			17.3	
Switzerland		25.4	29.5	45.9
United Kingdom			14.7	13.6

From Table 3 it can be seen that in the period 1985–86, about 500 million m^3 of deciduous trees were damaged in Central Europe. This is an increase of about 20% from the period 1984–85.

A source of under-estimation of the damage is the felling of damaged trees during the harvesting season. Much of this wood will not be registered during the monitoring. The monitoring takes place during a short period in the summer or early autumn. No systematic data collection is made on harvested damaged trees or volume with the exception of Hungary.

The second level of damage represents data from countries where it is impossible to make any statements about how representative the basic information about the damage is from a statistical point of view. The extent of damage in this group is presented in Table 4.

The wide range for the extent of damage in the German Democratic Republic depends on quite different basic information about the damage situation in that country.

As discussed earlier, some countries regard a loss of 10–25% of foliage on conifers as damage attributed to air pollutants. It has also been stressed above that this degree of loss cannot for certain be regarded as generated by air pollutants. There is high probability that such loss can be caused by natural stress factors. However, the trees belonging to this category of foliage loss must be regarded as a risk group. The trees in this group will be more sensitive to air pollutants in adverse climatic conditions, such as severe frost and severe drought. The extent of the damage in the potential risk group is presented in Table 5.

If Central Europe and the mid 80's is considered, it can be seen that about 770 million m^3 belong to the potential risk group for conifers. If this is compared with data in Table 2, it is apparent that the volume in the potential risk group is about double the volume assumed to have been damaged by air pollutants.

Table 4. Volume of deciduous trees showing damage symptoms. The monitoring method is well-known and figures are expressed in million m^3 (Damage level 2).

COUNTRY	Year 1985
Czechoslovakia (Czech Republic only)	198.7 (including light damage)
German Democratic Republic	52.8–378.4
Spain	5.8
Yugoslavia	130.1
TOTAL	387.4–713.0

Table 5. Volume of coniferous trees in forests in the potential risk group. Figures are expressed in million m^3 (Damage level 3).

COUNTRY	1983	1984	1985	1986
Central Europe				
Austria	—	161.8	225.1	235.9
Belgium	n.a	n.a	n.a	n.a
France	—	—	—	152.5
Germany, Fed. Rep.	226.9	247.0	237.3	255.2
Hungary	—	—	3.3	n.a
Italy	—		n.a	n.a
Luxemburg	—	0.2	0.3	0.4
The Netherlands	—	4.8	5.6	4.3
Poland	56.5	—	n.a	—
Switzerland	—	58.8	65.1	75.6
United Kingdom	—	30.8	18.3	43.7
Yugoslavia	—	—	n.a	n.a
Nordic Countries				
Finland	—	—	n.a	
Norway	—	72.1	77.6	n.a
Sweden	—	n.a	n.a	n.a

With the information available, the conclusion is that about 7 normal yearly cuttings in each group of damage and in these European countries are affected or stressed by air pollutants and other unknown stress factors.

4. DEVELOPMENT OF DAMAGE

It has earlier been stressed that no statement can be made with confidence about the development of damage unless there are observations for a longer period with the same weather conditions. In the existing data, only two observation points can be utilized in a limited number of countries and the climatic conditions during the observed period have been quite different. It is therefore difficult to discuss any development of the damage. However, the change of growth rates of the damage in percent between 1983/84, 1984/85, 1983/86 and 1984/86 are calculated for the countries for which basic information is available (Table 6). The average value is calculated by weighting with the standing inventory in different countries. The growth rate is calculated as the change of extent of damage as percent between individual years.

5. NATURE OF DAMAGE AND CONCLUSIONS

After reviewing the information from the different countries, the following statements can be made about the damage. The damage is concentrated or dominating in, or on:

- mature stands;
- stands at high altitude for the years 1983, 1984 and 1985;
- stands with less water retention capacity;
- stands with less favorable nutrient conditions;
- stands located in a harsh climate;
- species which are known to be very sensitive to natural stress factors;
- dominant trees and trees at the edges of stands;
- stands with unsatisfactory silvicultural treatments; and
- regions with high concentrations of foliphagous insects and fungal pathogens.

During 1986 it can be seen that the damage patterns in mountainous areas are also appearing in non-mountainous areas.

One conclusion of the statements above is that the damage is concentrated on stands which are already exposed to natural stress. Perhaps this information can be used in predicting the future development of damage attributed to air pollutants.

On the other hand, the statements made above can also lead to another conclusion: namely, that the criterion used for estimating damage by air pollutants, i.e., loss of foliage, is an inefficient measure and mainly registers damage caused by natural stress factors.

Table 6. Growth rates of the extent of damage. Figures are percentages of the change in volume of damaged trees over the years indicated.

COUNTRY	1983/84	1984/85	1983/86	1984/86
Conifers, moderately + severely damaged				
Austria	—	– 19%	—	+ 6%
France (Vosges)	+ 10%	– 7%	– 8%	– 16%
Germany, Fed. Rep.	+ 78%	+ 5%	+ 69%	– 5%
Luxemburg	—	+ 67%	—	+ 75%
The Netherlands	—	+ 20%	—	+ 84%
Switzerland	—	– 6%	—	+ 67%
United Kingdom		– 55%	—	+ 98%
AVERAGE	+ 47.4%	– 7.6%	+ 34.4%	+ 7.7%
Deciduous, slightly + moderately + severely damaged				
France (Vosges)	– 32%	– 1%	+ 15%	+ 69%
Germany, Fed. Rep.	+ 109%	+ 8%	+ 150%	+ 20%
Luxemburg	—	+ 5%	—	+ 39%
The Netherlands	—	+ 42%	—	– 55%
Switzerland	—	+ 16%	—	+ 81%
AVERAGE	+ 3.3%	+ 2.3%	+ 48.8%	+ 57.6%
Conifers, risk group				
Austria	—	+ 39%	—	+ 46%
France (Vosges)	+ 24%	+ 2%	+ 25%	+ 1%
Germany, Fed. Rep.	+ 9%	– 4%	+ 12%	+ 3%
Luxemburg	—	+ 66%	—	+ 73%
The Netherlands	—	+ 16%	—	– 3%
Switzerland	—	+ 11%	—	+ 29%
United Kingdom		– 40%	—	+ 42%
AVERAGE	+ 15.9%	+ 9.4%	+ 17.9%	+ 18.8%

APPENDIX 1. Sources of Information for Estimates of Forest Damage. Monitoring method well-known and for the risk group.

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6.2 THE OUTLOOK FOR THE EUROPEAN FOREST RESOURCE, AND POSSIBLE EFFECTS OF AIR POLLUTION DAMAGE*

K. Prins
Timber Section
ECE/FAO Agriculture and Timber Division
CH-1211 Geneva, SWITZERLAND

1. INTRODUCTION

It would be of great interest to many experts to dispose of authoritative, quantified projections for the forest resource, taking fully into account likely developments in air pollution damage. However, it may well not be possible in the present state of knowledge to produce this type of forecast. This paper therefore aims to:

(a) briefly examine the problems of forecasting forest damage;

(b) present two base scenarios for the development of the European forest;

(c) discuss how these scenarios could be affected by developments for air pollution damage.

The paper is based on the relevant sections (chapters 5 and 6) of European Timber Trends and Prospects to the Year 2000 and Beyond (United Nations, New York 1986) a major study of the outlook for the forest and forest products sector as a whole, referred to as ETTS IV.

2. IS IT POSSIBLE TO PROJECT FOREST DAMAGE?

There are two main approaches to projecting future developments in any sphere, which may be summarized as follows:

(a) simple projection of past trends. This method assumes that these past trends will continue unchanged and is not therefore suitable for situations where major changes in the underlying factors are taking place. It is of course desirable to have as long a series of past data as possible (a rule of thumb is that the series for the past should be twice as long as the forecasting period);

(b) analysis of the relationship between the parameter to be studied and others. Then, on the basis of assumptions for the other parameters and the assumption that the relationship will not change (or will change in a given, quantifiable way), it is possible to prepare projections.

Is either of these methods applicable at present to the outlook for forest damage? It is not possible to project past trends, as the historical series are far too short: no country has series of comparable data on forest damage of more than three or four years, which is clearly not sufficient to project trends 10 or 20 years into the future, especially in view of the absence of a clear trend in the results.

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

Perhaps the ideal approach would be to use dose/response relationships (between pollutant deposition and forest damage), established through research, and scenarios for future deposition of pollutants. However, at present there is no scientific consensus on the causes of the damage observed and a fortiori on the dose/response relationship. Individual scientists or institutes may be in a position to base projections on possibly controversial assumptions (indeed this may be a valuable contribution to the scientific debate) but it is not possible for organisations like the United Nations or FAO to prepare scenarios which would necessarily involve assumptions which may not be widely acceptable. ECE/FAO is not a research institution but an intergovernmental organization for technical and economic co-operation in the field of forestry and forest products and thus expected by its members to take a prudent position on politically sensitive matters. This does not of course prevent it providing researchers with raw material on which to base their own work.

It was therefore, regretfully, decided that in the course of ETTS IV, ECE/FAO could not provide quantified scenarios for forest damage, because such scenarios would be based on a different type of data and reasoning than the projections and forecasts presented elsewhere in the study, and might be misinterpreted as authoritative forecasts of future developments.

It was however possible to prepare and present two types of analysis which would be of interest to those concerned with the outlook for forest damage (including those who wish to construct their own quantified scenarios for forest damage):

(a) a complete set of base scenarios for the European forest resource, including area, growing stock, increment and removals, with indications of the assumptions concerning forest damage;

(b) a non-quantitative overview of the interrelationship between the different parameters in the forest resource in the case of forest damage.

3. BASE SCENARIOS FOR THE FOREST RESOURCE

National correspondents for ETTS IV were asked to provide two scenarios for their country's forest resource (area, growing stock, increment, removals) to the year 2020, taking into account all relevant national conditions. The "low" scenario was based on "modest but realistic" assumptions on biological, silvicultural and economic conditions, the "high" scenario on "more expansive, but still realistic" assumptions on these conditions. Thus "low" and "high" refer essentially to roundwood demand and the level of removals. (As a result, growing stock forecasts in the "high" scenario are lower than in the "high" scenario). The replies were all checked for internal consistency. For a few countries, national correspondents did not provide forecasts, so secretariat estimates were necessary. The study presents country-by-country data for all of these parameters, which are summarized below.

The forecasts are for a continuation of the existing trend towards a slight expansion of forest area and an increase in the intensity of use, leading to higher increment and growing stock per hectare. There are significant regional differences, notably between those countries which foresee little change in the future and those countries which are carrying out significant forest expansion plans. The latter group includes France, Hungary, Ireland, Portugal, Spain and the United Kingdom, who will all see the maturation of earlier plantations. For the export-oriented countries, notably Finland and Sweden, the rate of expansion of the forest will depend, at least in part, on the strength of demand for forest products and their success in maintaining or improving competitivity.

The share of coniferous and non-coniferous in total removals is expected to remain stable, unlike the trend until 1980 when the share of non-coniferous fell steadily (42% in 1950, 33% in 1980), because of the decline in fuelwood removals.

Some countries, notably Poland and Switzerland, have explicitly included assumptions about forest damage in their forecasts. Others however, have not. National comments on the impact of forest damage on the forecasts are reproduced in the annex.

Table 1

Europe: overview of forecasts for the forest resource to 2020
(million units)

	Unit	Base period a/	Low scenario 2000	Low scenario 2020	High scenario 2000	High scenario 2020	% change Base period - 2020 Low	% change Base period - 2020 High
Area of exploitable closed forest (ECF)	ha	133	138	142	141	148	+ 7	+ 11
Growing stock on ECF	m3 o.b.	16330	18509	20056	18109	19213	+ 23	+ 18
Net annual increment on ECF	m3 o.b.	504	540	565	566	614	+ 12	+ 22
Removals, total	m3 u.b.	350	391	431	438	490	+ 23	+ 40

a/ Around 1980. Varies between countries.

It is of interest to compare the present situation and forecasts for the countries most affected by forest damage with those for the rest of Europe.

Around 1980, the nine "affected" countries (listed in footnotes to table 3) accounted for 20.5% of the area of European exploitable closed forest, but 32.2% of the growing stock, 27.1% of the net annual increment and 29.9% of the fellings. Growing stock and net annual increment for the group were well over the European average:

		Nine most affected countries	Rest of Europe	European average
Growing stock per hectare	(m3. o.b.)	193	105	123
Net annual increment per hectare	(m3 o.b.)	5.0	3.5	3.8

Table 2

Europe: forecasts of area of exploitable closed forest and growing stock on exploitable closed forest for the year 2000, by country and country group

	Area of exploitable closed forest (ECF)			Growing stock on ECF (million m3 o.b.)			Net annual increment on ECF (million m3 o.b.)			Total removals (million m3 u.b.)		
	Base period	2000 Low	2000 High	Base period	2000 Low	2000 High	Base period	2000 Low	2000 High	Base period	2000 Low	2000 High
Finland	19445	20300	20300	1568	1741	1650	61.93	67.90	68.00	45.78	48.60	53.08
Norway	6600	6600	6600	575	714	695	17.31	18.81	18.04	9.52	9.50	11.30
Sweden	22230	22230	22230	2210	2632	2356	66.94	74.60	76.50	48.52	51.70	65.70
NORDIC COUNTRIES	48275	49130	49130	4353	5087	4701	146.18	161.31	162.54	103.82	109.80	130.08
Belgium a/	600	600	635	73	95	96	4.50	4.38	4.89	2.44	3.14	3.48
Denmark	365	371	383	47	53	55	2.80	2.80	3.10	1.89	2.34	2.43
France	13340	13490	13590	1550	1732	1688	54.00	59.73	63.44	38.48	43.99	50.88
Germany, Fed. Rep. of b/	6960	6960	7040	1500	1582	1549	39.67	38.28	40.13	33.03	30.15	33.65
Ireland	347	423	469	32	48	49	2.53	4.40	4.50	0.53	3.04	3.04
Italy c/	3868	3925	3975	557	623	627	11.88	11.78	13.00	8.96	9.77	10.57
Luxembourg c/	80	80	81	13	13	13	0.33	0.31	0.35	0.29	0.27	0.29
Netherlands	294	320	335	29	33	33	1.24	1.38	1.45	1.12	1.13	1.26
United Kingdom	2017	2400	2800	203	341	327	11.20	15.30	15.90	4.32	7.25	9.05
EEC(9)	27871	28569	29308	4004	4520	4437	128.15	138.36	146.76	91.06	101.08	114.65
Austria	3165	3175	3210	803	925	955	19.58	22.59	23.35	12.17	15.35	16.35
Switzerland	935	950	950	312	309	275	5.20	4.70	3.80	4.39	4.59	5.49
CENTRAL EUROPE	4100	4125	4160	1115	1234	1230	24.78	27.29	27.15	16.56	19.94	21.84
Cyprus	100	100	100	4	4	4	0.09	0.09	0.09	0.07	0.05	0.06
Greece a/	2300	2400	2500	159	180	180	4.10	4.56	5.00	2.59	3.35	3.66
Israel	66	80	80	3	5	5	0.20	0.21	0.20	0.14	0.19	0.20
Portugal c/	2590	2890	3690	189	218	209	11.45	14.97	15.69	8.42	9.98	10.74
Spain	6506	7800	8300	453	660	638	27.83	29.35	29.82	12.17	20.53	22.57
Turkey c/	6642	7440	8240	637	639	640	19.21	21.58	23.90	22.38	23.73	25.74
Yugoslavia	8500	8700	8700	1135	1280	1280	28.85	30.55	30.55	13.79	19.30	19.30
SOUTHERN EUROPE	26704	29410	31610	2580	2986	2956	91.73	101.31	105.25	59.56	77.13	82.27
Bulgaria c/	3300	3350	3400	298	309	308	6.00	6.70	7.48	4.44	4.51	5.14
Czechoslovakia c/	4185	4185	4200	923	934	933	22.50	19.50	21.00	19.32	17.55	18.90
German Dem. Rep. c/	2590	2590	2650	440	475	489	15.00	14.51	15.37	9.99	11.00	11.18
Hungary	1596	1726	1736	253	303	283	9.71	10.04	10.28	6.16	6.10	7.48
Poland	8410	8755	8880	1162	1266	1373	28.45	30.00	37.16	21.20	23.20	24.96
Romania c/	5723	5720	5820	1202	1395	1399	31.59	31.46	33.17	18.42	20.49	21.56
EASTERN EUROPE	25804	26326	26686	4278	4682	4785	113.25	112.21	124.46	79.53	82.85	89.22
TOTAL EUROPE	132754	137560	140894	16330	18509	18109	504.09	540.48	566.16	350.53	390.80	438.06

a/ Forecasts prepared by the secretariat, based on partial forecasts by the country.

b/ Unofficial forecast.

c/ Forecast based on partial forecasts by the country.

The national forecasts show that the nine countries expect their growing stock, increment and fellings to grow more slowly than those in the rest of Europe, and their net annual increment to diminish (see table 3). The damage attributed to air pollution is only one of the possible factors which could explain this. Furthermore, circumstances vary widely between countries, and it is necessary to refer to the comments of national correspondents on this subject.

Table 3

Forecasts (low assumption) of changes in net annual increment and fellings on exploitable closed forest in countries most affected by air pollution and in the rest of Europe, base period a/ to 2000 and 2000 to 2020

	Base period to 2000		2000 to 2020	
	Volume	Percent	Volume	Percent
	(million m3 overbark)	(%)	(million m3 overbark)	(%)
Net annual increment				
Four easterly EEC countries b/	- 1.39	- 3.0	- 1.35	- 3.0
Central Europe c/	+ 2.51	+ 10.1	+ 0.20	+ 0.7
Three northerly Eastern Europe d/	+ 1.94	- 2.9	- 1.22	- 1.9
Sub-total (9 most affected countries)	- 0.82	- 0.6	- 2.37	- 1.7
Rest of Europe	+ 37.21	+ 10.1	+ 26.49	+ 6.5
Total Europe	+ 36.39	+ 7.2	+ 24.12	+ 4.5
Fellings				
Four easterly EEC countries b/	- 2.39	- 5.8	+ 0.75	+ 1.9
Central Europe c/	+ 4.28	+ 21.4	+ 0.10	+ 0.4
Three northerly Eastern Europe d/	+ 1.70	+ 2.9	+ 4.12	+ 6.8
Sub-total (9 most affected countries)	+ 3.59	+ 3.0	+ 4.97	+ 4.0
Rest of Europe	+ 47.91	+ 17.0	+ 46.13	+ 14.0
Total Europe	+ 51.50	+ 12.8	+ 51.10	+ 11.3

Source: ETTS IV, Chapter 5.

a/ Around 1980 (see text of chapter 5 for explanation).
b/ Belgium, the Federal Republic of Germany, Luxembourg, the Netherlands.
c/ Austria, Switzerland.
d/ Czechoslovakia, the German Democratic Republic, Poland.

4. THE OUTLOOK FOR FOREST DAMAGE

As mentioned above, it is not possible for ECE/FAO to produce quantified scenarios for forest damage. This paper will therefore examine, in non-quantitative terms, the possible effects of increased forest damage on the forest resource and the forest sector as a whole. It concentrates on two possible effects of air pollution, a rise in sanitation fellings and a reduction in increment, and their possible consequences. This discussion of possible consequences of a deterioration in the situation should not be interpreted as a forecast.

4.1 The forest

An important and much discussed consequence of forest damage is an increase in sanitation fellings. The consequences of any increase in sanitation fellings for the roundwood markets are important and are discussed below, but such an increase would also have silvicultural consequences. Every effort is likely to be made to prevent sanitation felling from causing a rise in total removals. One reason for this is the constraints on harvesting capacity, but the most important reason is to avoid flooding the roundwood markets. A consequence of sanitation fellings would therefore probably be that other fellings - final fellings or thinnings - are not carried out as planned, leading to a less than optimal silviculture. These adjustments could take place inside or outside the damaged areas, with the consequence that the thinning backlog could increase and/or some stands could become overmature.

Replacement of damaged stands would depend on the type of damage and on local policy for sanitation fellings (selection cutting or clear cutting of damaged areas). Choices would have to be made as regards the species used to replace damaged trees. In the absence of pollution-resistant strains of the original species (which might require years to identify or develop), foresters would have to decide whether to replant the same species or variety and risk seeing it suffer the same fate before the end of its rotation or to choose a less economically desirable but more pollution-resistant species or variety. A possible result could be an increase in the species diversity of the European forest as different foresters answered this question differently. There might also be an increase in mixed stands as foresters tried to reduce their stands' vulnerability to pollution damage.

Some of the damage observed has been in forests grown with long rotations, and older trees have been more affected than younger ones. Some forest owners might therefore choose in their "post pollution damage" planning to favour shorter rotations, possibly at wider spacing, partly to accelerate the return on their investment in re-establishment of stands. This is however only one of many possibilities which a forest owner could choose.

It has been suggested that, in the initial stages, the fertilizer effect of airborne pollution may increase forest productivity, but, in later stages, increment almost certainly falls. With widespread forest damage, average increment might fall. Not only would this affect wood supply to the forest industries, which must be based on the principle of sustainable yield, but also the return on investment in forestry.

The forest's functions other than wood production would also be affected. Heavily damaged forest areas would have little attraction for recreation or hunting or for collection of non-wood products such as nuts, berries or mushrooms. Tourism in affected areas might well suffer negative consequences of the damage. One dramatic consequence would be the reduction in the forest's ability to carry out its protection function, notably with regard to soil erosion, avalanches and landslides in mountain areas. In some mountain areas, it has already been suggested that funds be set aside in case artificial (and expensive) avalanche barriers have to be provided to take over one function of the damaged mountain forest.

It is also conceivable that in heavily polluted areas it will prove impossible to re-establish a satisfactory forest cover at all. (This is already the case around a few major individual sources of pollution). The use of such land would pose major political, social and economic problems.

The public debate in recent years in some of the affected countries has provided ample proof of the intense emotional link between many people and "their" forest.

It is of interest to examine in more detail the possible interactions in the forest sector, notably between increment, growing stock and removals in areas affected by pollution damage.

Figures 1, 2 and 3 show <u>hypothetical</u> interactions of events in a forest area which is being damaged by airborne pollution. For these figures, it is assumed:

- that the forest damage observed is in fact due to air pollution
- that after reduction of pollution depositions, the forest will recover.

It must be stressed that these figures are purely schematic. It is not possible to quantify the volumes, areas or time spans involved. Nor do they address downstream consequences which are mentioned below.

The three variants proposed are intended to demonstrate the necessary interactions between the different parts of the forest ecosystem and to highlight those points at which the forest owner is required to take certain important decisions in response to the changed situation which he faces. To highlight this aspect, all three variants are based on the same scenario regarding those events which forest owners (public or private) are not able to influence in a direct way - the amount of pollutant deposition on the forest and how the forest in question reacts to these depositions.

<u>Common scenario for pollutant deposition and spread of forest damage</u>. In a first phase, pollutant depositions increase. At first, forest increment is unaffected or even increased, but subsequently, there is a reduction in increment. Later it is noticed that some areas of forest are damaged and that increment has fallen. It is decided:

(a) to carry out sanitation felling as soon as an area is classified "dying" or "dead"; and

[illegible]

[illegible]

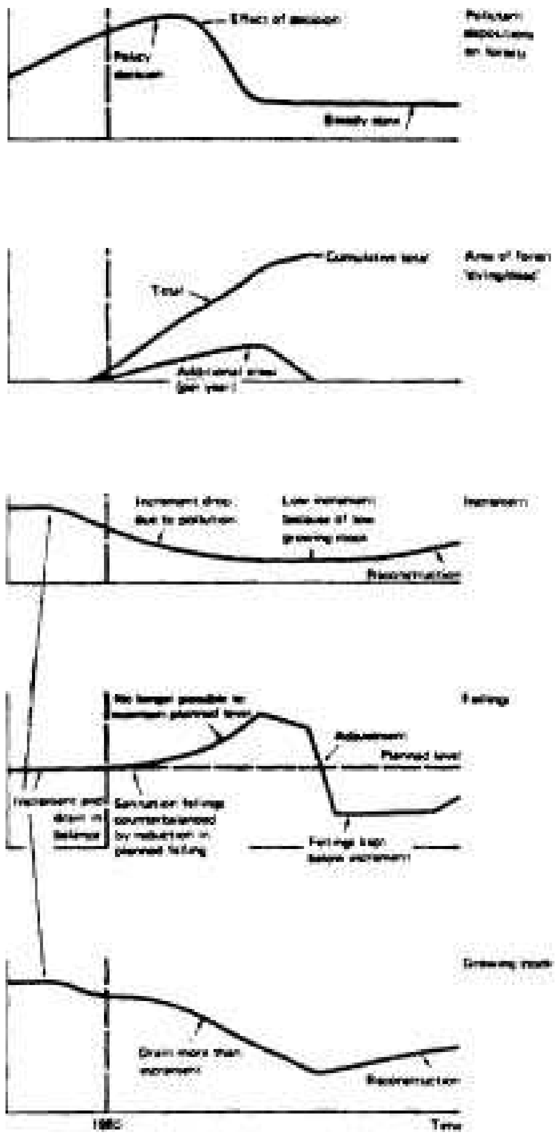

Effect of decision
Policy decision
Steady state
Pollutant depositions on forests
Cumulative total
Total
Additional area (per year)
Increment drop due to pollution
Low increment because of low growing stock
Reconstruction
Increment
Fellings
Adjustment
Planned level
Sanitation fellings counterbalanced by reduction in planned felling
Fellings kept below increment
Growing stock
Drain more than increment
Reconstruction
Time

FIGURE 2

Interaction in the forest sector: variant 2

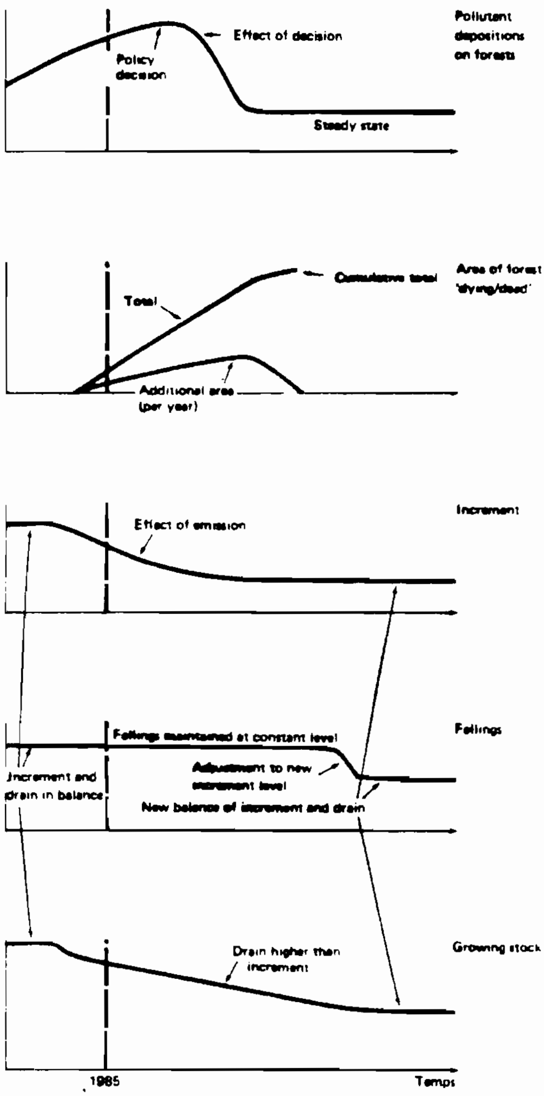
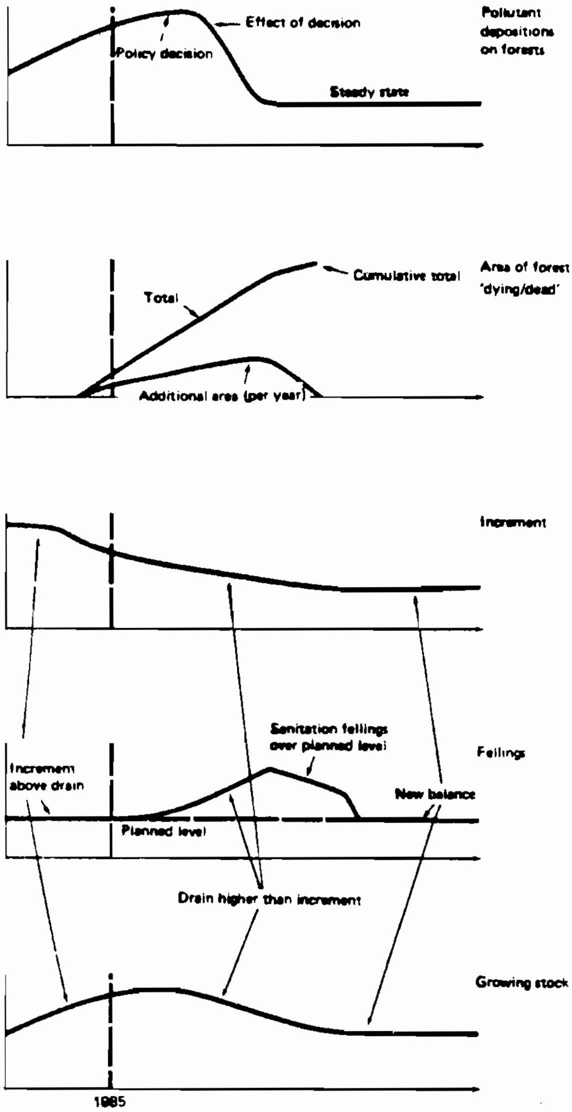


FIGURE 3

Interaction in the forest sector: variant 3



(b) to reduce other types of felling as much as possible in order to minimize fluctuations in volumes of removals and consequent disruptions of roundwood markets. As sanitation felling is organized, the area of sanitation felling is equivalent (with a small time lag) to the area of forest newly classified each year as "dying" or "dead".

As visible damage extends, a political decision is taken to reduce depositions of pollutants on forest areas (for this decision to be effective, it must take into account transboundary aspects and be designed to reduce those pollutant depositions which are in fact causing the damage).

It is almost certain, however, that there will be two types of time lag between the policy decision and a cessation of the increase in forest damage:

(a) the time necessary to carry out the measures decided and thus to reduce depositions. Some measures (e.g. vehicle speed limits) can be enacted quickly, others (e.g. catalysers on all cars, scrubbers on polluting industries) require a certain time to be implemented

(b) the time necessary for the forest to react favourably to the reduction in depositions.

During this period between the policy decision and an improvement in the health of the forest, visible damage would continue to spread and increment to drop.

Variant 1. In this variant, before the onset of the pollution damage, increment and drain are in balance, and the growing stock is therefore constant. As a result of the spread of visible damage, and the appearance of areas classified as dying or dead, sanitation fellings are undertaken. After a time, it becomes impossible to counterbalance these necessary sanitation fellings by adjusting existing felling plans (i.e. by postponing planned removals in undamaged forests) , so that total removals and, thereby, drain on the forest increase. Simultaneously, increment drops, due to the effects of pollution. As a result, drain is higher than increment, and the growing stock decreases. This continues until the area of forest classified as dying or dead ceases to expand. At this stage, sanitation fellings are no longer necessary and the level of fellings is adjusted to the new level of increment. This is lower than at the beginning of the period because the reduction in growing stock has reduced the increment. Increment is now high, relative to growing stock, but is low in absolute terms and relative to earlier levels.

Future developments from this point will depend on the decisions taken about future forestry objectives. If the new, lower level of increment and growing stock is considered acceptable, then the new rate of drain can be equivalent to that of increment. If however, it is decided to recover the "pre-pollution" level of growing stock, then drain must be kept below increment until earlier levels are recovered. (The latter course is shown in fig. 1).

Variant 2. As in variant 1, at the beginning of the period, increment and drain are in balance. In variant 2 however, it is possible to maintain the level of fellings constant, in order to avoid disruption of the roundwood markets even with a high proportion of sanitation fellings, by strongly limiting all fellings from undamaged stands. Nevertheless, increment is reduced by air pollution, so that the volume of growing stock declines (but less than in variant 1). As in variant 1, when the damaged area ceases to expand, fellings must be adjusted to the new level of increment which is lower than before (but higher than in variant 1, as the level of total fellings was lower than in variant 1). A decision must also be taken about the desirable future level of growing stock: fig. 6.2 shows a new balance of increment and drain at a lower level than before i.e. drain is not kept below increment to increase growing stock.

A significant difference between variants 1 and 2 is that in the latter, less felling takes place on undamaged areas. There is a danger than on these areas thinning may not take place, or that stands become overmature.

Variant 3. In this variant, before pollution damage becomes apparent, increment is above drain and the growing stock is increasing. As pollution damage spreads, sanitation fellings are undertaken, and increment drops. However, the existing situation makes it possible to absorb this increase in drain, without a drop in growing stock, at least in a first phase. In variant 3, sanitation fellings do ultimately reach a level where they cause a decline in the growing stock, but it is conceivable, if drain is at the beginning of the period very much less than increment, that increased sanitation fellings could be absorbed without a decrease in growing stock.

As in the other two variants, when the damage ceases, drain must be adjusted to increment and decisions taken as to the future level of growing stock.

Needless to say, these three variants are not the only possible ones and, in the present state of knowledge it is not possible to assign a degree of probability to any one of them. They are intended as examples of the type of interactions which might take place if the forest damage attributed to air pollution does follow a negative course.

It appears from the discussion above that there are three major areas for policy decision:

(a) decision to reduce pollutant emissions. This is the most important and necessary decision of all (although it lies outside the area of direct influence of the forest administration or forest owners);

(b) decision on whether to undertake sanitation fellings, and on what basis (compulsory or voluntary, subsidized or not). For forest hygiene reasons, however, some type of sanitation fellings appears inevitable;

(c) decision on future forestry objectives. Although final decisions are probably only possible after forest damage has ceased to expand, provisional decisions, e.g. on species for regeneration, need to be made at an early stage.

After each sanitation felling, it will be necessary to decide on the future use of the land. If it is decided to regenerate the forest cover (probable in the great majority of cases), further decisions will have to be taken on species and provenance, and silvicultural regime. Inevitably, there will be a significant element of experimentation in these choices, as the reaction of "new" species to the prevailing conditions would not be well known. It will be necessary to monitor carefully the success of the different types of regeneration. In the light of these results, it would be possible to build up gradually a more general forest policy for the affected areas, which would take into account all relevant factors. One possibility would be the reconstruction of the "pre-pollution" forest but the decision might well be taken to create a slightly or radically different type of forest. The debate on the type of forest which is to be established on the area of sanitation fellings and what its major functions should be will no doubt be at the centre of forest policy discussions in affected countries for many years.

Satisfactory decision-taking requires adequate information, in this case on extent and type of forest damage, pollutant depositions, volume, location and assortment of sanitation fellings and changes in increment rates. It is a prerequisite for the establishment of new forest policies for changed circumstances that monitoring systems are set up, if this has not already been done, to provide accurate and up-to-date information on these matters.

4.2 Roundwood markets

As mentioned above, trees which are considered dying or dead should be removed for silvicultural and phytosanitary reasons, notably to avoid insect infestations. Clearly, if there are large volumes of sanitation fellings and if normal felling levels are not sufficiently adjusted, there is a risk of market disruption due to oversupply. Up to the mid-1980s, however, it appears that in most cases it has been possible to avoid disruption at the national level by reducing planned fellings. There have however been effects at the local level. This procedure is easier for large-scale forest owners, public or private, who have more flexibility in their felling plans than for small-scale owners, e.g. those who may only harvest occasionally. The latter, when faced with the prospect of silviculturally necessary sanitation fellings, may not have the possibility to reduce fellings elsewhere on their land. Furthermore, those small-scale owners who are not faced with sanitation fellings may be unwilling or unable to reduce their own fellings to preserve the balance of the roundwood market.

The market situation is unclear in many cases, as no separate statistics are kept in most countries on sanitation fellings and no precise definition of them is agreed in practice. Furthermore, forest owners are understandably unwilling to weaken their negotiating position by admitting publicly that they are obliged to fell a certain volume of timber.

If market disruption due to sanitation fellings were to occur, some or all of the following could take place:

- market reactions

(a) a fall in roundwood prices

(b) a surplus of some assortments (e.g. logs) or species (e.g. spruce/fir)

(c) increased transport costs as certain areas were saturated with roundwood and the surplus had to be transported elsewhere.

- measures to minimize market disturbance

(d) storage of harvested wood (e.g. with sprinkler systems or in ponds); this can, however, only be a temporary measure

(e) exports of surplus wood in unprocessed or processed form

(f) increased co-ordination of fellings, notably the reduction of planned fellings in favour of sanitation fellings. This co-ordination could be undertaken by associations of forest owners or by official bodies, and might therefore implicate unaffected areas in the management of the consequences of forest damage

(g) rapid build up of processing capacity and efforts to increase markets (see next sections).

Apart from the actual progression of the damage, the level of sanitation fellings and the capacity of the roundwood markets to absorb them are the most uncertain aspects of the pollution damage question. Most of the negative consequences for industry, trade or consumption result more or less directly from a high level of sanitation fellings (possibly followed by a low level of fellings as suggested above). It should be borne in mind, however, that changes, such as a fall in roundwood prices may be negative for some participants in the market, but positive for others.

4.3 The forest industries

It appears that, if the wood from damaged forests is not allowed to dry out in the forest or in storage after felling, it can be used as raw material for most processes, although there may be increases in processing costs or reduction in yield (the situation varies according to the process concerned). If it is allowed to dry out, however, its value is much reduced - so that it is sometimes only suitable for fuelwood. The period during which the tree has been affected before being felled also appears to play a role.

It is possible that wood prices would diminish because of oversupply, although this hypothetical benefit for the industries could be partly counteracted by higher harvesting and transport costs and poorer yields. It is also possible that, in the affected areas, official bodies might take measures to safeguard the income of forest owners, which might or might not affect prices of wood raw material, according to the way the measures were defined.

The first consequence of increased wood supply for the forest industries would probably be a more intense use of existing capacity in affected areas, in order to use the extra volumes of wood becoming available. In some of the affected countries, capacity utilization rates are at present quite low, especially for the sawmilling industry.

If the price of damaged wood did fall and the quantities available were greater than the needs of local industries, it is likely that buyers in other parts of the country or in other countries would seize the opportunity to secure a source of cheap raw material. In this way, the surplus of damaged wood could depress wood raw material prices far beyond the area suffering from forest damage. This might apply particularly to the more homogeneous assortments, such as pulpwood (roundwood or residues).

If it became apparent that significant volumes of cheap wood raw material were likely to become available in the areas of damaged forests over a period of several years, it is possible that forest industries would seek to instal new capacity to process this raw material locally. As the availability of the raw material would be limited in time, it would be desirable to choose a type of industry for which the capital invested could be recovered fairly rapidly, (e.g. sawmills, particle board mills, MDF, CTMP, wood energy installations).

In the longer run, however, it is most unlikely that forest industries would rely on raw material transported long distances or resulting from sanitation fellings. The size and location of the European forest industries would essentially be limited by the annual increment of the forests within a reasonable transport radius. If forest increment, and therefore allowable cut, were to be lower in the long term than at present (see for instance variants 1 and 2 above), the forest industries in affected areas would eventually have to reduce capacity, leading to mill closures and loss of employment, after the period of high capacity utilisation and possible installation of new capacity.

Some adjustments might also be necessary where mills are dependent on raw material of a particular type. If this raw material were no longer available in sufficient quality and quantity, technical modifications to the installations could prove necessary, or even a change in the type of product produced.

4.4 Demand for forest products

How would demand for forest products be affected by large volumes of sanitation fellings and the corresponding industrial adjustments? It is possible that any fall in wood costs could lead to cheaper products and thereby to stronger demand, which would, of course, contribute to managing the situation. It is not clear however to what extent markets for forest products are price sensitive, and whether a fall in prices would significantly increase consumption.

It is also likely that forest industries, faced with the prospect of marketing the products of sanitation fellings, would mount major promotion campaigns to encourage the use of forest products, preferably of domestic origin. It has been suggested that such campaigns could be supported by public funds made available to alleviate the consequences of forest damage.

In the new atmosphere of awareness of forest problems - notably forest damage attributed to air pollution - psychological aspects cannot be ignored. Cases have already been reported of fears that "infected" wood could prove harmful to human health as well as of fears, apparently unjustified, that wood from damaged trees is not suitable for structural purposes. It is also conceivable that some consumers would not understand how "the forest can be helped" by cutting down trees and making products from them. Such attitudes could have a negative effect on consumer acceptance of forest products, but should be overcome through public information measures.

4.5 International trade

Any significant change in the underlying economic conditions of the sector e.g. heavy sanitation fellings, possibly leading to lower roundwood prices, or major changes in forest management objectives due to forest damage would have an effect on international trade. The consequences for individual areas would of course vary according to the underlying trade position as well as to the location and severity of damage.

It is also useful to separate short-, medium- and long-term effects. In all of these, effects on trade flows would be intimately connected with the capacity of the processing industries and the rates of capacity utilisation.

The trade situation of the countries affected by forest damage in 1984 (the most recent year for which computer-readable trade flow data are available) is summarized in the annex tables. These tables show matrices of trade flows of the most affected countries divided into western and eastern European sub-groups. (For list of countries see footnote to table 3). The affected countries of western Europe, despite their own large forest resources are quite heavily dependent on imports of products, from the Nordic countries and elsewhere. They have a positive trade balance with the "rest of western Europe", but import all products, from the Nordic countries, and the rest of the world and wood in the rough and sawnwood from Eastern Europe. They already export wood in the rough to the rest of western Europe and the Nordic countries. The eastern European affected countries on the other hand are as a group basically exporters, especially of wood in the rough and sawnwood although they also import substantial volumes, notably from the USSR.

Some of the possible trade consequences of a temporary increase in roundwood supply, a lowering of prices and a long-term reduction in increment are explored below (it is assumed there are no changes in tariffs or other protectionist measures):

- in the western European affected countries, there could be higher domestic production of forest products, the expansion being limited in the short term by the capacity of the industries. This production could be marketed on the domestic or even export markets. In both cases it would compete with the products of traditional suppliers to the region. The outcome of the competition would be determined to some extent by the degree to which lower wood costs could be reflected in lower product prices;

- there would however probably be international competition for the wood from sanitation fellings (from all areas) and some at least might be exported e.g. to the Nordic countries who have bought storm damaged wood from other countries in the past. This would put downward pressure on roundwood prices in the Nordic countries. The products of the sanitation fellings, processed in the Nordic countries, might return to compete on the domestic markets of affected countries, at least in western Europe;

- the affected countries of eastern Europe in particular, faced with an increased wood supply, might have difficulties in expanding their processing capacity (investment problems) and would therefore be likely to increase their exports, principally of roundwood;

- if sanitation fellings were to continue in the medium term at a high level (i.e. above the processing capacity of the industries in the affected countries), the question would arise of whether to instal new processing capacity, thereby reducing the availability of roundwood for export and further heightening competition on the domestic markets;

- however in the long term, the phase of sanitation fellings is likely to end and may, in certain circumstances be succeeded by a reduction in harvest (see 4.1 above). If this occurs, it is likely that industrial capacity and trade flows would be adjusted to avoid permanent large flows of raw material in international trade.

The above scenarios show how, through trade, forest damage can have consequences for countries whose forests are not themselves affected. They also show that the possibility exists of quite significant changes in trade flows, prices and market shares, with losses by some participants and gains by others as well as of downward pressure on all European roundwood prices if there were significant sanitation fellings. Furthermore changes in one direction in the first phase may be succeeded by changes in an opposite direction at a later stage. This could lead to pressures for protectionism or market regulation e.g. by domestic producers in countries affected by forest damage who might seek to prevent or reduce access to domestic markets, or object to the import of products manufactured abroad from domestic raw material.

It is likely that if protectionist measures were taken, this would only be after considerable debate, involving all parties, and in the context of broader trade policy. There is also the possibility of international discussion, involving governments and industries, to reduce disruption through some form of international co-operation.

5. CONCLUSIONS

At present according to the team of specialists on the subject led by Mr. L. Schotte (Sweden), it appears that the forest damage observed in several European (and North American) countries has not caused significant market disruption. Nor is it possible, for the reasons given in section 2 above, to prepare reliable official forecasts on the development of this damage and its consequences for the sector as a whole. Yet further development of the damage and consequent market disruption cannot, unfortunately, be ruled out.

It is of course possible to construct scenarios based on models of the forest and forest products sector. A paper prepared for the ECE Timber Committee by Messrs Kallio and Dykstra (TIM/R.123/Adds 1 and 3) analysed the sensitivity of forecasts of outlook studies (in this case the IIASA Global Trade Model) to differing hypotheses for developments in forest damage. This type of exploratory analysis can be extremely valuable because of its explicit assumptions and its quantitative nature. The disadvantages are that it is necessary to construct a model, itself a long and difficult undertaking, and that it is difficut to evaluate the results if one cannot accept some of the model assumptions.

At present the only complete set of forestry forecasts for Europe are those prepared for ETTS IV. These do not fully incorporate assumptions for forest damage but can be used as a basis for forest damage scenarios, if researchers incorporate some of their own assumptions. By doing this, they avoid the work of researching and making comparable national data, filling in gaps etc, which is in any case better done by an international organisation with the help of the countries concerned. Furthermore the different scenarios for forest damage will have a common starting point and the results will be more easily comparable. This would be a considerable help in the debate which would follow the publication of the forest damage scenarios.

WORLD TRADE OF 16 PRODUCTS IN MILLION M3 EQ, YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	16.7	12.7	4.5	0.8	25.5	60.2	17.3	77.5
Rest of W. Europe	20.2	14.7	2.5	2.0	39.6	79.1	32.1	111.1
Affected E. Europe	0.1	0.3	0.4	0.1	0.7	1.6	4.9	6.4
Rest of E. Europe	0.4	0.4	0.3	0.0	0.4	1.4	3.5	4.9
Nordic countries	1.3	2.2	2.7	0.0	5.9	12.1	4.5	16.6
Total Europe	38.8	30.2	10.3	3.0	72.1	154.4	62.2	216.6
Rest of World	4.0	5.4	0.2	1.6	22.7	33.9	239.5	273.4
Total World	42.9	35.5	10.5	4.6	94.7	188.3	301.7	489.9

WORLD TRADE OF WOOD IN THE ROUGH IN MILLION M3, YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	2.9	2.9	2.0	0.5	0.0	8.3	0.8	9.0
Rest of W. Europe	2.1	2.1	0.3	0.8	0.1	5.3	4.7	10.1
Affected E. Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9
Rest of E. Europe	0.0	0.0	0.1	0.0	0.0	0.1	0.6	0.8
Nordic countries	1.0	1.6	2.6	0.0	2.6	7.8	4.2	12.1
Total Europe	6.1	6.5	5.0	1.2	2.8	21.6	11.2	32.8
Rest of World	0.0	0.2	0.0	0.0	0.3	0.5	64.0	64.5
Total World	6.1	6.8	5.0	1.2	3.0	22.1	75.2	97.3

WORLD TRADE OF SAWNWOOD IN MILLION M3, YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	1.7	1.0	0.8	0.1	3.4	6.9	2.6	9.5
Rest of W. Europe	3.2	1.7	0.9	0.4	6.5	12.8	6.5	19.3
Affected E. Europe	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3
Rest of E. Europe	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.8
Nordic countries	0.0	0.1	0.0	0.0	0.5	0.6	0.0	0.6
Total Europe	4.9	2.9	1.7	0.5	10.4	20.4	11.1	31.5
Rest of World	0.8	0.8	0.0	0.8	2.9	5.3	47.9	53.3
Total World	5.8	3.7	1.7	1.3	13.3	25.7	59.0	84.7

WORLD TRADE OF WOOD-BASED PANELS IN MILLION M3, YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	1.6	0.6	0.1	0.0	0.3	2.6	0.8	3.4
Rest of W. Europe	1.7	1.0	0.1	0.2	0.9	3.9	1.7	5.6
Affected E. Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Rest of E. Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nordic countries	0.0	0.1	0.0	0.0	0.2	0.3	0.0	0.4
Total Europe	3.3	1.7	0.2	0.2	1.4	6.9	2.8	9.7
Rest of World	0.1	0.2	0.0	0.1	0.2	0.5	7.7	8.2
Total World	3.4	1.9	0.3	0.3	1.5	7.4	10.5	18.0

WORLD TRADE OF WOOD PULP IN MILLION M. T., YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	0.2	0.5	0.1	0.0	1.8	2.5	1.8	4.4
Rest of W. Europe	0.4	0.8	0.1	0.0	2.1	3.4	1.9	5.3
Affected E. Europe	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.3
Rest of E. Europe	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.4
Nordic countries	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.2
Total Europe	0.6	1.3	0.2	0.0	4.3	6.4	4.2	10.6
Rest of World	0.0	0.1	0.0	0.0	1.2	1.3	7.1	8.4
Total World	0.6	1.5	0.2	0.0	5.4	7.7	11.3	19.0

WORLD TRADE OF PAPER AND PAPERBOARD IN MILLION M. T., YEAR 1984

TO	FROM							
	Affected Western Europe	Rest of Western Europe	Affected Eastern Europe	Rest of Eastern Europe	Nordic countries	Total Europe	Rest of World	Total World
Affected W. Europe	2.3	1.4	0.2	0.0	3.2	7.1	0.6	7.7
Rest of W. Europe	2.5	1.3	0.1	0.0	5.2	9.1	1.2	10.3
Affected E. Europe	0.0	0.1	0.1	0.0	0.0	0.2	0.2	0.4
Rest of E. Europe	0.1	0.0	0.1	0.0	0.0	0.2	0.1	0.3
Nordic countries	0.1	0.1	0.0	0.0	0.4	0.5	0.0	0.5
Total Europe	5.0	2.8	0.4	0.1	8.9	17.2	2.1	19.2
Rest of World	0.7	0.8	0.0	0.1	3.6	5.2	14.0	19.2
Total World	5.7	3.6	0.4	0.2	12.4	22.4	16.1	38.4

Annex

Comments by national correspondents on scenarios for the forest resource, with regard to pollution damage

Austria The effects of air pollution were not included in the calculation.

Denmark The correspondent was "not afraid of 'forest death'", (although some reduction in increment and fellings due to this cause was included in the forecasts).

France "The effects of pollution or insect attacks, as well as those of storms, remain negligible for the moment, while fires only concern those stands generally with very low wood production."

Hungary "Air pollution, which is affecting the region more and more and has the effect of lowering increment, as well as considerable damage by game ... (is) having a negative impact on the development of growing stock. The increase in harvesting will be limited or influenced by, amongst other things, the increasing damage due to air pollution and to game damage."

Poland "The GAI (gross annual increment) in 1978 was less than in 1970 and also than in 1990. From 1976 to 1984 we experienced the nun moth infestation. Due to control measures the loss of timber was relatively small, because the trees regained their assimilation systems. But a strong decrease in increment occurred.

The lower forecast of increment is the result of negative impacts on forest, of which the most important is air pollution."

Sweden "We agree it would be valuable to make estimates of probable effects. So far, however, we have no knowledge of the size of damage and of the consequences of such damage. In my opinion, it will take several years before we can give some quantitative estimates of effects."

Switzerland "The effect of noxious emissions has led, over the last 10-15 years, to a diminution in growth rates in our forests. A study of stumps of 3800 samples confirms a sharp loss of increment in sick trees. We estimate that this loss in increment up to now is about 5-10% on average and we fear that the situation can only deteriorate further. (Moderate damage forecast: 10% drop in increment, with maximum effect between 1990 and 2000; serious damage forecast: 30% drop, with maximum effect between 2000 and 2010).

The damage to forests from air pollution has become a reality in Switzerland, so that the forecasts in Part A (of the forestry forecasts enquiry) follow the following senarios:

"low" : moderate damage
"high" : serious damage.

These forecasts can only be intuitive, because the assessment of damage is not yet complete and solid information is lacking."

<u>German Democratic Republic, Luxembourg</u> Forestry forecasts are secretariat estimates. For the lower forecast, it is assumed that there will be a gradual decline of NAI under the impact of air pollution and other causes of damage.

6.3 THE FUTURE WOOD SUPPLY IN EUROPE*

K. Kuusela
Forest Research Institute
SF-00170 Helsinki, FINLAND

ABSTRACT

The European Timber Trend Studies are a story of increasing forest resources. Although the removals are increasing, the fellings in 1980 were and their projections up to 2000 are about 20 percent smaller than the reported increment.

Density and age of the growing stock, as well as the harvestable mature stock, are continuously increasing.

Prophesies of trees dying in new and old forest damages have left minor, if any, traces in the production projections.

General institutional conditions do not favour effective and profitable production of timber. Recognizing the fact that current silvicultural regimes increase, at least partly, the damages, may lead to increasing harvest and supply of timber.

INTRODUCTION

The wide-ranging study of European forest resources and production-consumption trends published in three volumes by the organizations of United Nations in 1985 and 1986 is the base for current wood supply estimates. Although the information available is voluminous, the future of the European forestry is much less certain than during the past 40 years.

Growth in the consumption of products such as sawnwood and wood-based panels has decreased, and in the case of sawnwood almost stagnated, since 1980. Electronic and tele information has so far increased the print media, but how long will this last? The past interdependence between demographic and economic parameters and the consumption parameters, which have been the basis for projecting the future, may change, so changing the reliability of the projections. Economies importing forest products may increase their domestic production, or exporters may change their exports in ways which differ from the projection assumptions. Old and new forest damages may also unexpectedly disturb the market for forest products.

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

The country groups used in this review are the same as those in the reference studies:

Nordic Countries (NC): Finland, Norway, Sweden
EEC-countries (EEC) : Belgium, Denmark, France, Federal Republic of Germany, Ireland, Italy, Luxemburg, Netherlands, United Kingdom
Central Europe (CE) : Austria, Switzerland
Southern Europe (SE) : Cyprus, Greece, Israel, Portugal, Spain, Turkey, Yugoslavia
Eastern Europe (EE) : Albania, Bulgaria, Czechoslovakia, Democratic Republic of Germany, Hungary, Poland, Romania.

PROJECTED PRODUCTION

The production of timber during the period 1950-1980, and the projected lower and higher levels are presented in Figures 1 and 2. Base production, the annual average of 1970-1980, in mill. m3 of under bark volume, equals 100 and other values are in proportion to it. The base values are presented in figures.

The projection for Europe is:

	1979-81	2000 lower	2000 higher	average
	mill. m3 per annum			
roundwood, total	350.5	390.8	438.1	414.5
- coniferous	228.7	256.4	289.2	272.8
- non-coniferous	121.8	134.4	148.9	141.7
sawlogs	160.0	183.7	200.4	192.1
- coniferous	123.7	141.1	154.3	147.7
- non-coniferous	36.3	42.6	46.1	44.4
smallwood	190.5	207.1	237.7	222.4
- coniferous	105.0	115.3	134.8	125.1
- non-coniferous	85.5	91.8	102.8	97.3

Growth rates in the projections are markedly greater than in the past (Fig. 1 and 2). There is an obvious aim in Europe to increase the production of non-coniferous and smallwood timber.

On the basis of the projected higher levels, one can conclude that the potential supply is greater than the realistic production possibilities in the future.

Country-group projections differ in some cases from the European totals:

In the Nordic Countries, the lower level projection production more or less stagnates. On the other hand, the higher levels are proportionally higher than in the European totals. Apparently there are difficulties in achieving the silvicultural potential in production.

FIG. 1. DEVELOPMENT AND PROJECTION OF ROUNDWOOD REMOVALS

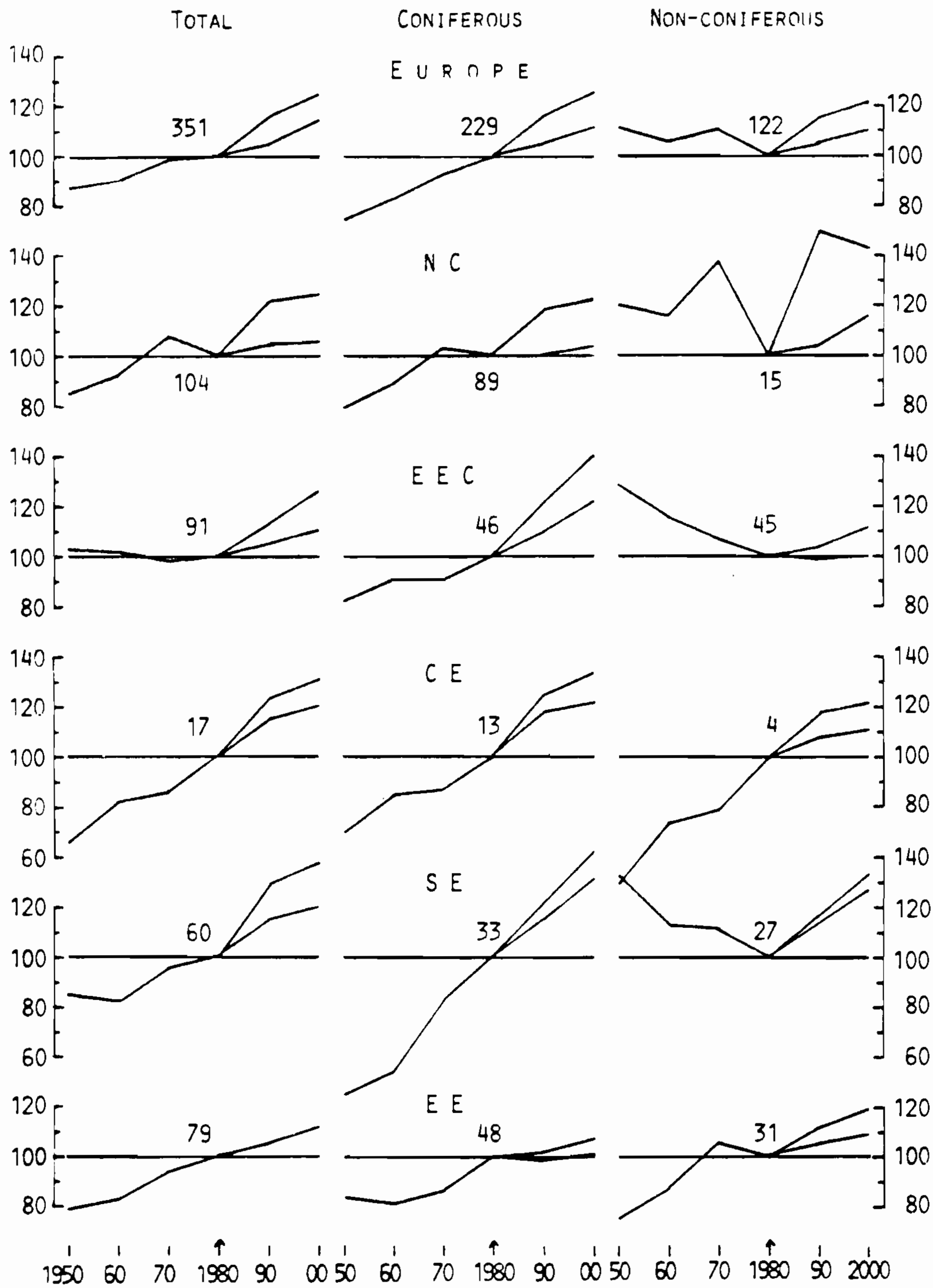


FIG. 2. DEVELOPMENT AND PROJECTION OF SAWLOG AND SMALLWOOD REMOVALS

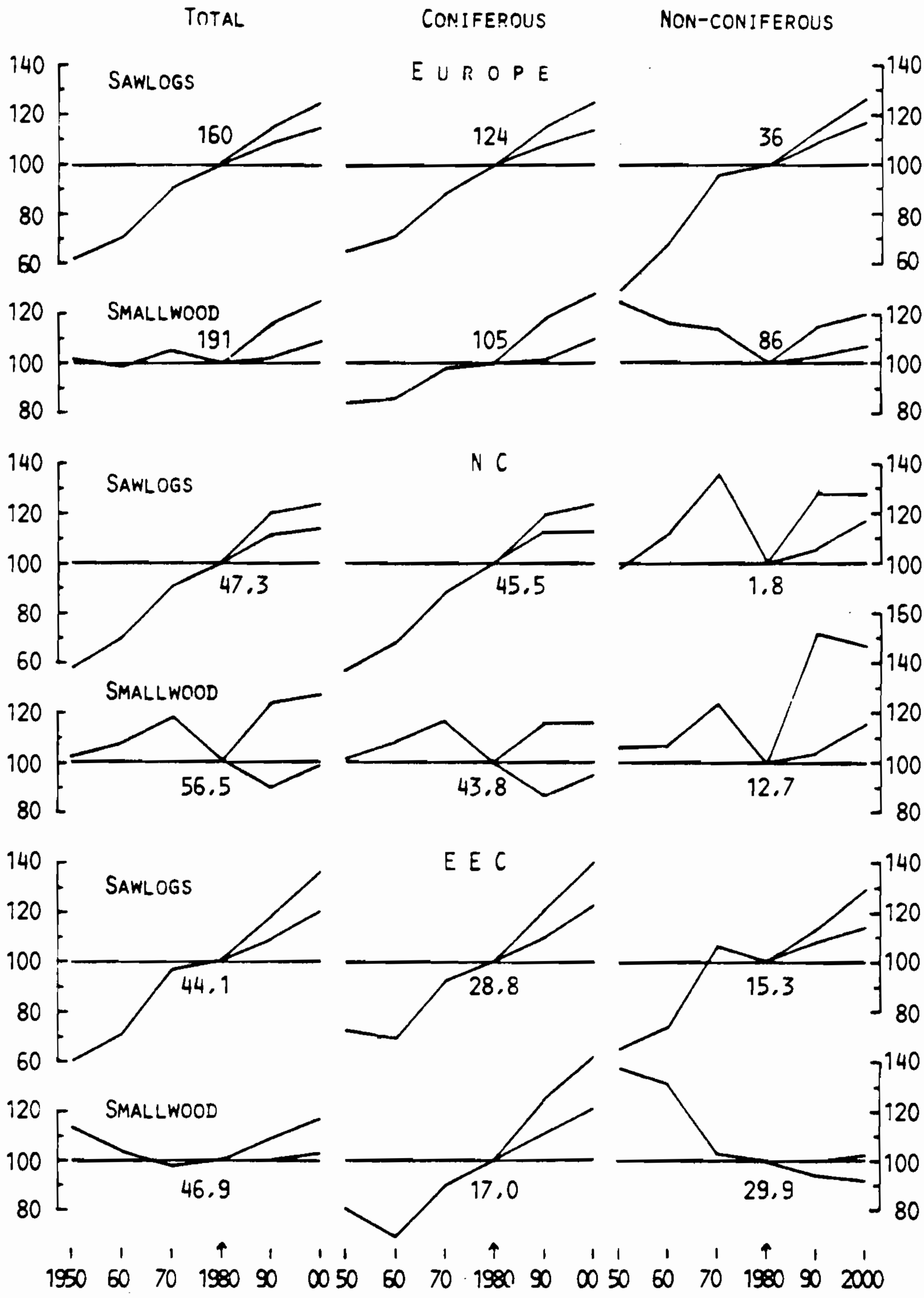
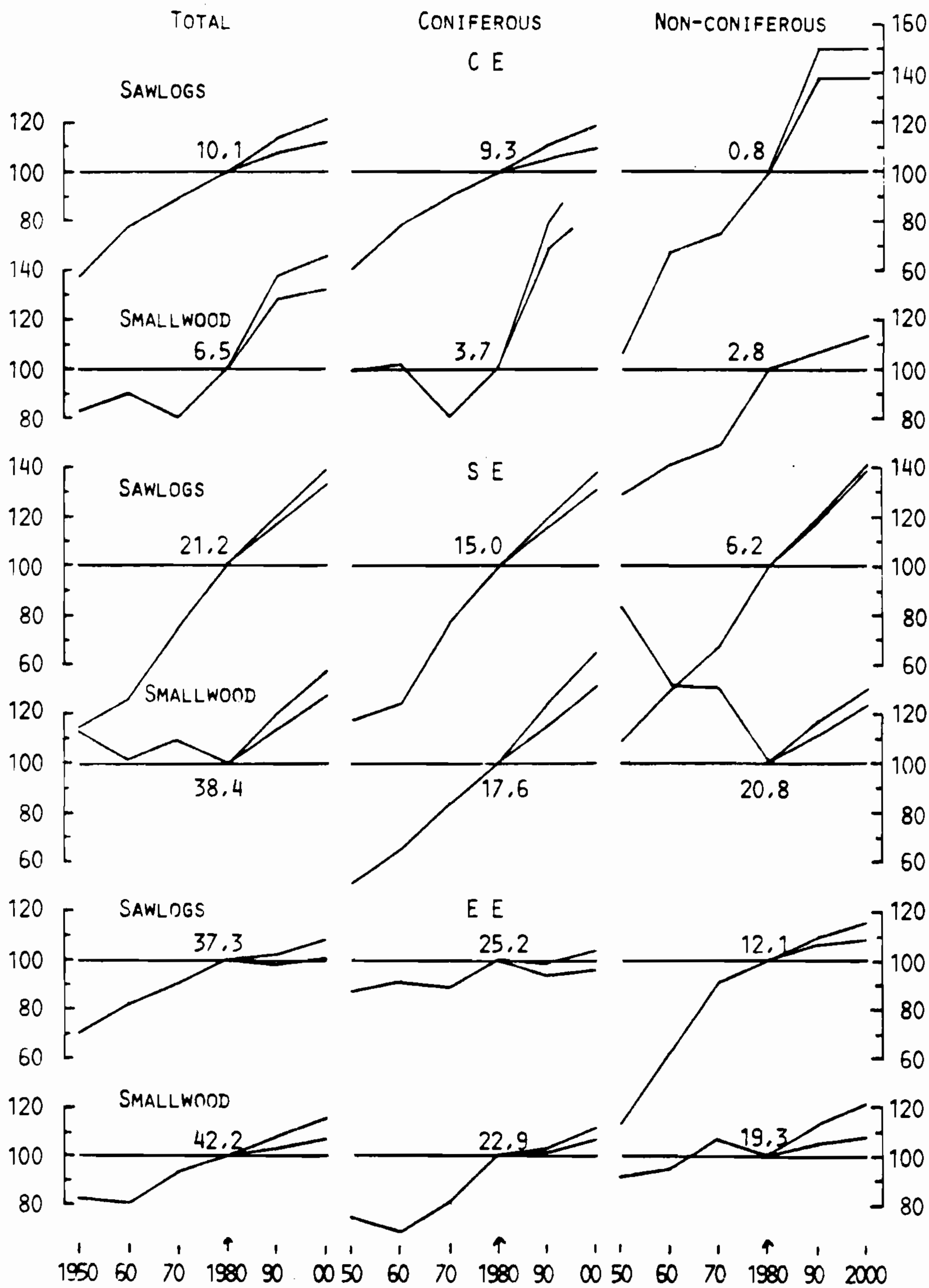


FIG. 2. CONT.


TOTAL
CONIFEROUS
NON-CONIFEROUS
C E
SAWLOGS
10,1
9,3
0,8
SMALLWOOD
6,5
3,7
2,8
S E
SAWLOGS
21,2
15,0
6,2
SMALLWOOD
38,4
17,6
20,8
E E
SAWLOGS
37,3
25,2
12,1
SMALLWOOD
42,2
22,9
19,3
1950 60 70 1980 90 00 50 60 70 1980 90 00 50 60 70 1980 90 2000

In EEC-countries the potential coniferous supply seems to be markedly greater than the past production.

Projections of Central and South Europe reveal an aim to considerably increase the production in these areas.

In the East European projection, especially in the case of coniferous timber, the past growth of production almost stagnates.

ASPECTS OF THE TIMBER SUPPLY SITUATION

Structural changes in requirements and removals

Forestry as a supplier of timber assortments has had to adjust to great structural changes of the timber requirements during the period 1950-1980:

	change of requirement	removals
	mill. m3 per annum	
saw- and veneerlogs	+ 62	+ 63
round pulpwood	+ 90	+ 66
sub-total	+152	+129
pitprops	- 9	- 9
other industrial wood	- 6	- 5
fuelwood	- 69	- 68
sub-total	- 84	- 82
total roundwood	+ 68	+ 47
wood residues for pulp and wood-based panels	+ 40	

Use of wastepaper for paper and paperboard, 16 mill. ton in 1980, equals approximately 40 mill. m3 of pulpwood.

The difference between demand and removals has been covered by net imports.

It was observed earlier that the potential supply of non-coniferous and small wood timber is much greater than the actual removals. European forestry and forest industries have not been able to adapt fully to the situation where the consumption of fuel and other small-sized wood has decreased leaving large timber resources available for industrial use.

Great increases in the consumption of wood residues and wastepaper have decreased the demand for roundwood in proportion to the growth of the production of wood-based panels and paper and paperboard.

DEVELOPMENT OF FOREST RESOURCES

The principal parameters of the European forest resources have increased and are projected to increase:

	1950 to 2000	1980 to 2000
	increase percentage	
growing stock	45	14
- coniferous	46	15
net annual increment	46	11
- coniferous	51	13
removals	18	18
- coniferous	34	19

Removals were 351 mill. m3 in 1980, and are projected to be about 415 mill. m3 in the year 2000. Corresponding fellings (comparable with the net increment) are about 402 and 480 mill. m3. The reported net annual increment was 504 mill. m3 in 1980 and it is projected to be 553 mill. m3 in 2000. Fellings have been 20 percent and are projected to be about 13 percent smaller than the net increment.

In those countries where the first national forest inventory by sampling has been carried out, the resource estimates have increased markedly compared with the earlier estimates based on the compiled results of the management planning inventories. European forest resources are apparently greater than reported.

As a result of large afforestations made in the 19th and 20th centuries there are many tree stands requiring thinning and regeneration. Compared with the prescribed thinning and rotation regimes, over large areas the density of tree stands is too high and mature tree stands are becoming too old. In addition to the production forests dominated by coniferous trees there are fast growing poplar and eucalyptus forests with increasing cutting possibilities and poorly productive coppice and other broadleaved stands to be harvested and regenerated by production tree-species. In order to fully utilize the existing mature timber resources, to improve the growing stock and to maintain a good environment, the annual fellings should equal the current net increment. Fellings should be at least 580 mill. m3 and removals 506 mill. m3 instead of projected 551 and 415 mill. m3 in 2000.

FOREST DAMAGES ATTRIBUTED TO AIR-BORNE POLLUTANTS

According to the results of the forest damage inventories carried out during the past five years "the area of the damaged forests" in Europe is 6 to 8 mill. ha and "the area of dying and dead forests" is at least 200 000 ha. Estimates are based on the observed defoliation and discoloration of the leaves and needless. Damades are attributed to the air-borne pollutants.

The direct effect of fumes and the forest damages caused by pollution are indisputable. Also acid precipitation over large areas is harmful to the trees and to the forest ecosystem as a whole.

The method for extrapolating the single-tree observations to data concerning the area of damaged forests, however, is unscientific and highly misleading. In every healthy forest, however, there are single trees and small groups of trees which are loosing their vitality and dying. This is especially the case with dense and old tree stands.

Observations of tree damages should be scrutinized by multifactor analyses and within the framework of the tree-stand ecosystem. The role of the current actual thinning and rotation regimes in the damage stands should be giving much greater consideration.

In spite of the doomsday prophesies, the "new forest damages" have left only minor traces in the timber-production projections. In some countries the projected lower level is a possible course of events if forest damages decrease the increment of the growing stock. Projected net increments and removals indicate a firm belief in the increasing production potential of the forests.

On the other hand, the accumulated mature timber stock is a prey of many potential damages. Storms, snowbreaks, insects, fungii and pollutants can increase unexpectably the removals by millions of cubic metres above the planned harvest. Past experience imposes a readiness to manage such situations with a sudden increase in removals.

INSTITUTIONAL FRAMES

Side by side with the development of agrarian societies into industrial and post-industrial welfare societies, the commodity and timber function of the forests has become multifunctional, with protective, recreative, social and cultural components. The economic criteria of timber production such as net discounted revenue, net annual income and marginal rate of return have lost their importance.

Rationalization and mechanization of forest works have been neglected in many countries. Low profitability of timber production and zero interest on the capital tied to the heavy and old timber stock have become acceptable under the scapegoat of the multiple-use forest.

The producing principle has changed into a preserving principle which in its extreme mode picks dying trees away from the forest and tries to keep the tree stands as dense and as long-living as possible.

Even in those countries where forestry and forest industries are of great economic importance, public opinion is against the effective and profitable methods for producing timber.

As an inevitable result, mature timber crops accumulate in huge quantities. Tree stands become denser and the growing stock older. Harvesting less than the increment of the growing stock can not continue for ever without severe disturbances in both forestry and the timber markets. European forestry is undermined by a situation which may increase the removals around the end of this century irrespective of the aim of man as forest manager.

CONCLUSIONS

The growth rate of the projected production is greater than in the past. The higher level projections are obviously greater than the realistically possible production. Especially, the potential supply of non-coniferous and small-sized timber is particularly great.

Annual fuelwood requirements have decreased by 69 mill. m3 in the period 1950-1980. The bulk of this timber has been left to accumulate in the forest, because the harvesting costs are high and there has not been enough industrial capacity to use all of these resources.

Fellings in 1980 and their projections up to 2000 are about 20 percent smaller than the reported increment. The actual increment is obviously greater than the reported one.

Density and age of the growing stock, as well as the harvestable mature stock, have increased and are increasing.

The method for extrapolating the single-tree observations of forest damages attributed to the air-born pollutants is unscientific and highly misleading. Doomsday prophesies of dying forests have left minor if any traces in production projections. On the other hand, the old forest damages combined with new ones may unexpectably increase removals compared with the planned harvest.

General institutional conditions do not favour effective and profitable production of timber. In large areas, the silvicultural regimes are at least partly increasing the forest damages. Recognizing this must lead to the increase harvest and sypply of timber.

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6.4 FOREST RESOURCES OF THE WORLD AND THEIR FUTURE*

R. Persson
SAREC
S-105 25 Stockholm, SWEDEN

1. INTRODUCTION

Tables 1 & 2 give a few selected figures about forest resources in different regions. Most of the table (and this paper) is based on a report published in Swedish (Persson 1984). Information about the tropical forests is mainly derived from an FAO-study published in 1982 (FAO 1982). For other regions ECE/FAO reports and national sources have been used.

There are many gaps in our knowledge about the world's forests, especially in those tropical countries. This is due not only to inadequate inventories but also to difficulties in arriving at clear definitions.

In the tropics, closed forest should be characterized by such dense tree cover that grasses are shaded out. In open woodland (e.g. "savanna forests") on the other hand, grass is found on the ground. This means that the fire is of great importance in open woodland. Bush is vegetation types with woody elements 0.5-7 m in height covering more than 10% of the ground. In ECE/FAO reports (temperate countries) closed forest is said to have a crown-cover of more than 20%. Open woodland (e.g. open forests close to the tundra) has a crown-cover of 5-20%.

It is virtually impossible to achieve universally valid, completely logical and indisputable definitions of different categories of forest. In Table 1, "closed forest" denotes the undegraded vegetation-types which, in theory, can be used for industrial forestry.

This paper, of course, cannot possibly cover all aspects in detail. It highlights certain aspects thought to be of interest. Certain simplifications and categorical statements are unavoidable. Space will not permit any proofs. A complete reference list would take up all 10 pages.

2. TODAY'S FOREST RESOURCES

2.1 Areas

About 20% of the world's land area is covered with closed forest. Of this area about 40% is coniferous. The coniferous forests are mainly found in the USSR and North America (about 87% of the total). The broadleaved forests are to 70% found in developing countries.

The open woodlands cover about 10% of the land area of the world. An area of perhaps the same size is covered by different types of bush land. In the tropics over 400 million ha is covered by forest and woodland in bush fallow. In the statistics such areas are often (or ought to be) classified as agricultural land.

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

TABLE 1 World Forest Resources - Forest Land

Region	Closed forest Broadl. Mill ha	Con.	Total	Open woodland	Bush	Bush fallow
Industrial	422	1043	1471	432	.. d/	- e/
North America	(168) f/	301	469	215	..	-
Western Europe	43 a/	60 a/	109	18	..	-
Eastern Europe	14	15	29	1	..	-
USSR	147	645	792	128	..	-
Other b/	50	22	72	70	..	-
Developing	1301	90	1392	848	675	(406)
Africa	217	3	220	500	450	160
Latin America	669	29	698	250	150	170
Western Asia c/	6	4	10	13	9	..
South East Asia	277	28	306	27	35	74
China	97	25	122	15	30	..
Other	35	0.5	36	43	0.5	2
Total	1723	1133	2863	1280	..	..

a/ Information missing for certain temporarily clearcut areas; b/ Australia, New Zealand, Japan, South Africa, Israel; c/ Turkey to Afghanistan; d/ .. = Information not available; e/ - = Nil; f/ () = Crude estimate.

TABLE 2 World Forest Resources - Plantations and Volume

Region	Plantations Total Mill ha	Con.	Volume Closed forest Broadl. Billion m^3	Con.	Total	Open woodland
Industrial	(74.2)	D a/	35	112	147	..
North America	(15)	D	13.5	32	45	(13)
Western Europe	(17.7)	(15.8)	3.5	6.6	10.1	(0.3)
Eastern Europe	(13.3)	(8.9)	1.7	2.4	4	0
USSR	(16)	D	14.3	69.9	84.2	..
Other	12.2	11.4	2.2	1.7	3.9	0.2
Developing	49	(26)	185	11	196	(23)
Africa	2.8	1.1	45	0.1	45	11
Latin America	6.4	2.7	91	2	93	11
Western Asia	0.6	0.5	0.7	0.6	1.3	0.2
South East Asia	9.1	2.5	40	2.6	42.5	0.9
China	(30)	..	(4)	(5.5)	9.5	..
Other	0.1	0.1	4.5	0.1	4.6	0.1
Total	(123)	(90)	220	123	343	(40)

a/ D = Dominating.

Of the closed forest areas about 4% are covered by plantations. The information available for tropical countries are probably better than for industrial countries. In tropical countries the plantations are normally distinctly different from the natural forests. In industrial countries this is not always the case. There is widespread ignorance of the amount actually planted.

In tropical countries the annual planting rate seems to be over one million ha. For China, figures of over 4 million ha/year are often quoted. This, however, is the plan. For industrial countries the latest estimates (FAO 1985) indicate over 8 million ha/year (world total is given as 14.5 million ha/year).

As a rule, figures for annually planted areas are over-estimates, normally representing plans. Often the plans are not put into effect, and the plantations which materialize often fail. Natural regeneration is sometimes included in the planted area. A pessimistic analysis (Persson 1984) gave 8-9 million ha/year (figures from about 1980).

Trees planted or sown in homeyards are on the other hand often not included in officially planted areas. In many countries such tree-groups cover considerable areas.

2.2 Volume and increment

The total wood-volume in closed forests can very roughly be put at about 340 billion m^3 (120 m^3/ha). Of this about 36% is found in coniferous forest. In open woodland the volume may amount to about 40 billion m^3.

There is no point in giving any total increment figures for the world's forests. (Increment of what?) A lot of the "increment" in the tropics is, for example, in species not presently commercial. It takes also place partly in forests which will be cleared in coming decades. Plantations, on the other hand, could boost the "increment" considerably (in areas not having forests at present).

2.3 Production

For 1984 FAO statistics gives a production of over 3 billion m^3 of wood. More than half this production is said to be fuelwood and other householdwood. The developing countries produce 85% of the fuelwood. The statistics have many deficiencies, especially in the case of fuelwood.

2.4 Changes in forest area

The latest official national statistics seem to indicate an increase in the closed forest areas of developed countries. Question-marks concerning the statistics may make it safer to say that there are no important changes for the time being.

In tropical countries 7-8 million ha of natural closed forest is cleared each year (FAO 1982). This is not an exact figure. Both underestimates and overestimates can be found for individual countries. About half of the cleared area reverts to bush fallow for some time. It is doubtful if any of these areas will really go back to high-forest within the foreseeable future. In closed forest an area of over 4 million ha is also selectively cut each year. In open woodland FAO figures say that about 4 million ha is cleared (perhaps an underestimation). In bush fallow an area of 20-40 million ha may be cleared each year (assuming an average rotation period of 10-20 years).

Protectionist groups normally want to give still more alarming figures. It is often said, for example, that more than 20 million ha is destroyed (or "converted") each year. The term "conversion", though often used, can hardly be defined in a meaningful way. It should in theory take account of all influences from minimal to complete destruction (from 1 to 100%?), which is hardly possible or worth while.

The area used for selective cutting (4.3 million ha/year) is often added to the area cleared (to give "converted" area). This gives 11.8 million ha/year when using FAO figures, but it means that certain areas are considered as being destroyed twice (areas selectively logged are clear-cut). If the double counted areas are excluded, the so-called converted area comes to about 9.5 million ha. The question is, however, if it is an advantage to show these two very distinct categories in one group.

The figure 20 million ha do certainly contain a lot of clearing in bush fallow but it is doubtful if this was the intention. The figure is basically a result of multiplying global guesstimates (e.g. area cleared by each shifting cultivator).

The direct reasons for the deforestation of natural closed forests are indicated below (the indirect reasons may be different):

Clearing	for	shifting cultivation	45 %
"	"	permanent agriculture	10-20 "
"	"	grazing land	10-20 "
"	"	mining, roads, dams etc.	10-15 "
"	"	forestry (incl. plantations)	5-15 "
Fire			1-5 "

Thus about half of the deforestation is due to poverty (shifting cultivation) and about half to commercial activities. (FAO 1982 & Persson 1984)

From the information given here one ventures to conclude that of the wood felled in closed tropical forest, perhaps only 20-30% is used as wood. The rest is simply burnt or left in the forest.

2.5 Forest and man

There is more forest where there are fewer people. Most people live in regions where forest is scarce. In developing countries 75% of the population lives in countries which have less than 25 m^3/capita (includes wood in closed forest and better types of open woodland). Only 17% of the population have more than 50 m^3/capita. As a somewhat contradictory case, the more people there are in a rural area, the more scattered trees one normally finds in homeyards etc. In developed countries about 45% of the population live in countries with more than 50 m^3/capita. (Figures based on FAO statistics).

2.6 Trees outside forest land

When forestry and forest products are being discussed, reference is basically made to closed forest and occasionally to open woodlands. Some examples will prove that this has its limitations:

- In Kenya a study shows that 47% of the rural need for fuelwood is met from agricultural land (Openshaw 1982);
- In Sierra Leone there are officially 29% "forest and woodland" (4% closed forest). According to another type of classification over 65% of the land is covered by some form of tree or bush vegetation (Persson 1977);

- In Bangladesh farmers are reported to have "trees/forests" corresponding to an area of 10% of the so-called state-forests. This area contains 40% of the volume. These farm-forests supply 70% of all timber and 90% of all bamboo and fuelwood (Ohlsson 1984).

In tropical regions, most industrial wood comes from forest land. Most of the population, however, lives outside forest land. Quite logically, a large proportion of household wood comes from non-forest land. In most tropical regions, wood from non-forest land means more to the local population than wood from forest land. One ought perhaps to speak in terms of tree-resources, not forest resources. Increment in scattered tree resources may be different from increment in dense stands.

In many countries trees outside forest land are reported to be decreasing. We do not know how common this situation is.

3. THE FUTURE

3.1 Introduction

During this century foresters have stated that "the world's forests will become depleted". The world's population is continuously increasing and its forest areas decreasing. It may therefore seem logical that demand for wood will ultimately exceed production capacity.

Some confusion has been caused by fuelwood and industrial wood being lumped together. Industrial wood and fuelwood must normally be discussed separately. Yet it is often difficult to discuss the need for industrial wood without considering the demand for fuelwood. Sometimes there is competition between them. Ideally one should discuss the situation in each country (or part of country) separately.

We will now consider, very briefly, the possibility of increasing production and export in different regions. First, though, we will consider deforestation trends. How will they affect the future supply of wood?

3.2 Deforestation

Developed countries will hardly experience any drastic change in forest area. We will most likely see a continued increase in the productive capacity of the forests (if atmospheric pollution does not finally spell disaster).

In developing countries the forests are decreasing. There are certainly a lot of exaggerations and a lot of myths. But the fact seems to be that most trends are going in the wrong directions. An immense number of people in developing countries live in great poverty. Deforestation often aggravates their situation, reducing their chances of improving their lot. It is difficult to repair nature without first having repaired the conditions of the poor. It is fairly easy to prove that unless some trends change direction soon a number of developing countries will be in a continuous Ethiopian situation.

What are the possibilities of stopping or reducing deforestation in tropical countries within the foreseeable future? This question should really be raised for each country or part of a country. Deforestation is often very local-specific. Its main causes are discussed in 2.4.

It has been thought that shifting cultivation will cease when poverty is reduced. This is certainly true, but with the present pace of development it is likely that in many countries the forests will be gone before poverty ceases. Do we have time to wait for decreasing poverty as the solution to deforestation? Can we on the other hand expect "poverty deforestation" to cease as long as poverty remains the reality for innumerable people?

It should, however, be clearly stated that not all deforestation is due to poverty (as is often said). In Latin America, for example, reduction of subsidies for clearing forests for grazing land would quite naturally reduce deforestation. Land reforms would reduce the deforestation caused e.g. by squatters. Most of the deforestation now going on in Latin America could be reduced through political decisions. Political decisions cannot have the same impact in Asia, still less in Africa. There the typical poverty-deforestation is more common.

Where many of the commercial activities are concerned, there is unlikely to be any considerable reduction in deforestation. It is not very likely developing countries, for example, will (or rather can) stop clearing forests for production of cash-crops. The colonization schemes carried through are not always very wise or successful. Alternatives may exist, but for political reasons these may be difficult to accomplish. There is of course little prospect of developing countries being able to stop building dams, opening up mining areas etc.

Forestry is often blamed for more or less all deforestation. This is not true. Quite often forestry indirectly causes deforestation by making areas accessible. But no one can argue that developing countries should not be allowed to produce their own industrial wood. Exports are often described as very destructive. A complete ban on all kinds of "tropical wood exports" would, very theoretically, reduce the deforested areas by "only" 0.5-1 million ha. Such a step is unlikely.

In theory, reduced poverty, increased productivity in shifting cultivation, higher productivity/employment on existing agricultural land, better use of waste land, plantations etc. should reduce deforestation. The main method for reducing the deforestation, then, is basically to reduce the pressure on forest land. For what should the forest then be used? The problem as things now stand is that land without trees is often valued more highly than land with trees (at least after selective cutting). Can we expect large tracts of tropical forests to be left more or less idle?

Historically, forests have hardly ever been protected for environmental reasons. The land has been used in the way the people have found best or necessary. Forest protection became an issue when wood-shortage occurred. In certain developing countries this may now be the case concerning fuelwood-supplies (and perhaps watersheds) but rarely concerning vast tracts of lowland natural forests. The pressure for forest protection is coming from developed countries, NGO's and occasionally governments. Can we expect the developing countries to change the historical trend?

We cannot predict developments in developing countries. Poverty will, however, hardly diminish rapidly. Governments will hardly make forest conservation the top priority. In many parts of the world (e.g. West Africa, Central America) large parts of the remaining natural forests will be cleared. 25-50% of the remaining closed tropical forests will probably disappear before the situation at best is stabilized. No stabilization will take place until poverty is reduced and/or governments get stronger.

3.3 Demand for wood

Fuelwood: The fuelwood shortage is a problem in many developing countries. Rough FAO calculations indicate that about 2 billion people use fuelwood as their main source of energy. Of these, 1.4 billion experience a "shortage" of fuelwood. In the year 2000 it is estimated that 3 billion people will experience a fuelwood shortage. Yet another estimate states that demand in the year 2000 will be 3 billion m^3/year, but supply only about 2/3 of this volume. IBRD has in one report calculated that 2-2.5 million ha/year ought to be planted in order to cover fuelwood needs in the year 2000. (FAO 1981 & 1982).

It should be made clear that the figures given for consumption, demand, shortage etc are at best crude estimates. A fuelwood shortage is no doubt a fact but it is difficult to discuss at global level. Discussions can easily become too general. Questions related to fuelwood production/consumption are normally very local specific.

The global fuelwood shortage can hardly be planted away in a traditional manner. The task is simply too big. Production must also be local. Long-distance transport is hardly possible. People's participation in fuelwood production is a must. Farmers ought to produce fuelwood as naturally as they produce food.

If available, wood is burnt as the first alternative. It is, however, normally considered a "free" good. If it is not available other alternatives are used (e.g. dung, straw). Farmers often know how to grow trees. It is, however, often difficult to motivate the local people to grow trees for fuelwood. In cases where farmers grow trees they normally consider them too valuable to burn. The trees are sold as a cash crop.

Shortage of fuelwood certainly causes difficulties for the local population (primarily for women). The local population may, however, not always consider it as serious as the aid-bureaucrats do. Often they have so many problems that the shortage of fuelwood may not come at the top of the priority list.

When farmers use home-grown wood for fuel it is often a question of waste from "homeyards". It will probably be difficult to make a success of pure fuelwood plantations as long as free wood/fuel still exists. Agroforestry may be part of a solution. Not just for the production of fuelwood but because the combination of trees/bushes and agricultural crops may often be the best way to use the land. Improved land use of this kind can give more fuelwood as a waste product. More interest will also have to be shown in natural regeneration.

In towns a market exists for fuelwood. This demand is often the main cause of tree-destruction around towns. This can be solved by concentrating commercial fuelwood plantations around towns. Alternative energy sources will probably often prove to be the solution.

The problem of fuelwood production may be much more difficult to solve than aid organizations thought 10 years ago. Not because farmers are ignorant but because farmers do what is in their interest. If fuelwood production pays it will take place. In many cases fuelwood production does not pay. What is worse is that a large percentage of the rural population are landless and have no possibility of producing fuelwood for their own use or for sale. The fuelwood crisis will not just go away.

Industrial wood: Table 3 indicates very crudely the present (1984) balance between export and import in different regions (based on FAO figures). It also gives certain indications of possible changes.

Europe has long been a net importer of wood products. Both consumption and production are expected to increase. FAO/ECE (1986) indicates a "deficit" of 40-60 million m^3 in the year 2000.

In North America, Canada is a net exporter and the USA a net importer. In theory, production can grow considerably in both countries. There are reasons in favour of both increased and decreased exports from the region. As a working hypothesis one can assume that North American exports will by and large retain their present volume.

TABLE 3 Trade-flows and possible future changes in trade-flows.

Region	Trade flows a/ Mill m^3 WRME		Possible changes b/
Europe	- 37		-
North America	+ 68		0
USSR	+ 33		0
Japan	- 57		-
Oceania	+ 6		+
		Subregions	
Africa	+ 1	Developing wood short	-
Latin America	+ 1	Developing wood rich	
Asia/Pacific	- 8	-natural forests	0
		-plantations	+

a/ - = Net imports, + = net exports; b/ + = increase in existing surplus, - = increase in existing deficit, 0 = no important changes likely.

The USSR has enormous forest resources and in theory a large potential for increased production and export. The unutilized forest resources are to a great extent inaccessible. Partly for that reason, the USSR is unlikely to raise its exports of wood-products appreciably.

In spite of its large population, Japan has considerable forest resources, production from which is expected to rise in coming decades. Demand, however, is expected to grow still more. Imports may have to be increased.

Both New Zealand and Australia have expanded their plantations acreage. If this continues the region is likely to have an increased export surplus of wood.

In wood-short developing countries the supply of fuelwood will be the basic problem. Normally they will also have great difficulties in covering their need for industrial wood. The need for imports of wood products will increase. Economic development will finally decide how much can be imported.

Some wood-rich tropical countries with abundant resources of natural forests have since the fifties been important exporters of tropical wood. Just now South-East Asia is the most important region. Roundwood-exports totalled 2.6 million m^3 in 1950 and in 1980 38 million m^3 (of which 84% from South-East Asia). In addition, processed products corresponding to about 20 million m^3 WRME were exported. Will these trends continue?

There are some reasons in favour of increased exports:
- More tropical species can be used. Pulp, for example, can now be produced from mixed tropical hardwoods;
- The utilization of hardwood is increasing globally;
- Logging waste can be reduced;
- Many countries need to increase their export revenues.

But there are also factors arguing against an increased export:
- Remaining forests are more inaccessible;
- The forest-rich countries of South East Asia have exploited large areas and are cutting down on their exports of roundwood;
- Pressure from protectionist groups will result in more careful logging;
- The price of tropical wood is likely to increase, e.g. because of more careful exploitation;
- Domestic consumption will increase;
- The wood will go to domestic industry;
- Management of tropical forests is difficult. Sustained yield is hard to achieve.

As a group, tropical countries will hardly increase their exports of "tropical wood-products" from natural forests in coming years. A drastic reduction in the present level of exports is perhaps not very likely.

The "shortage" of wood in Europe, Japan and wood-short developing countries is likely to increase somewhat. It is unclear if North America, USSR and Oceania can supply the market with additional volumes. Fast growing plantations can, however, make good possible "shortage".

In theory the potential for increased production from fast-growing plantations in tropical and sub-tropical countries is enormous. The increment in certain plantations is incredible (60-70 m^3/ha/year in certain projects, 120 m^3/ha/year in certain plots). Land is in theory also available, 100 million ha with an annual increment of 20 m^3/ha would yield 2 billion m^3!

Some countries like Brazil, Chile (and Portugal) have established both plantations and industry. Others like Madagascar, Congo, Malawi and Zambia have established successful plantations but not succeeded in raising funds to establish the industry.

Plantations are certainly easier to establish than industries. Much of the debate about the potential of tropical plantations has been concerned with the possibilities of establishing export-mills. These possibilities are certainly limited.

Today, however, wood-chips are beginning to be exported from tropical plantations. Most developing countries oppose this, but in countries with mature plantations and no industry it may be the only alternative. Establishing plantations for wood-export is in fact now being discussed as a possible alternative.

The establishment of fast-growing plantations is not without its problems. Some specialists describe ecological and economic difficulties and risks. For instance, it is difficult to find really good land for plantations. In most cases only marginal land is available (e.g. abandoned agricultural land). Such soils can often be used successfully, but it is then more a question of intensive agriculture than traditional forestry. Mechanical soil preparation, fertilization and mechanical weeding are often essential.

The above considerations may make it difficult to establish successful plantations in very poor countries. The expansion will mostly take place in countries in the middle income group (e.g. Brazil, Malaysia, Chile). Then again, it can be difficult to establish village wood-lots on marginal land with bad soils, due to the impossibility of providing the necessary intensive management.

In the long run tropical plantations will become important but it is unclear how much they will mean in the coming 10-20 years. After all, large plantations take some time to establish. Some plantations and industries will, however, be established, due to political decisions. Not all actions will be based on economic calculations. Some failures will certainly also occur, which will make some governments hesitant to start large-scale industrial plantations.

Looking some decades ahead, the industrial wood that is needed will be produced. If trends are calculated for a 50-100 year period, the world will experience a shortage of a number of things if present trends continue. That type of static trend-study is not very meaningful.

3.4 Some Conclusions

The deforestation (of forest land) in tropical countries is not the main trigger of the fuelwood-crisis in developing countries. Forests are primarily cleared for agriculture. A serious fuelwood shortage can develop in agricultural areas.

Deforestation somewhat reduces the possibilities of producing industrial wood. Tropical wood, however, is a luxury which developed countries can do without. In all, 3-5% of the wood consumed in developed regions comes from the tropics. In developing countries an increasing share of industrial wood is coming from plantations.

In the case of industrial wood, people who are prepared to pay will get the wood they want. Plantations in the tropics can make up any deficit in the traditional producer regions. The importance of commercial plantations will gradually increase.

This may sound strange, as one can foresee an increasing shortage of fuelwood in developing countries. But in a sea of poverty there are islands which can develop plantations for export.

From the purely technical point of view it is also possible to produce adequate quantities of fuelwood in developing countries and, furthermore, to reduce the destructive deforestation now taking place. The problems this involves are economic and political.

These problems cannot be solved by traditional governmental intervention (investments or legislation). Local participation is necessary. The local population will only take actions which make sense to them. Fuelwood production must be worth the effort. Forest protection must also pay. Strong governments can of course push through a number of actions (especially when it comes to commercial undertakings). Most governments in developing countries, however, can be classified as soft.

It is doubtful or at least uncertain whether deforestation can be reduced and fuelwood produced sustainably in adequate quantities as long as poverty and "underdevelopment" remain widespread in developing countries. Anyone able to foresee developments in developing countries can also foresee the development of the forestry situation. "Tell me the situation of man and I will tell you the situation of the forests".

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6.5 FOREST DECLINE AND SATISFYING THE DEMAND FOR FOREST PRODUCTS IN EUROPE*

T. Bencze
Department of Forestry and Forest Industry
National Planning Office
H-1370 Budapest, HUNGARY

ABSTRACT

Forests and their products are inseparable from our everyday life. Wood is one of the most important raw materials in the world. The non-wood benefits of the forest, in particular environmental protection, play a more and more important role. The forest, the wood, cannot be replaced as regards its comprehensive functions. It's consumption areas can be modified at most.

The forests are endangered by the airborne pollution first of all in Europe. But the forested areas have been decreasing continually all over the world for other reasons as well. This is why the question arises, how can the demand for wood products and other service functions of the forests be satisfied in the future.

This question is very important from the European viewpoint as a wood importing continent, where forest decline attributed to air pollution is the most serious. The revelation of the reasons for forest decline represents the common ground where our interests coincide. Therefore, forces should be joined to stop and avert this forest decline and damages, not only in Europe, but all over the world.

* * * * * * *

Ladies and Gentlemen,

The manifold benefit and the triple function of forests are well-known for all of you. I am sure that many of you agree with my opinion according to which among the three functions of forests relating to the wood production, the environment protection and the recreational one, the environment protection plays a more and more important role which is easy to understand in our continually industrializing world. Taking

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these facts into consideration our increased anxiety raised by the considerable decline of forests does not appear to be unjustified. It follows from this that "our doctor" has to be taken care of, he is attacked by such an illness the cause of which is not known for us, so we are reduced only to conjectures.

However we should discover and find remedy against this illness, because if we are not able to get a good solution, we will suffer such consequences that are difficult to foresee. We, ourselves who are engaged in protecting forests, would suffer these consequences, as well, but first of all, those who make use of our work.

Therefore the title of our "workshop" is very appropriate: "The forest decline and reproduction". The title - according to my opinion rightly - suggests a certain optimism. In my judgement, as well, the main purpose of our discussion can not be other than to draw the attention to that - summarizing the experiences gained till now - why it is important to take measures as soon as possible for discovering and annuling the reasons of the forest damage and which are the circumstances to be taken into account during the discovery.

It is probable that the question "how" can be answered, actually, by no experts engaged in the forest protection. But they have to know, as well, why it is important to give the answer to this question as soon as possible. And that too, at which extent it is risky if the question is answered too late.

It would be reasonable to be conscious of the fact that the work aimed at discovering the reasons of the forest damage and their ceasing, is followed with a great and comprehensive attention. For obvious reasons.

Since forests and their products are inseparable from our every day's life, in the strict sense of the world. And this statement can be only said on some products and services.

The life - in the developed industrial countries, first of all - can not be imagined without wood or wood products. Wood is the building material of our houses and the raw material of our furniture, it is the basic material of paper, so I have mentioned only the most important possibilities of its utilization. In many developing countries, wood is considered as the only source of energy. But during the last years, its utilization for energetic purposes has increased in the developed countries, as well.

Our forest stands, yielding wood, protect our soils, contribute to the water-production and improve the climatic circumstances of our environment etc. By this way - however indirectly - they contribute to safe and successful performance of other similarly essential productive activities, primarily to that of the agriculture. On certain areas, the agricultural production can not be imagined without forests.

And I have not yet mentioned that the same forest stands provide opportunities for us to retire to rest and to refresh ourselves. And, in the respect of the human life, this opportunity is considered as an unappreciable treasure in our industrializing world where the stress-impacts become the more and more intolerable.

But let's return - after this short digression from the subject - on the tasks relating properly to wood production. We have to be conscious of the fact - occupying with the prevention of the forest damage and its ceasing - that wood is one of the most important raw materials in the world. As regards the utilized quantity there are only coal and crude petroleum which can be compared with it. Actually, the production (utilization) of these three raw materials exceeds 1 thousand million tons per year. In 1985 the coal production was 3,2 million tons and the production of roundwood exceeded 2,2 million tons.

And among the three raw materials, wood can only be reproduced!

I think it can be realized why I said at the beginning of my presentation that we have to be fully aware - all of us who are present at this workshop - of the dangers resulting from the neglect of the reasons of the forest damage and of the methods for ceasing them or of the necessity to find these reasons in time.

In my opinion the forest, the wood can not be replaced as regards its comprehensive functions, its consumption areas can be modified at most.

But we can develop this train of thoughts. In respect to the human life and subsistence - in universal dimensions and on a smaller scale, as well - it seems to be an essential condition to ensure the raw material- and power-supply.

Looking ahead - and such an approach does not seem to be unusual with regard to the long rotation period of the forests - the most reasonable utilization possibility of solar energy, considered so far as the only inexhaustible source of power, is ensured by forest vegetation. This source of energy is not only absorbed by forest vegetation and made utilizable for the mankind, but it is beneficial to the production of a new raw material which is suitable for structural purposes.

Therefore, the insurance, in the future, of our supply with raw material and energy, as well, would be considerably endangered by the decline of our forests. I think it would be reasonable to discover these potential dangers, as well. A similar attitude is necessary in order to make unambiguous the extent of the potential danger for the governments and the decision-making organs of some countries for the sake of ensuring the financial coverage of the appropriate measures to stop and eliminate the forest damage.

Our workshop is dealing with the forest damage attributed to air-pollution and changes of climate. I am of the opinion it would be reasonable to discuss the issues relating to forest damage and -loss more comprehensively. The preparatory materials of the conference and the study published not long ago and entitled "European timber trends and prospects to the year 2000 and beyond" by the FAO European Forestry Commission refer to this problem.

I want only to confirm these statements by the following data:

- In Europe the forest damage attributed to air pollution and changes of climate concerns actually an area of about 6 million hectares, but it grows to huge dimensions in some countries of Europe.

Simultaneously, the forest area of the world - taking into consideration the statistical data of the last 10 years - has decreased by 10 million hectares a year, on the average. Therefore, this decrease is approximately by 70 % more than that forest area which is actually affected by such forest damages in Europe.

- According to the above mentioned study of FAO, the surplus felling, attributed to the storm-damage, can actually play a more important role in "disruption" of the balanced market than the appearance of wood oversupply originating from the felling of damaged timber attributed to air pollution.
- The extent of the systematically appearing forest damage caused by forest fires or that caused by games exceed - in some countries - the extent of forest damage attributed to air pollution and so on.

I think that these damage-causing factors are not equivalent to the effects of forest damage attributed to environment pollution as regards their long-term influences and their dangerous nature, but they can not be excluded from our investigations on different market disturbing effects.

Moreover, they call attention to the fact that the efforts made in order to solve the disadvantageous effects, of the forest damage, produced on the market, are not new, especially under the actual extent of damage.

And this circumstance can be advantageous in the elimination of the "short-term" damaging effects, during the search of appropriate methods for solution.

I think it is a greater problem that the market disturbing effects caused by different factors can be summarized. And if this supposition comes true, we shall have to face much greater tasks than "the usual ones".

And these tasks can be tackled only in the case if we are prepared for them, in due time.

But in order to solve the problems arising on a longer run, it is not enough to take into account only the timber volume of the damaged areas known at present. Several pieces of information confirm that the forest decline already perceptible - which has grown to disquieting dimensions in Europe - has occured on the influence of deteriorating environment conditions of a longer period. And the gradual deterioration of the environment - without any visible damaging signs - has decreased, for an already longer period, the productivity of those forest stands which can be yet qualified as healthy ones.

In the 58th issue of the WORLDWATCH PAPER entitled "Air pollution, acid rain and future of forests", Postel Sandra - author of the study - writes that in California, in the mountains San Bernadino, in the stands of Pinus ponderosa - according to the investigations on growth rings - a 38 % decline of the annual radial-growth has come about in the 30 years between 1941-71 comparing with the period of 30 years from 1910 to 1940, in consequence of air pollution. The already mentioned examinations of FAO have already referred to this actually "invisible" phenomenon relating to the growth-decrease.

These circumstances refer to the fact that this picture on the damages, characteristic first of all for Europe, is a suddenly appearing pernicious consequence of deteriorating environment effects of a longer period. This involves - if this growth-decrease is widely spreaded - that the timber supply, owing to damages, can be reduced, later on, at a much greater extent as we have experienced till now.

Consequently, it would be justified to try to find the reasons of damages, furnishing a wider basis both in time and space. If - according to such comprehensive and well - concerted investigations - the deterioration in the productivity spreads over a greater and greater area and this appears, practically, as a consequence of deteriorating environment factors of a long period, then the methods for moderating and stopping the forest damages have to be found in full conformity of this purpose. It is quite possible that these problems can be solved by joining of forces not only of the whole continent, but by that of all the world.

From the point of view of Europe, a solution including the whole world would be extremely important. The reason of it, I think, is obvious for all of us. Since Europe is a wood-importing continent. And her wood-import - as regards its quantity and proportions - continues to increase. The import surplus of the continent, measured in roundwood equivalent, is actually about 15 %. However the above mentioned FAO-investigations demonstrate - in contrast to the previous forecasting - that the own timber-production of the continent can be considerably increased, and so do enlarge the utilization of wood residues and of waste paper and the import of this territory till the turn of century, moreover, they are expected to get larger and larger beyond this period.

It is necessary to take into account that circumstances to satisfy the demands for timber are not identical in all the countries of Europe. And just those European regions where the forest decline has grown to greatest dimensions, because of environment pollution, stand in need of more significant import than the average. It is a fact that a considerable proportion of this timber import can be ensured by other countries of the continent. But it is not indifferent that under which conditions and at what prices this import will be satisfied.

Consequently, the importing countries, in Europe, - and Hungary, as well, belongs to them - have to face, at a longer run, a lot of troubles. But in my opinion the troubles appearing, at a longer run, can not be solved without eliminating the short-distance problems.

By developing the methods of solving and the appropriate plans, it is necessary to take into consideration that wood is a profit flexible product as to the GDP. It follows that the consumption demands - at a longer run - are defined, primarily, by gross domestic product, measured in real value, of certain countries and continents. As a matter of course, the momentary price level of timber, as well, - in the given period of time - play an important role. Nevertheless, that is the relative devaluation or revaluation of wood or wood products which can modify the demands for wood. But demand depends, first of all, on shaping of the economic development level.

This circumstance should be especially kept in view in respect of the efforts aiming at the moderation of the disadvantageous market effects of the oversupply to be expected, at a short run, in consequence of forest damage and in respect of the methods of solving, as well.

According to a lot of pieces of information, it seems to be unambiguous that the forest decline in Europe, because of environment pollution, can have, in the first period, a wood-supply increasing effect, through which the wood price can be reduced. This is easy to understand, taking into account the endeavours to save the timber stocks still utilizable of the damaged areas. But as regards the later periods - in consequence of the previous forced overproduction - the reduction of possibilities of felling and subsequently a certain rise in prices and an increasing import-demand have to be taken into consideration.

But the realization at lower prices of damaged - but certainly inferior in value, i.e. depreciated timber-would put difficulties, from two points of view in way of the forest owners. On the one hand, because the forced felling of damaged timber is possible only under higher per unit costs. On the other hand, forestries - in order to moderate, if possible, the decline of possibilities for felling on a longer run - would be obliged to carry out reforestation, in much larger scales as till now.

Therefore, it would be reasonable to reduce the sale of timber "in surplus quantities" on the markets. On the one hand, for the sake of blunting the decline in the income situation of the forest owners and, on the other hand, in order to satisfy - under relatively more favourable conditions - the demands on wood-consumption, in later times.

Of course, such a solution possibility presents itself, as well, according to which the wood-consumption attributed to the forced surplus felling has to be ensured by means of different demand-growthing measures. This way of solution - according to my opinion - raises several problems, and it is not sure whether it is feasible or not.

The first trouble is that - as a result of the relative price inflexibility of wood products - the price reduction still acceptable by the forest owners would not have, supposingly, a genuine demand-growthing effect. (In the most European countries, the sylvicultural and wood working industrial sector representing the 10 % or rather less than 5 % of the national economy are not capable of influencing, efficiently, the remaining 90-95 % of it.)

But such a considerable reduction of timber prices - by means of which a more serious growth of demand would be, accidentally, to be expected - would not be tolerable for the forest owners. I think it can not be considered as reasonable - supposing a deliberate demand-growthing - to fell a surplus timber in a considerable quantity (felling of normal and damaged timber, all together) knowing that a sudden fall in timber-supply and an intensive import-demand could be, in a longer run, its consequence, in the whole Europe.

The smooth and easy arrangement of problems arising from the damages and the more sure satisfaction of the consumers' demands, in a longer run, can be furthered, the best of all, by such a solution which is capable of moderating the surplus demand, in the first period. But this intention can be carried out only by decreasing of felling of the healthy forest stands there, where it is not unbeneficial from biological point of view. This target can be realized according to my opinion only by government measures. Nevertheless, the solution can be made more safe and strengthened by shaping and widening the international co-operation in this spirit.

But taking into consideration the fact, that - in consequence of the decline in the productivity and other reasons - the forest damages can be considerably greater as the actual ones, in European and universal dimensions, as well; so I take it justified to be engaged, already at present, in those steps which are necessary to be taken in the given situation. (At the beginning of my lecture I have mentioned that the speedy reduction of the forest areas, in itself, can give the reason for this more comprehensive survey.)

It seems to be reasonable, already at present, that the countries where the dangers arising from the forest damage are not yet considerable or they have not arisen at all - and where the environment pollution as the main raison, probably, of the forest damage, can be still prevented - do take measures, making use of the experiences of the countries hit by damages, to hinder the reduction of forest areas and the forest damage.

It would be reasonable to call, in an increased degree, the attention of the competent international organizations to this circumstance. It is worth thinking over to what extent this problem represents the troubles of certain countries or in which measure it is justified to take it as a public concern crossing the frontiers of countries or accidentally those of continents. And it can be and has to be treated and solved accordingly.

I think that from our point of view, that is from the point of view of the Europe this problem can be considered as a public concern.

Ladies and Gentlemen,

In my lecture, I wanted to draw your attention at the more comprehensive interrelations concerning the possibilities to satisfy the demands on the forest products and services and the problems relating to the forest damages.

I am convinced that the demands, at a longer run, will be satisfied only in the case if the forest decline and damage are stopped and averted. But it can not be imagined without an international joining of forces.

I am sure of that, the revelation of the reasons of forest decline represents our common matter where our interests coincide and of that, as well, you agree with me in this respect.

Thank you for your kind attention!

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6.6 FOREST RESOURCES OF TWO COUNTRIES ON THE PACIFIC RIM – COMPARISON OF JAPAN AND NEW ZEALAND*

Y. Konohira
Faculty of Agriculture
Shinshu University
Ina, Nagano 396, JAPAN

1. INTRODUCTION

The objective of this paper is to give an overview of the present situation and future trends of forest resources and forest decline in two island countries on the Pacific rim, Japan and New Zealand. The comparison of the forests in these highly industrialized countries can contribute to the understanding of the problems of forest decline in the Pacific region related to air pollution. This paper suggests that in both countries which have enjoyed the benefits of forests for a long time, like many European countries did, these forests are not suffering from acid rain nor are they affected by air pollution and related problems. However forestry production is facing an economic and social crisis in these countries.

Although both countries have differences in natural conditions, the history of their forest development, and in their economic circumstance, they are sharing many common problems in forest management strategy and social/economic environment. First, the forests in both countries are largely domestic resources which have contributed to keeping a sound natural environment. New Zealand is about 2000 km from the Australian continent and Japan is 1000 km from the China-Siberian continent. This isolated location of these two countries has contributed to cut off the harmful effects of polluted air caused by other countries.

Secondly the industrialization in the last 20 years in both countries and the change of international climate of world trade have caused a depression of forestry production which results in the decline of forests in their quality and quantity. The plantations in both countries can be healthy only when they have been managed in a proper way, because the silvicultural regimes are established by intensive management. Poor management or improper care of the plantations results in them becoming unhealthy and poor as a resource. The damages of forests caused by poor management or lack of concern of the people can be called "forest decline by social-economic impacts".

2. NATURAL CONDITIONS

Japan and New Zealand are long island countries stretching from north to south on the Pacific Ocean between latitude 35-45 degrees in north and south, which locations bring them a mild oceanic climate with enough precipitation and relatively warm temparature. This geographic advantage ensures a sound environment from air pollution and other problems caused by

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industrialization as mentioned before.

In both countries the land was totally covered by forests before any development, that is, the outcome of the vegetation is forest. The terrain in Japan is generally very steep where natural forests as well as plantations are located. Although in New Zealand, natural forests are scattered in remote areas or in steep mountains, the plantations are located in gentle terrain. The fundamental data of forests in the two countries are shown in table-1.

TABLE 1 Forest area

	Japan	New Zealand
National area	37,772(100%)	26,848(100%)
Forest area	25,277(67%)	7,200(27%)
Natural forest	15,166(60%)	6,200(86%)
Plantation	10,111(40%)	1,000(14%)
Total	25,277(100%)	7,200(100%)

(1000 ha)

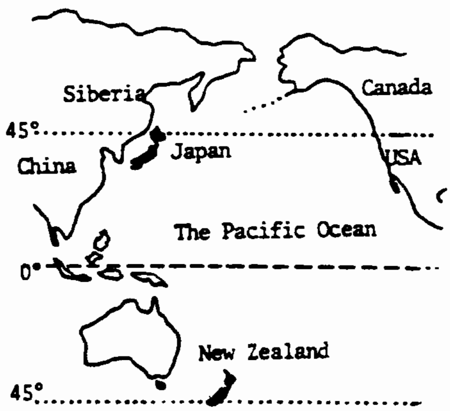

FIGURE 1 Japan and New Zealand

3. HISTORY OF FOREST DEVELOPMENT

The land in New Zealand was totally covered by the native forests before the Maori people came around the 10th century and then the forests areas declined slowly. In the middle of the 19 century when Europeans came, the forests covered about 75% of the total land. The Europeans cut the native forests and burned the bush on a large scale and in a more organized way to establish the grazing farms. Only 100 years after the European's immigration, forest areas declined from 75% to 25% of the land which caused serious problems like landslides, soil erosion, floods and a shortage of timber resources.

They then recognized the necessity of proper management of forest resources. First preservation of native forests and second, the establishment of new plantations. Planting booms occured twice between 1920 to 1930 after World War I and secondly between the 1960s and 1970s. These plantations of radiata pine which grow very fast with 25-30 m^3 annual increment per hectare and 30 years short rotation were established, so that today they can supply almost all the timber needed in this country. Native forests today are all preserved for environment functions.

In Japan the forests cover 67% of the total land as shown in table-1. This percentage has not changed for a long time and will not change in the future. Some sections of forests located in flat areas or close to urban areas are being changed to farming or residential areas, however it is certain that of this percentage of forest land in Japan will continue in the future. This stability of forest areas in Japan is based on the steepness of the terrain of the country. That is, the flat areas proper for rice field or crop farming had been already developed before the 19 century, the remaining forest areas are too steep to be changed to any other usages.

Forest management in Japan has a long history of around three hundred years. The first plantations had been developed in the middle of the 19 century and large scale harvesting and planting occured in 1920s. Large planting booms occured again after World War II in the 1960s. As a result the plantations cover about 40% of the total forest area and most of the remaining natural forests are unmanaged or preserved for water control and land protection. The growth of plantation is shown in figure-2.

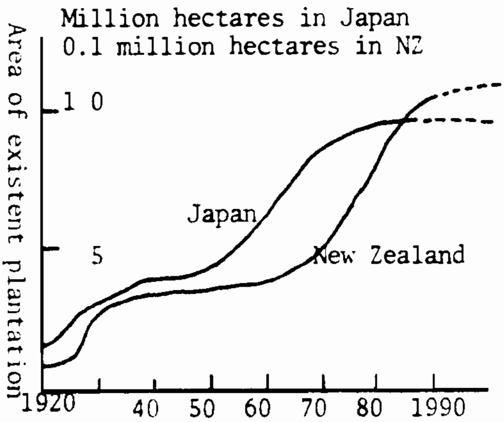

FIGURE 2 Growth of plantations

4. FOREST RESOURCES AND MANAGEMENT

The forest today is the result of management in the past, and the forest situation in the future can be decided by management today. To understand the present resources it is essential to examine the problems today and in the future. Fundamental statistics of forest resources and management in Japan and in New Zealand are shown below.

TABLE 2 Tree species of plantations

Japan		New Zealand	
Cedar	47%	Radiata pine	88%
Cypress	22%	Douglas fir	5%
Pine	11%	Other conifers	5%
Larch	11%	Eucalyptus	1%
Spruce and Fir	9%	Other broad-leaved tree	1%
Total	100%	Total	100%

In Japan the highest quality of timber has been supplied by natural forest, however the plantations are becoming the main sources of timber production today. Natural forests are emphasized to preserve watershed, erosion control, wildlife and recreational uses. The plantations cover

40% of total forest area where cedar and cypress are the common species. The ownership is roughly classified into three categories; national forest, other public forest and private forest. The percentage belonging to timber companies is very small. An irregular age distribution of plantations by the planting boom in the past has caused difficulty for sustainable harvest plans. The characteristics of silvicultural regimes are intensive management based on high density control of the stands.

TABLE 3 Ownership of forest

Japan		New Zealand	
National forest	32%	National forest	54%
Other public	10%	Private companies	35%
Private individuals	58%	Private individuals	7%
		Others	4%
Total	100%	Total	100%

In New Zealand, natural or indigenous forests cover around 23% of the total land. All are preserved for watershed, erosion control and other environmental functions. The plantation is typical monoculture, that is, Pinus Radiata occupies 88% of the plantations and Douglas fir, larch and eucalyptus are minor species. Great efforts for radiata study have been made including genetic improvement, silviculture regimes and conversion of timber products. Then the radiata was changed from a weed to a superior tree for forestry because it has the ability to grow fast, produce high quality timber and be resistant to the outside conditions. Radiata plantations planted after the 1960s, which are called "new crop" can provide higher quality and large amounts of timber in the near future. The silvicultural regimes are very intensive with three times the amount of pruning and thinning as shown in figure-4.

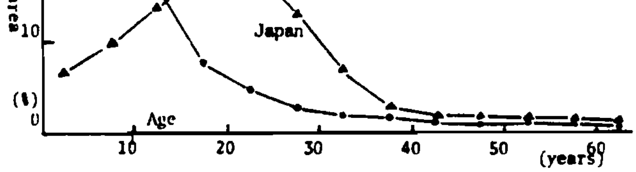

FIGURE 3 Age distribution of plantations

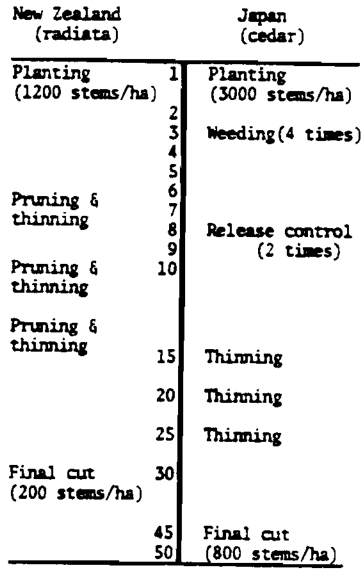

FIGURE 4 Silvicultural regimes

5. SOCIAL AND ECONOMIC CIRCUMSTANCES

In Japan productivity in forestry including silviculture, logging and processing operations has been improved, however it is now far behind other industrial sectors. This low productivity and resulting low profitability of forestry was not disclosed when the demand for domestic timber was strong in the 1960s-1970s. A dramatic increase of timber imports from the USA, Canada, the USSR, and low demand for timber products have disclosed the unbalance between cost and price as shown in figure-5.

The first problem is shortage of the labour force which occured because of the moving of the young generation from forestry/agricultural areas to cities, which made it difficult to carry out the scheduled silvicultural operations; weed control, release control and thinning. Many plantations aged around ten to twenty years are becoming too high in density, which mean they are becoming weak against wind, snow and disease. Figure-6 shows the age distribution of the forest workers in Japan, which suggests the forest workers will not be available in the 1990s unless younger workers return to the rural areas which is a hopeless expectation.

Secondly, almost all small private forest owners have lost their interest in the management, subsequently their forests are left unmanaged. On the other hand, the national forests, one of the biggest timber companies in the world, is facing financial crisis with huge debt.

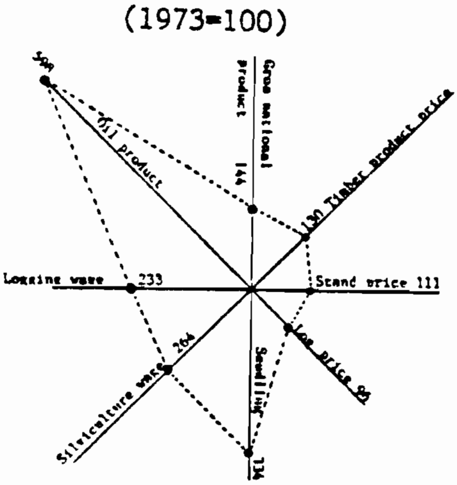

Figure 5 Price and cost trend in Japan (1983)

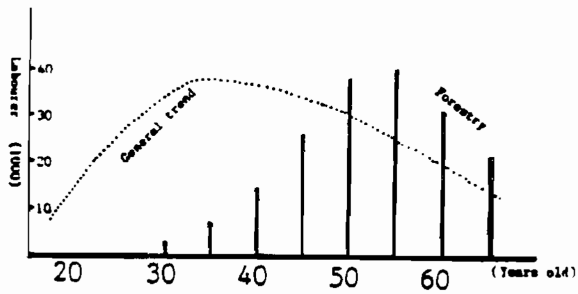

FIGURE 6 Labourforce by age classes in Japan

In New Zealand radiata forestry is profitable and attractive investment for big companies and state forests, and it provides job opportunities for rural people. Studies on logging, silviculture and processings system as well as more fundamental research like soil, genetic improvement, fertilizing under the coorporation of private sectors, national research institute and the university, have been contributing to improve the productivity of forestry. These organized research and communication systems in the forestry sector support forestry as a prosperous and most important industry in New Zealand. However, the international environment of the timber market is becoming severe and more competitive. On the Pacific rim the USA, Canada, Chile and the USSR are exporting large amounts of timber products and are also developing new markets. These international market circumstances do not allow for an optimistic forecast of timber exports from New Zealand. If the international timber price became lower than the production cost, forestry in New Zealand would be seriously damaged, which would result in the decline of radiata plantations in their quality and quantity.

6. FORECAST OF TIMBER PRODUCTION AND PROBLEMS

Timber production can be forecast from two aspects. First is the aspect of the resource availability which is calculated by the volume of the stands reaching maturity each time. Secondly the harvest can be strongly affected by the market demand including the international climate. The figure-7 is a rough trend of sawn timber production based on the resource availability and on market situations respectively in both countries.

In private sectors in Japan, the plantations have been established based on the expectation that stands they plant can be a source of income for the next generation, and they don't necessarily think of the planting as an economic investment. The low demand and low price in the timber market today and labour shortage have caused less interest of the owners in plantation management which results in prolonging the cutting age of the stands; that is, the owners are discouraged to cut and replant the stands because of the low profitability as shown in the figure-5. Around 50% of plantations planted after the World War II will be subject to thinning in the next two decades 1980-2000. However these thinning operations are being carried out only in limited areas. By rough estimation, one-third of the plantations which urgently require thinning are being carried out, and the rest of the young stands are gradually becoming denser than the intended silvicultural regimes. Regarding the high density stands, there are discussions as to whether they can continue to grow and be healthy, or will they be easily damaged by wind and snow. These unthinned plantations are becoming worse in quality and in quantity from a managerial point of view.

High logging costs and low timber prices have reduced the areas of stands which can be harvested with any profit. A forest road network model shown in figure-8 suggests the border line between profitable areas and not profitable ones. An average forest-road density in Japan is 6m/ha, which means the average distance between two paralleled roads is 1600m. Around 50% of the plantations located within 400m of the nearest road can be the subject of harvest and the rest of them are left in an unmanaged condition.

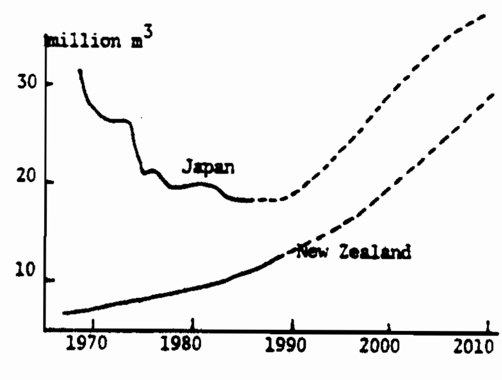

FIGURE 7 Forecast of sawn timber production

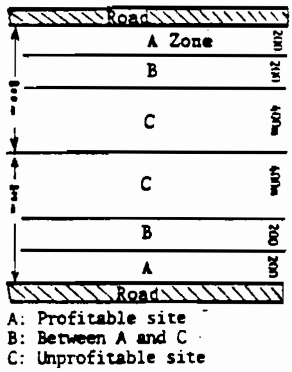

FIGURE 8 Forest road and management site

In New Zealand, the plantations planted in 1960s will become the source of a harvest boom in the 1990s. The timber production will increase to two times that of today by 1990 and to three times by 2010. These dramatic increases of timber flow can be successfully realized by the development of international markets for the radiata pines. The domestic market in New Zealand is active but small in scale, and considerable parts of this timber must be exported. The success of plantation management is deeply dependant on the international climate of the timber market. Failure to export will cause serious crisis of management in plantations. Even if the large amount of matured radiata pine plantation remains, they cannot be harvested and replanted, which will cause the unemployment of forestry labourers who will then move to other industries and give up forestry. If the investors who control the big timber companies lose their interest in forestry, the plantations would be left in an unmanaged condition in New Zealand. Old over-matured stands may cause many problems from the environmental aspect as well as managerial aspect.

7. CONCLUSION

In both countries Japan and New Zealand forests are not damaged nor affected by air pollutant. The advantages of geographical locality and mild climate of the countries contribute to prevent the forests decline which in other regions of the world occurs seriously.

However, the management of forests in both countries is and will be depressed, affected by the environment of the international timber market. Mismanagement and lack of proper care of plantations may cause social and economic conflict and the plantations themselves will become unhealthy forests. Many people in Japan have lost their interest in forestry today. On the contrary people in New Zealand have become interested in forestry and they expect that the most productive forestry can be realized by radiata plantations with intensive management. However it seems difficult to continue profitable management in the future even in New Zealand.

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6.7 IMPACTS OF AIR POLLUTION ON THE HUNGARIAN FORESTS*

R. Solymos
Ministry of Food and Agriculture
H-1055 Budapest, HUNGARY

Acid deposits

Among the harmful factors on environment, acid deposits are considered to be the most dangerous for the forests in Hungary. As it is known, in energy production, sulphur and nitrogen oxides get into the atmosphere where, with the rain water, they form acids. From the 1950s to our days, sulphur emission increased, reaching 2.5 times of the starting value. At present the per capita sulphur emission in Hungary amounts to about 70 kg, that is 2.5 times higher than in Austria. The emission of nitrogen-oxide depends proportionally on the number of inner combustion engines and motor cars. In this respect the situation in Hungary is more favourable, among other factors, because of the lower number of vehicles.

In atmospheric conditions the air pollutants emitted usually form oxides by reacting with free radicals of OH or H_2O, and later, they form acids. The air pollutants reach the forest trees by dry or wet deposition. The dry form is more characteristic near to the pollution sources, while the wet deposits are common in greater distances. The transmission of pollutants depends on air conditions and movements, i.e. on the meteorological conditions. As it is generally known, in Hungary extreme weather conditions prevail caused by the characteristics of Carpathian Basin on the one hand, and by the oceanic, continental and Mediterranian climatic influences on the other. The relatively extreme weather conditions appear with great deviations even within short distances. At the time being, in Hungary we have no accurate inventory about emissions, and even the pollution from other countries of the region is mainly determined by estimation. According to the recent prospects we have no chance to reduce the nitrogen oxide emission till the next century, in spite of the fact that more than a hundred different methods were developed to absorb sulphur from the smoke gases. But about one tenth of these methods can be utilized on a large scale basis. In determining the maximum load of acids, the following results have been gained.

As it is illustrated in Table 1, the amount of nitrogen and sulphur compounds are quite the same in dry and wet deposition. So, when speaking about acid rain, the dry deposit of acid trace substances should always be taken into consideration. In Hungary it must also be noticed that according to the experiences gained in the developed industrial countries, the nitrogen dioxide emission increases with the development of transports.

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Table 1: The qualities of air and rain on a national basis /mean values/

Mean value for the country	Sulphur		Nitrogen			Sulphur	Nitrogen
	SO_2	sulphate aerosol	NO	nitrate aerosol	nitrous acid vapour	sulphate	nitrate
Concentration kg/m3	6.2	2.2	2.1	0.47	0.47	-	-
Acid deposition g/m2/year	1.57	0.081	0.40	0.015	0.29	-	-
Wet deposition g/m2/year	-	-	-	-	-	0.75	0.40

The nitrogen monoxides emitted by the inner combustion engines are oxidated by the atmospheric ozone /O_3/ and the hydrogen peroxide /HO_2/ radical into nitrogen dioxide /NO_2/, while a part of them is oxidized by the atmospheric hydroxile radical /OH/ into nitric acid /HNO_3/. The atmospheric sulphate is formed by the oxidation of sulphur dioxide of predominantly anthropogen origin. This oxidation is homogeneous when it has its origin from photochemical gas reaction and following thermical reaction, but it is heterogeneous when the whole process runs in small fog or cloud particles or on the surface of elementar carbon particles. During the last 25 years the sulphur emission in Budapest has been reduced to 1/3 of the original value, while the sulphur dioxide concentration decreased to 1/6 of the starting level. The maximum concentration values occur around the main sources in the Central-European region. During the last three decades, the sulphur emission increased to 2.7 times of the original value, while the sulphate concentration in the rainwater became 1.4 times higher than that of the origin.

According to the measurements carried out in Hungary the average pH value of the rainwater amounts to about 4.7. This is due to sulphur and nitrogen compounds in the rate 3:1. Their rate in the dry deposition is 3:2. The dry acid deposition is responsible for 60% of the damages, while the share of the wet form represents about 40%.

Direct and indirect effects of the acid deposit

Air pollution affects the living creatures, including forests, in a direct and an indirect way. In this respect, research is extended even in Hungary. In the course of the direct influence the SO_2 and NO_x molecules reach the interior of the living cells and through chemical transformations of toxic nature they disturb the cell functions. During this process, auto-oxidation produces free radical reactions. At first the indirect effect causes harmful changes in water and soil threatening the plants. Particularly the later one needs careful and complex analysis, mainly in its ecological aspects.

According to the investigations performed in Hungary the conifers are more sensitive to SO_2 than the broadleaved trees. The most sensitive species are Norway spruce, fir, European larch as well as beech, hornbeam and lime-tree. The indirect impact provokes mainly disturbances in the nutrition of trees, but this is noticed usually later. For revealing its presence, the effective biotic and abiotic ecological factors should be discovered. The least problem is caused by the water with relatively high salt concentration. Due to the presence of carbonate and hydro-carbonate, Hungarian waters are not tending to become acid to such an extent as in the Scandinavian region. The conditions of soil, on the other hand, may be serious, because of the sulphur and nitrogen-oxide deposition from the air. Recently, the forest soils in Hungary are tending to be more and more acid, which is indicated by the disappearence of mykorrhiza mushrooms. The developed symbiotic forms of co-existence are weakened or moderated, while the vitality of trees decreases, or the trees completely perish.

Environment and the health conditions of forests

Among the main components of the natural environment of mankind, forests have a vital importance. At the same time several fields of economy are not able to exist without timber as a raw material. Either the protection of the environment or the importance in the economy is considered, the health condition of the forests must be maintained on a favourable level in order to fulfil the requirements raised and increased by the human society. The quality of human life as well as the conditions of human health depend on the health status of forests. That is why the highest priority should be attributed to the tasks of maintaining healthy forests, preventing pests and putting an end to injuries. Considering that trees are more decades, sometimes more hundred years old, the dangerous situations must be on the basis of long term foresights immediately detected and eliminated. The cause of damages must be settled; and the authors of the damages must assume responsibility for the restitution.

Recently, as the factors of environment deteriorated, the health condition and the resistance of forests decreased. Various reasons have been studied till the following conclusion: first of all, the ecological considerations must be revealed and the potential sources of dangers identified, with special attention to water, air and soil pollution. The solution of the presumable problems should not affect production development in forestry, and the answers to the technical challenges should be consistent with environment protection. The forest ecosystem is affected by various impacts. When the health of trees is endangered, the combined effect of these impacts, must be assessed and counterbalanced.

In the ecological system, the forest trees take their nutrients from the soil, meanwhile cooperating with various organisms living in the soil and connecting with water; the trunks and crowns are situated in the air, where the leaves and needles are directly exposed to air pollution and acid deposits. Foresters had called for public attention in that respect a century ago. The magnitude of the problem reached, however the level catching attention only in the recent decade. Considering the complexity of the topics, prior to discussing the damages due to acid deposits, in order to get a better overall picture about the situation, the status of the forests will be described in a more detailed way.

Forest as ecosystem and anthropogen impacts

The forest ecosystem is one of the most complex environmental systems. The rich variety of its biotic and abiotic components creates such a complex, which - as a result of the great self-controlling ability - can be generally characterized by stability. When the hierarchic system of the components is disturbed by effects from the environment that are large enough and overrun the self-controlling and counterbalancing ability of the forest ecosystem, this can lead to serious damages. They can raise great difficulties in the fulfilment of the social requirements by forest management.

Forest is a component of the biosphere, a main source of raw material production, an integral part of the national wealth, supporter and composer of the environment, contributing to the effective recreation of men tired in labour. Its services and productivity, however, have an upper limit: the ecologic potential. Society continuously needs the material and immaterial products of the forest, that is the maintenance of continuity is a priority task of the forest managers. The forests must be managed and treated, and this increases anthropogen impacts. The human interaction should be carried out to reach the production goals, in full harmony with the requirements of the nature.

One of the groups of human interactions is sylviculture which is mostly favourable for the forests. The second group is not goal-determined, but rather a secondary intervention, when a primary, mainly industrially motivated operation has some by-effect on the forest. One of them is the conversion of afforested areas into other land uses. As a result of this, the afforested area of the world decreases.

The secondary interactions include air pollution, and further harmful effects on environment. The most unfavourable effect that may be considered as indirect human interaction is caused by such agents as sulphur dioxide, nitrogen oxide, soot, dust and other smoke gases, as well as their compounds formed by reacting with the moisture of the atmosphere. In Europe, acid rains and their deposits are the most dangerous factors on historical monuments, natural values and forests.

Investigating all unfavourable environmental effects from an ecological aspect, it is quite clear that the abiotic factors inducing damages in chain structure encouraged the appearance in mass of biotic destructors. The formerly healthy trees were attacked with a sorrowful success by insects and fungus diseases. The dead trees have a reduced value, and in addition, they serve as feed for wood-destroying mushrooms.

After these considerations, the facts characterizing the health condition of forests in Hungary will be presented in a more detailed way. On the basis of a comprehensive evaluation, at first the main goals and results of the Hungarian forest management will be briefly discussed, then - on the ground of the introduction - the damages surveyed and the measures taken and envisaged will follow.

Area and composition of the forests in Hungary; the forest management

After World War I, the forests in Hungary decreased from the previous 7.4 million hectares to 1.2 million hectares. The share of the State owned forests represented about 5%. After the Second World War, 90% of the afforested area became State property, and a comprehensive program aimed at forest reconstruction, stand conversion and afforestation had been initiated. As a result, during the last four decades more than one million hectares of forest had been planted. The afforested area had also been increased by more than half million hectares. As a result of those efforts, at present, the forestry in Hungary manages 1.76 million hectares, including 1.5 million hectares covered by forests.

The site conditions in Hungary are favourable for the broadleaved tree species. The forests of natural type are composed by oak, Turkey oak, hornbeam and beech mainly. The rates of the different species are as follows: oak 23%, Turkey oak 11.9%, beech 6,7%, pseudoacacia 18.1%, poplars 10.5%, conifers 15.1%. The rate of the indigenous species amounts to about 50%. The whole situation seems to be favourable because the increased forest area exceeding half million hectares has been established at very poor sites /Great Plain, barelands around Veszprém, etc./ where the productivity is very low. It is worth to mention that the rate of conifer species in other countries is quite different: 53% in Europe, 76% in the Soviet Union, 70% in Czechoslovakia and 25% in Roumania. In spite of this, the main problem in timber supply is the shortage of conifers. The acid deposition in Europe, in addition, causes damages, first of all, in coniferous stands. It is worth to highlight that about half of the forests in Hungary are younger than 30 years. This is clear as more than one million hectares have been planted during the last four decades. It is obvious that the rate of the older stands is remarkably lower. The mortality of trees does not depend on the age of stands.

The larger forest area, the greater living stock and the increased growth rate enabled a greater felling. After the Liberation, the annual yield was around 3 million m3, and now, it amounts to 8 million m3, while at the end of the century it will reach about 9 million m3. The available cut, determining the ways and species of reproduction, has been envisaged in management plans valid for 10 years combining the needed sums and defining the individual stands /subcompartments/. The tree damages and the following forest mortality caused some problems and indicated some changes in that conceptual regulation.

Felling, timber supply and timber export are well defined and directly measurable indices of production results in forestry. It is well known, however, that forest supplies many other services for the benefit of the mankind. About 20% of the forests in Hungary contribute directly to environment protection, tourism and recreation. Of course, the rest of the forests serving the main goal of timber production has also some additional function to these services. About 25 million of people visit the forests in Hungary annually; there are park forests afforested nature conservation areas, and other special forests illustrating and proving that immaterial services are more and more prevailing in forestry. The need from the society as well as the public attention following the conditions and health status in the forests have increased. Only the healthy forests can protect the human environment and fulfil the requirements of the multiple use. The forests in Hungary produce an amount of oxygen enough for 30 millions of people.

The health condition of forests in Hungary and the injuries from the environment

When expecting the protection and improvement of our environment, mankind rely on forests. The harmful factors meanwhile reached our forests. During the last decades, as in the forests of other regions of the world, the Hungarian forests also suffered from light or severe diseases or mortality. These phenomena were not unusual and new.

Oak disaster and damages in coniferous stands

Recently a special situation developed in the oak/Quercus sessiliflora L./stands of the mountainous and hilly regions previously considered to be the most stable ones. The outstanding good individuals of this indigenous species suddenly started to dry and perish in groups. After detecting this, selective cuttings removed the dead trees, and an investigation of the cause of damage started. The investigation performed by scientific institutions and universities did not result in final findings, but the multilateral approach to the problem enabled two preliminary statements. According to the investigation of the wide range of ecological factors, the disaster was caused by acid deposition, by the unfavourable developments in the pH of the soil and in the concentration of heavy metals in the subterranean waters, by the drought, by the increasing occurence of insects and fungus diseases and by the termination of the connections between mykorrhiza mushrooms and the roots of the trees. These interactions of the primary and secondary Factors caused the mortality of the trees in a combined way. According to the other approach, the experiences concerning oak disaster were studied at previous occasions in foreign countries. Accepting the importance of several effective factors and their impacts, the "mushroom ceratocistis" is considered as decisive factor.

The damage in the oak stands did not come to its end, but seems to be lower. Sometimes, even the nurseries were affected.

About 10% of the forests in Hungary are affected by damages caused by several factors. The damage of the oak stands represents about 7.5%. There is a factor that is not easy to interprete: the disease attacked not the so-called culture forests, but the indigenous native forest stand types. The situation is the same in the natural spruce and fir stands in Austria and Bavaria, where these species are on their proper site. In Hungary, spruce stands were not attacked by this injury.

Plans for maintaining the health of forests and decreasing damages

Foresters are always keen to detect and react to damages in the forests caused by environmental factors. They want to decrease or stop the unfavourable damages even in the future. The measures applied and planned could be primarily concentrated to aspects depending on forestry matters. For controlling damages caused by harmful environmental immissions the means of the forestry are obviously insufficient. National and international cooperation is necessary on that field.

In forest management, for keeping the health condition of the forests on a favourable level, the following measures are planned:

The elements of natural forest management supporting the establishment and maintenance of a stable forest ecosystem will be reinforced. Considering the ecological basis, in the solution of the multiple tasks of forestry, the prevailing role of the biological factors the site impacts will be further emphasized.

A forest protection organization has been established in the circle of forest managers, surveyors and supervisors; it is responsible for the health status of forests. The responsible organs of the forest protection are the State forest supervisory offices.

The regular observation has been extended to the whole territory of the country, using a 4x4 km permanent network. Two permanent observatories are going to be constructed, where comprehensive studies will be carried out, in cooperation with the Central Institution of Atmosphere Institution.

Cooperating with the stations for plant protection and agrichemistry of the Ministry of Food and Agriculture, in addition to the primary tasks of preventing any damage, all necessary means will be placed at disposal.

The scientific work of forest protection will be developed as a priority task. The interdisciplinar connections will be broadened, further, special attention will be paid to all aspects of the health status of forests in all fields of forest science. The fulfilment of the hygienic needs in forests will be improved.

We are going to encourage a broad cooperation in the whole society for the forests. There was such an event last year: 1985 was the Year of Forests in Hungary as well.

The harmful environmental effects discussed, the acid depositions are general problems not only for our society, but even for the whole world. The good condition of the biosphere has to be improved and maintained in order to survive and ensure welfare for mankind. That is why the forester should turn to the society and attire the public attention to the health condition of forests. There is no human health without healthy forests. The only way to keep the natural environment on the required level is to stop the sources causing environmental damages.

According to an old chinese proverb, the forest grows slowly and perish in silence. Recently, this has a special actuality as the acid deposits damage our forests and after the silent death of the forests it will be late to cry over the spilt milk. The difficulties must be met in time, because as the last link in the chain of flora and fauna, men will follow. The preconditions must be formed in order to avoid the silent death of the slowly growing forests. They should rather serve mankind and make the world more beautiful and happy! The foresters strive for the realization of this ambition and cooperate with all those who want to serve that goal.

6.8 TRENDS OF MULTIPURPOSE MANAGEMENT AND UTILIZATION OF BEECH FORESTS IN BULGARIA*

M. Marinov
Forest Research Institute
Bulgarian Academy of Sciences
Sofia, BULGARIA

Forests in the People's Republic of Bulgaria are formed at a greatest extent, of beech ecosystems. These ecosystems play an unique environmental-forming role and they are a base for raw material for 38 per cent from the total timber production.

Aiming the further elaboration of the beech forests' problems, in the Central part of the Balkan Mountain, long-term investigations are carried out by the Forest Research Institute at the Bulgarian Academy of Sciences. On this base an attempt is made for establishing and analysing of some regional features, which determines the application of a new multiplicational approach to the further managing and utilization of the beech ecosystems; numerous approaches and questions of practical and theorethical nature are clarified and specified. It must be pointed out that the insatisfactory status of the beech forests, which are an object of utilization, dues mainly of the regional features of the beech ecosystems which because of their complicated and discreet character, are not well studied.

Not only in Bulgaria, but in other European countries, the scientific information about the beech forests is still unsufficient and it is not adapted for introducing in practice, for achieving of a positive sound social and ecological result. It substantiates the necessity of establishment of the main and the concomitant social functions of each beech ecosystem type and of the way for keeping of the ecological balance. The ecological and economical specific character of the beech ecosystems determines their special plase at the people's economy division into branches - as an rear not of the separate branches, but of the whole people's economy and society.

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Beech forests today have limited territorial distribution on about 550 000 ha or 20 per cent of the total forest area. The main part of the forests is high-stem - 350 000 ha, 100 000 ha are coppice forests and are provided for convertion into seed forests, and the another 100 000 ha are low-productive and are a subject of convertion. About a half of the mature wood mass is concentrated in the beech forest, which play a significant role in the economy of the country.

Economical significance of the beech forests is determined by the increasing consumption of beech wood. The annual timber production is about 2,5 mln cbm. Timber is processed in plywood, venner, boards, furniture parts, plates and cellulose,

Therefore, our beech forests are one of the basic sources of raw-material for the industry and for the building. But this function of the beech forests is not the only one. Every one of these typical mountainous forests which are distributed in the middle forest belt in an altitude of 600 up to 1700 m performs the exceptionally significant role for water accumulation, water flow regulation , keeping of soil fertility, recreation, resort and satisfaction of the growing aesthetical needs. It forces a limited combination of the forest exploitation with the preservation of the forest environment.

Particular specificity of the beech forests in Bulgaria is a result of the circumstance that a significant part of them are located in more inapproachable places, as compared with the oak and coniferous stands. Another circumstance is the technological lack of training 30 years ago in our forestry for wider use of beech wood and the exceptional biological stability of this vital and with a great regenerative potential tree species. These are the main reasons which determine the preservation of some beech formations in our mountains, while much of the oak and coniferous stands are devasted or turned into arable lands and extensive pastures.

In physical and geographical point of view the main beech forests are in the middle, western and eastern part of the subarea of the main mountain chain of the Balkan Mountain, which charactorizes with a mountainous and transitional continental climate and a temperate climatic influence on the river flow. As concerned to the hydrological factor more of the beech stands are included in the subarea with a significant or prevailing snow supply of the rivers and only a little part towards the subarea with rain water supply.

Beech forests on the northern slopes of the Balkan Mountain are divided into three groups according to the inclination: a) on level and sloping areas - from 2^{0} to 10^{0} inclination - 5,9 %; b) on inclined areas - from 11^{0} to 20^{0} - 25,2 % and c) on steep and very steep areas - 21^{0} to 45^{0} - 69 %, or the steep and very steep terrains (ravines) are prevailing.

This geographical characteristics of the beech forests gives a reason for making of the conclusion that their microclimate forming soil protective, water-providing, anti-erosional, etc., socio-ecological and productive functions are extremely great and unique.

On the first place it is remarkable the hydrological role of the mountainous beech forests, which by accumulation of the snow and delaying of its thawing gives a permanent water capacity of the springs and rivers. Besides the stand and the other forest vegetation, this role depends to a great extent from the forest soils' characteristics under the beech stands. The soil is not only a growth substratum and a source of nutrients and water for the trees and forest stands, but it is an integral part of the beech forest.

Soil-forming process in the beech forests, forming as a result brown forest soils, leads to establishing of such basic forest growth properties - physical, water-physical and chemical, which determine their relatively most favourable water-air regime and their increased biogenity. In this connection, it must be pointed the role of the litter in the beech stands.

Value indices which characterized these properties of the brown forest soil under the beech stand really confirm it favourable water-controlling and soil-protecting role. In this relation indicative are the soil nutrient contents, resp. humus content and its stock, porosity and structure of the soil which values correlate in a direct dependence with its role.

Thus, according to data given by the stationary "Balkan ts" in the middle Balkan Mountain, humus content in the brown forest soils under preserved beech stands and in dependence to the soil subtype and to the altitude, is average from 3 to 7 per cent, sometimes it is more, and the value of the humus stocks - average from 90-141 up to 207-272 t per ha (for the 100 cm soil layer). These data show that the soil is characterized by well expressed and relatively steady structure and it is in a good state (quantity of structural aggregates, bigger than 0,25 mm is over 35 per cent, as one of the conditions for determination is the bigger humus content).

This circumstance in one side and the relatively light texture of the brown forest beech soil, much often loamy sandy soil to light sandy-loamy one; they determine a good expressed aggregate soil porosity(in the limits from 50 to 60 per cent for the humus horizon), and hence the greater moisture retention capacity and better moisture permeability.

For the favourable water and thermic regime of brown forest soil under beech stands the quality and properties of the litter contribute. The soil is with a mean thickness 5 cm and more and a looseness of structure, a good porosity and filterability. This has confirmed by much available comparable data in the literature, according to which the annual organic fall from aboveground vegetation, forming litter in beech forests, amounts to 4 t per ha. While the organic fall in spruce and pine stands is 3,5 t and 2,0-3,0 t per ha,resp., depending on the stands' productivity.

The soil under beech stand represents a peculiar mushroom, hardly decreasing the surface water flow, hence the development of the erosion process. The moisture absorbed by the soil is filtered between the soil particles and even supply the underground water and springs.

It is proved by the numerous investigations that the beech forest with the created rich vegetative covering and litter is a certain filter for the bacteria and it betters the chemical and gustatory characteristics of the water. The belt along the rivers make shadows on the little rivers and springs and do not allow undesirable increasing of the water temperature. The fallen beech leaves do not effect negatively on the gustatory properties of the water. That is for the presence of beech vegetation along the water flows favours the keeping of the water clear and with good drinking properties.

Besides the expressed water-protective role of the beech forests, their mechanical protective role is well known: protection against avalanches, torrents and decrement the danger of landslips.

The beech biogeocoenoses are with the greatest purificational functions, from all of the stands. The great surface of the overground mass - leaves, branches, stems, leads to a deposition and detention of the air pollutants. The forest stands are arranged in rising sequence, according to the filterability, as follows: 1 ha spruce forest detents anually 32 t industrial dust, 1 ha Scots pine forest - 36 t and 1 ha beech forest - 68 t (according to R. Meldau, 1970). These data show that the beech forest is the best clarificator and regenerator of its environment.

It is well known that the European beech is one of the most stable tree species - resistant to fires and insect and fungi wreckers. It is the prefered species for planting in the regions with industrial pollution influence. The participation of the beech in the coniferous stands improves their resistance, and water-protective and timber productive properties.

Besides the ecological influences, it must be pointed the spatial and aesthetical role of the beech forests as an element of the Bulgarian mountainous landscape. Spacious pure and mixed beech stands on the slopes of the Balkan Mountain, Sredna Gora, the Rila Mountain, The Rhodopes, the Pirin Mountain, Osogovo Mountain, Vitosha, Ograzden, Belasitsa and Malashevska mountains, at an altitude of 500 up to 1700 m, are a healthy environment for man's recreation because of the clarified air by the leaves, decreased noise and strength of the wind. Their favourable influence on the climatic factors, soil, water regime, air quality and on all the living beings spreads out to the deforested areas. Hence, the increased significance of the beech forests for the environmental protection.

Environmental protection requires forest complex structures with the most favourable properties, with greatest possibilities for noise and industrial pollutants protection, with water-protection properties and with the most favourable recreational conditions. These requrements reflect on the beech stands management and on the problem of stands' structure.

For keeping the beech complexes in a good condition, for better fulfilment of their protective and social functions, their utilization must be realized according to the stands' status in the frames of the annual increment and with consideration with their biocenological specifics. First of all the methods of management with preliminary natural regeneration must be carried out. Preference must be given to logging maschines and techologies which further the soil and the new growth protection from damages. Selective management must be used wider because this kind of management is the most natural and suitable for the mountain forests and it is compulsory for the slope terrains and for the upper forest boundary.

The area of high stemmed beech forest in the Balkan Mountain during the past 30 years have decrease with 31,5 per cent, that is why for restoration of the area the extention of afforestation with beech trees is imperative. It must be done by creation of mixed plantations in the lower oak subbelt of sessil oak and beech, pine and spruce, and in the upper belt beech-pine spruce mixed forests, with raising the upper forest boundary. In this connection a part of the Scots pine stands, created on beech sites, after thinning of the pine storey, must be planted with beech seedlings. Thus most stable mixed and two-storey pine-beech stands will be created. They will be with about 30 per cent more productive than the pure beech stands.

In typological relation the beech forests are jointed in three common groups, according to the purpose of the management: a) group of the mixed beech-broadleaved forest types in the lower part of the beech sub-belt - in an altitude of 500-800 m (so-called valley beech-sessile oak forest of I-II site class, valley beech-hornbeam forest of II site class, etc.), where the depth and fresh to moist soil allow to be managed mixed stand from beech, sessile oak, lime-tree, hornbeam with the participation of sycamore, Norway maple, birdcherry tree and ash, of high productivity. The crops in these forest types fulfil a pronounced water protective role, protecting the banks of the water flows and the river from silting up. Here with the help of appropriate and with moderate intensity final cuttings and thinning and measures for promotion the regeneration it must be supported the mixed composition and it must be prevented the objectionable replacement of the beech and the sessile oak by the hornbeam.

b) a group of the high productive pure beech forest types on fresh to moist and rich brown forest soils in the middle beech sub-belt (in the altitude of 800-1400 m) - so called beech forest with litter type of II site class, beech forest with different grass species of II site class, beech forest with woodruff of I-II site class, beech forest with laurel of II-III site class, etc. The beech in these forest types is in the optimum of its distribution, forms high-productive pure stands with valuable stems, which at the age of 100 years reaches an average height of 26-28 m and diameter over 40-50 cm. Natural regeneration in the gradual overthinning is taking spontaneously and it is distinguished for overgrowth. That is why the stands have a high timber producing and socio-protective functions. The purpose of the economy must be the production of thick timber, as by the help of gradual and selective main cuttings on small areas it would secure the permanent timber production and keep the uneven-aged stands' character.

c) a group of the beech forest types in the upper beech subbelts (beech forest with fescue of III-IV site class, Beech forest with blueberry of IV-V site class, subalpian beech forest of V site class, etc.) distributed at an altitude of 1400-1700 m with extremely great protective role. Improvement of their Nature-protective and timber-producing functions is in request on the way for creation of mixed stands from beech, Fir, as peace, Scots pine and Norway spruce, which are more high-productive and with better useful properties than the pure beech stands. It would lead to stabilizing of the upper forest boundary, especially in the Balkan Mountain.

With elaboration and introduction in practice of more rational methods for final cuttings and thinnings in the beech stands, an object of intensive utilisation, of more perfect methods for convertion of the low-productive stands and their change by planting of higher productive stands, and with permanent cares for protection of the soil and the landscape. Inevitably, it would secure the quick and in high level solving of the question for increasing of the total productivity and the productive functions, as well the social ones of our beech forests

6.9 LONG-TERM WOOD DEMAND COVERING: PROBLEMS OF STRATEGY ELABORATION IN THE G.D.R.*

H.U. Brautzsch
Faculty of Agriculture
Bruno Leuschner School of Economics
Hermann-Duncker-Strasse 8
DDR-1157 Berlin, GERMAN DEMOCRATIC REPUBLIC

1. Introduction

Worldwide there is expected a further increase in wood demand. So the FAO has projected that the wood demand of 2,800 mill m in 1975 will increase to 3,900 m in 2000 (FAO 1982).

Considering that currently only two third of the wood demand in the GDR can be covered by domestic wood resources and a further increase of this demand is expected, elaborations of long-term strategies for satisfying this demand are very important.

This requires investigations on the following subjects:
- the analysis of the factors determining the long-term development of wood demand,
- the estimation of optimal paths to cover the long-term wood demand.

The purpose of this paper is to discuss some relevant aspects concerning these two subjects.

2. Factors determining the longterm development of wood demand

The prospective raw wood demand will be mainly determined by the following factors:
- the development of human needs,
- the development of the raw material base,
- the possibilities to cover the increasing wood demand.

2.1. The development of human needs

From the beginning of human production activities wood has been of great importance. Wood was needed for the production of 200 goods 2000 years ago, 2,000 goods in 1919, 4,500 goods in 1930, 10,000 goods in 1960 (OFFNER 1961), and in the GDR, 12,000 goods today.

Relevant data for the allocation of raw wood and intermediate wood-based products are summarized in table 1.

Changes in the structure of needs determine structural changes of the production and the needed resources. For the longterm analysis of the development of human needs investigations with less but more aggregated items have to be prefered. As there are certain dependences between the satisfaction of different needs (e.g. accomodation - furniture),

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it is possible to unite different goods and services to homogenous consumption entities, called complexes of needs. These complexes of needs develop relatively independently. Thus continous changes of the structure of needs can better be investigated and guided by measures than in case of isolated measurement of single products (LUDWIG et.al.1983). An analysis of strucutral changes in consumption according to complexes of needs in the GDR (LUDWIG et.al.1983) shows, that the single consumption complexes have different growth rates which is due to the fact that saturation levels are or are not achieved and new needs are in process of development respectively (table 2).

Table 1: The allocation of wood and intermediate products in the GDR in 1980

Distribution of raw wood (Consumption of raw wood = 100%)		Distribution of intermediate products (Consumption of intermediate products = 100%)				
		Furniture	Wood-based Packages	Paper& Boards	Construc-tion	other final products(1)
31.8%	Sawnwood	9.4%	18.6%		21.2%	50.8%
2.2%	Fiberbd	36.3%	3.2%		36.2%	24.3%
10.9%	Particlebd	86.6%				13.4%
24.1%	Chemical pulp			69.6%		30.4%
4.6%	Mechanical pulp			100.0%		0
0.8%	Veneer(2)	96.1%			2.4%	0
25.6%	other					

(1) inclusive of remedy
(2) not for plywood

According to the author's estimations, at the beginning of the 1980s in the GDR wood was allocated to the following consumption complexes:
- 20 % to the consumption complex "accomodation",
- 17 % to the consumption complex "transportation",
- 16 % to the consumption complex "education, culture, recreation". The main part of wood is used in such complexes which will be developing quickly.

2.2. The development of the GDR raw material base

Table 3 contains the production structure of primary raw materials in the GDR. Despite of the relative low share of forest products on the total primary raw materials production, wood is one of the most important domestic raw materials because wood represents approximately 17 % of all industrially used raw materials.

Table 2: Structural change in consumption according to complexes of needs in the GDR (LUDWIG et.al.1983)

Complex of needs	Structure of consumption in percent 1972	1977	2000
Nutrition	45.4	41.5	31.1
Clothing	11.7	10.9	9.8
Accomodation(1)	18.4	19.8	25.8
Health care(1)	4.7	5.7	7.8
Education(1),culture, Communication	7.2	7.8	9.1
Transportation	8.1	9.3	10.0
General public needs	4.5	5.0	6.4
Total	100.0	100.0	100.0

(1) without non-productive investments in residential construction

Table 3 The production structure of primary raw materials in the GDR (in % of the volume of primary raw materials in value terms)
(GROSCHOFF et.al.1981)

Treasures of the soil	
- coal and minerals	14.0 %
- natural gas and mineral oil	1.3 %
- stones and earth	6.6 %
Water	9.9 %
Organic raw materials	
- agricultural production	64.4 %
- forestry	3.5 %
- other	0.3 %

In particular the development of world market prices since the beginning of the 70s has raised the question what strategic importance wood will have in the GDR raw material base. LANGENDORF (1981) emphasized with regard to the subject-matter wood is beeing approached from a completly new angle. In this connection the prospective importance of wood as energy source, as chemical basic material, and as a basic material for processing industries is discussed.

2.3.The possible sources for wood-demand covering

In general we have three ways to cover an increasing wood-demand:

a) increase of imports of wood and intermediate products,
b) increase of the utilization of grown wood,
c) increase in organic production per area and time.
Besides of these, the possibilities for substitution and resubstitution of wood by other raw materials should be kept in mind analyzing the opportunities to cover the demand.

The increase of imports

Despite of the advanced level of wood processing industry the domestic demand can not be satisfied by domestic production. Thus to a high extent raw wood and intermediate products have to be imported. In contrast to the large netimport of these products the GDR forest sector is characterized by a large netexport of products of the secondary wood processing industry. A further expanding of imports of raw wood and intermediate products is not likely to be considered for various reasons. World market prices of wood and intermediate products have been increased rapidly (table 4). The forest sector should contribute to achieve an active payment balance of the GDR. Besides of this the imports have been concentrated on the USSR where we can observe a regional shift in raw wood production to far-away regions. Therefore transportation costs would increase rapidly if imports would be expanded (table 5).

Table 4 World export price indexes of wood products compared with selected commodities (1975=100) (Source: United Nations Statistical Yearbook 1979/80, 1982)

	1950	1960	1970	1974	1976	1980	1982
Coal	19	21	32	85	95	127	116
Crude petroleum	15	16	15	100	106	295	311
Natural gas	...	...	34	57	118	183	272
Iron ore	36	62	59	80	97	121	115
Forest products	...	...	49	101	113	191	155
Log	...	...	57	113	130	313	259
Lumber	34	46	51	112	118	169	121
Woodpulp	30	35	41	82	96	122	112

The increase of the utilization of wood grown

This includes two processes:
- The increase of utilization of harvested wood. Currently only 50...60% of the dendromass of the harvested wood is utilized.
- The increase of utilization of wood and intermediate products in the processing industries. That means the closing of the wood cycle in the national economy. Currently approximately 50...60% of the supplied wood is really incorporated in wood-based final products.

Table 5 Transportation costs of USSR exports to other member countries of CMEA in dependence of transportation distance (in % of export prices) (Source: SCHONINA 1982)

	distance (in km)								
	100	300	500	1000	2000	3000	4000	5000	6000
Iron ore	11.5	32.8	53.0	95.8	187.0	282.0	386.0	470.0	517.0
Pig iron	2.6	7.5	12.1	22.0	43.0	65.0	86.8	108.0	130.0
Mineral coal	4.5	12.9	20.8	37.6	73.7	111.0	148.0	185.0	222.0
round wood	3.6	10.7	17.2	31.2	61.0	92.0	122.0	153.0	183.0
sawn wood	1.2	3.6	5.8	10.5	20.6	31.0	41.4	51.8	62.0
chem. pulp	0.6	1.7	2.8	5.0	9.9	14.8	19.7	24.8	29.7

Altogether, only 20...30% of the grown wood are efficiently used (LANGENDORF 1981).

The possible reserves can be quantified as follows:

-The hitherto not used dendromass, which can be utilized by considerable technical and economic conditions and under ecological constraints, amounted to 1.5...2 million m.

-The volume of wood residues amounted approximately to 2.2...2.6million m (LANGENDORF 1983). Approximately 0.87 mill m. were recycled to the wood processing industries, 0.45 mill m were used in agriculture for humus soil production. In the range of 0.64 mill m were used for energy production. The potential for the further increase of wood residues utilization in the wood processing industries amounted to 0.85...1.3 mill m.

- The closing of the wood cycle in the national economy comprises also the increased utilization of the waste paper.Despite of the advanced level in waste paper utilization in the GDR the reserve in waste paper recycling amounted to approximately 440,000 tons (ARNOLD/RAHN 1981).

Expecting that upon 2000 the cycle of wood utilization will be closed, an increase in annual organic production per area is the only way to cover an increasing demand (KURTH/LUCAS 1980).

The increase in the organic production per hectare and time

To achieve a higher organic production the application of so-called intensification measures has to be extended. KURTH/LUCAS(1980,1984) diveded:

- measures for increasing the soil fertility,
- measures for increasing the productivity of forest stands.

Assumed that the intensification measures will be applied an increase in increment amounting to 3 m per hectare and within the horizon of time a doubling of the volume of timber cut per unit of area in 100 years will be achieved (KURTH/LUCAS 1980). To obtain this increase in organic production additional material and personal resources have to be used in the forest sector which may lead to an increase of costs of wood production (WALTER/PAUL 1983). In this connection we have to consider a timelag between expenditure and results revealed in increases in grown wood.

Without intensification measures an increase in the annual raw wood production will only be possible in the next 40 years, according to computations of KURTH/ANDERS/LUCAS (1985).

3. The elaboration of longterm strategies for covering the wood demand

The prospective wood demand is not only determined by the development of the human needs but also by the development of the sources which cover the demand. Hence the elaboration of efficient strategies to cover the increasing demand can not be restricted to computing an optimal utilization structure for covering the exegenously estimated demand of wood-based final products. Rather the strategy elaboration requires also the complex consideration of the longterm development of possible resources to cover the wood demand. That means that a number of things must be considered at once: forest resources in particular, the development and application of effective harvesting and processing technologies, the possibilities of imports and exports of wood and wood products , the possibilities of substitution and resubstitution of wood by other raw materials, changes in consumer behavior, etc.This claim leads to some methodological problems. Two particularly important problems shall be discussed in more detail below:

- Conditioned by very longterm reproduction time of forest resources, the strategy elaboration for covering the wood demand has to be done over a time horizon which exceeds the traditionally used forecasting horizons.
- The intended simultaneous consideration of the three possible sources in the strategy elaboration, which is based on model computations, lead to the question, in what manner especially the long-range development of forest resources and the forest industry can be reflected in one model structure.

The time horizon for the strategy elaboration

The reproduction of the forest resources occurs in an extremely longer time period than the production cycle of forest industry which has to cover the demand of wood-based final products. Assuming a reproduction time of forests in the order of 60...80 years the development of the wood demand of about entire century must be considered for the forest planting. MANTEL (1973) called this a mere speculation. He emphasized that at the time of the "Early Victorian Style" the extremely high wood demand for pulp, paper,board or artificial wood products could not be forecasted. In the same way it is impossible to forecast the wood demand in 100 years (MANTEL 1973).
The time horizon, which is used for such demand forecasts can normally not be longer than the time horizon, which is used for forecasts of the national economy (BRAUTZSCH 1985). Hence, the time horizon for wood demand forecasts can hardly exceed 15...20 years. But this would mean that the development of forest resources can only be insufficiently assess with regard to their contribution to covering of long-term wood demand. This is mainly

due to the fact that the consequences of realization (or non-realization) of intensification measures to increase the forest production are visible after a long time.

The following pointed example shall elucidate that a span of 15...20 years is too short for the elaboration of a strategy of the longrange development of the forest sector.
Under the conditions of limited resources (especially limited investment fonds and labor forces) it is thinkable that as a first step the available resources are concentrated on the closing of the wood cycle (i.e. on the development and application of advanced harvesting and processing technologies), and for the present it is dispensed with the application of the intensification measures. After the closing of the wood cycle (possibly at the beginning of the next century), these intensification measures will be realized consequently.

Such a strategy seems to be tempting because the expenditures are shortly reflected in increasing outcomes (namely in an increasing covering of the wood demand by domestic forest resources) whereas the "unattractive" task to use limited resources without a shortly visible result can be "shift" in the future. The consequences of such a strategy can not be estimated within a forecast time period of 15...20 years.

In similar investigations about the longterm development of the forest sector (KALLIO et.al.1986, KALLIO et.al.1987) the scenario analysis was applied successfully. In these investigations the aim is not primarily the forecasting of a certain "state", which will take place at certain time point. Rather the elaboration of different paths of the development by certain sets of conditions is the main concern. A possible path of development will become reality by the existence of certain conditions. Hence the investigations aim to estimate possible strategies for wood demand covering under certain scenarios of conditions.

In connection with the formulation of scenarios for long-term development of the forest sector one has to consider the following: The most important uncertainty in the future development is caused by technological progress. In the forest sector the mainly used production technologies are to a long extent based on old and well known principles. Product or process innovations which could lead to important structural changes in wood utilization occur - as the past development shows - seldom. The last very important product innovation seems to be the particleboard at the beginning of the 1940s. On the macroeconomic level a clear trend of the technological coefficients can be observed which seems to make the formulation of scenarios of the technological development easier.

Integrated forest sector planning

ANDERSON et.al.(1986) give a survey of different approaches to link the long-range development of forestry and forest industry.

A simple approach which was used in a linear dynamic optimization model describing the wood utilization (BRAUTZSCH/SCHOEPP 1986) is to consider the development of the annual cut in one separate constraint. The annual cut (which represents the "copula" between the forestry and the forest industry) is estimated in dependence of the development of annual growth, the choosen strategy of application of intensification measures and the annual accumulation (see KURTH/ANDERS/LUCAS 1985). This approach follows the philosophy that in a programming model it is not only the objective function but also the constraints which reflect important objectives.

As for each choosen strategy of intensification of forest production the necessary expenditure for resources (labor resources, investment, etc.) can be estimated, this principially allows to compute the longterm consequences of the distribution of limited resources **within** the forest sector ,i.e. between the forestry and forest industry (see BRAUTZSCH/SCHOEPP 1986).

Hence, an integrated assessment of the long-range development of forest resources and forest industry is possible.

The mannifold possibilities which this model provides for scenario analysis of long-term strategies of wood demand covering can be shown from figure 1. In this figure the reflection of these possibilities in the model structure is also considered.

4. Conclusions and possible directions for future research

The aim of this paper was to demonstrate the need to analyze long-term strategies for wood demand covering and give an approach how one can handle this problem.

Considering that investigations on this subject are still in its infancy some problems for future research shall be discussed. First it should be tried to link the function of the realizable annual cut (see KURTH/ANDERS/LUCAS 1985) in the optimization part. This leads to a nonlinear dynamic optimization model. The explicitly incorporation of this function would allow to reflect the different objectives of the forest sector better. This could be made possible to use the techniques of interactive multiple-criteria analyses in forest planing and policy assessment. Future research should also concentrate on linking the forest sector model with the rest of the econmy and especially with the environment. The strategy elaboration would then have a broader basis. The treatment of uncertainty is another subject which deserves more attention. In view of the fact that there is considerable uncertainty with regard to the long-range development of demand of wood-based final products, consumer behavior, forest demages etc., there is clearly a need to estimate efficient and "robust" policies.

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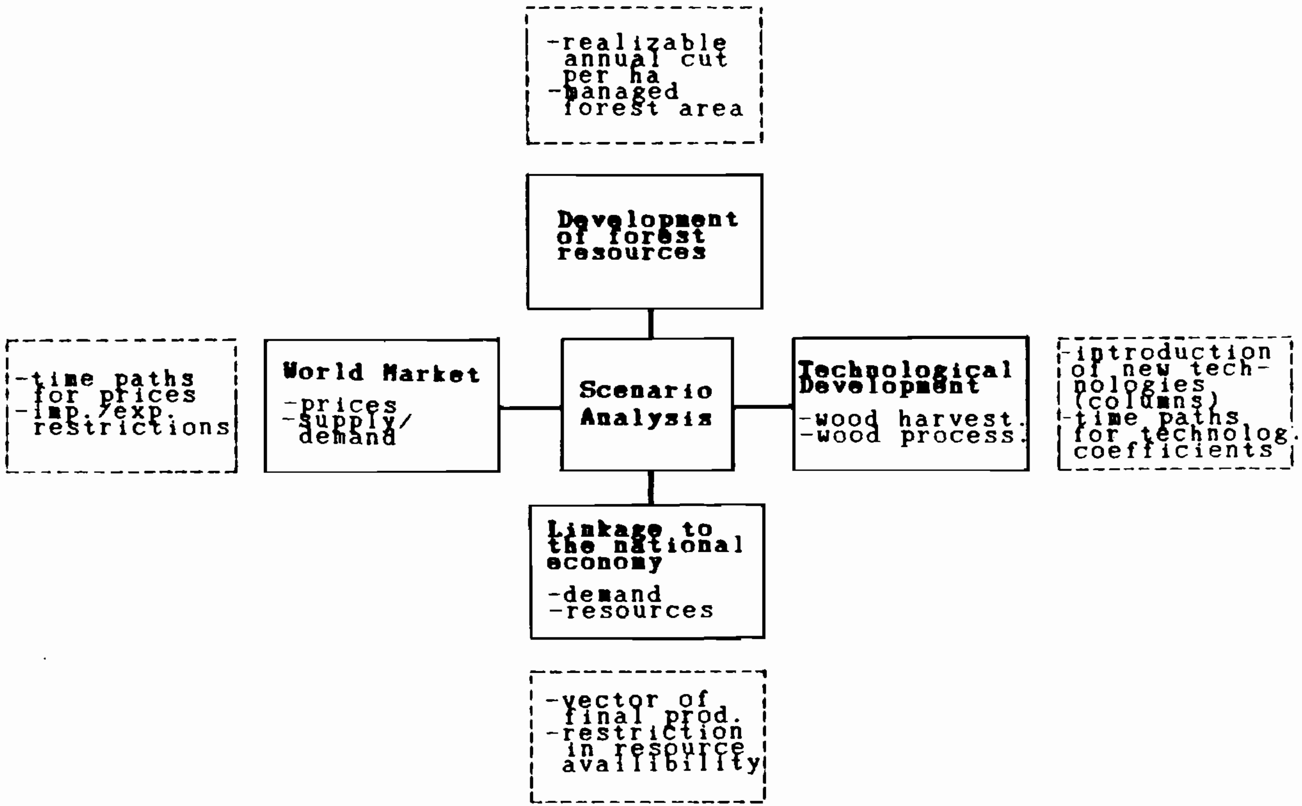
Figure 1


-realizable annual cut per ha
-managed forest area
Development of forest resources
-time paths for prices
-imp./exp. restrictions
World Market
-prices
-supply/ demand
Scenario Analysis
Technological Development
-wood harvest.
-wood process.
-introduction of new technologies (columns)
-time paths for technolog. coefficients
Linkage to the national economy
-demand
-resources
-vector of final prod.
-restriction in resource availibility

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7. REGIONAL AND GLOBAL CONSEQUENCES OF FOREST DECLINE

7.1 ECONOMIC EVALUATION OF FOREST DAMAGE*

T. Stemberger
Präsidentenkonferenz der Landwirtschafts-
kammern Osterreich
A-1014 Vienna, AUSTRIA

The technical literature available so far on the economic evaluation of forest damage focuses on different levels of the problem and has been written to serve different purposes. Therefore, the papers are based on different calculation models which, in turn, have different starting points. As a consequence, the results vary considerably. When discussed by the public, these results are not seen in a discriminate way, as would be the case among scientists, but they get mixed up, they are compared and, regardless of the underlying calculation models, they are used to support the most different arguments. In solving the problem of dying forests, great social and economic problems will have to be overcome. Therefore, the data base should be as solid and reliable as possible. Confusion and apparent contradiction do a lot of harm because they unnecessarily hamper the process of making people conscious of the problems - which is a prerequisite for effective countermeasures - by affecting this process in a counter-productive way.

This paper is intended as a stimulus in the effort to reach international agreement on certain calculation models.

*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

1) Levels of evaluation
2) Time horizons of evaluation
3) Purpose of evaluation
4) Critical remarks on the economic evaluation of forest damage
5) Summary - suggestion

1. Levels of Evaluation

1.1 Evaluation on the micro-economic level: Evaluation of the objective forest damage in a narrower sense

1.2 Evaluation on the macro-economic level: Calculation of the damage caused to the entire economy by considering the effects of forest damage on forestry, all related branches of the timber industry, tourism, public health, and water balance - to mention but a few areas which are affected by forest damage.

2. Time Horizons of Evaluation

2.1 Retrospective Evaluation: Translation into monetary terms of the damage done to forests up to a certain point of time

2.2 Dynamic Evaluation: On a ceteris paribus basis, this type of evaluation also includes the secondary (future) consequences of the forest damage caused so far.

2.3 Scenario Evaluation: Assumptions concerning the development of damaging factors (emissions) and the course of the damaging process serve as a basis for the translation into monetary terms in relation to a future point of time and/or aggregated over a period of time extending into the future, also expressed (discounted) as present value.

3. Purpose of Evaluation

3.1 A Clear Basis for Calculations on the Level of the Enterprise: A basis for decisions on forest management, and for the assessment of forestry enterprises - assessment of the efficiency of individual forestry enterprises and of the forestry sector as a whole

3.2 Compensation: Translation into monetary terms of the forest damage caused by polluters through the externalization of costs - submission of claims for damages to be paid by individual polluters or polluter collectives, thereby fully utilizing all possibilities offered by the respective social and legal situation in order to get a monetary compensation for the damage caused and to make the polluters accept the internalization of these costs.

3.3 Statements of Costs: by individual fields of forestry (e.g. regeneration measures, production costs, etc.)

3.4 Extension of National Accounting: The inclusion of forest damage as a negative quantity would result in a more realistic calculation of the gross national product as an indicator of prosperity and economic growth.

3.5 A Helpful Argument supporting action to reduce emission and press forest conservation within the framework of opinion-forming and decision-making processes which are guided by economic rather than by ecological considerations.

4. Critical Remarks on the Economic Evaluation of Forest Damage

The wider the limits and the more complex the nature of evaluations within such categories as level - time horizon - purpose, the more arbitrary and the more contestable they become.

The spectrum ranges from a narrow, standwise, exclusively retrospective evaluation according to established rules of forest valuation on the level of an individual forestry enterprise to a future-oriented evaluation embracing the national economy as a whole on the basis of damage scenarios, including as many secondary consequences of forest damage as possible.

- Retrospective evaluations are insufficient because damage to forests, as a rule, is inflicted over long periods (accumulation effects), while the effects of the damage are not necessarily acute and easily recognizable, as they may be latent or chronic.
- A necessary prerequisite for scenario evaluations is the fact that the underlying scenarios have to be accepted by those addressed. If a critical approach is used, this means that the scenarios need to be plausible and transparent, i.e. they should be such that they can be understood. Those addressed should at least be prepared to accept that the scenarios used have a certain probability. Most evaluations of this type take this into account by offering different scenarios - e.g. different trends as far as damaging factors are concerned -, thus providing a whole gamut of possible results. As a consequence, the values vary considerably, which in the opinion-forming and decision-making processes may reduce their indicative value.

In the case of forest damage, the mechanisms at work are usually highly complex: harmful substances and other biotic and abiotic damaging factors combine to prepare, trigger or aggravate the damaging process. Moreover, a number of important harmful substances are produced by a secondary process in the atmosphere. Scientists have not yet been able to fully explain the causal relationships between emissions, contributing biotic and abiotic factors, and the effects of plant physiology and soil chemistry which finally lead to the damage. Scenarios, therefore, have to resort to simplifying hypotheses on the action of mechanisms and on the course of the damaging process. As a result, the plausibility of scenarios and/or the probability of the results derived from them are more difficult to assess.

Apart from these drawbacks, scenario evaluations have the indisputable advantage that they make people conscious of the imminent future costs which will be incurred as a result of forest damage, thereby increasing their readiness to finance rapid measures to reduce emissions as fast as possible and to set new priorities both in the field of private households and the economy as a whole.

- The dynamic approach cannot answer future-oriented questions relating to the transition to acute damage, the duration of such processes, the combined action of immissions and the contribution of other biotic or abiotic damaging factors, or the complex action of factors preparing, triggering or aggravating the damaging process. From the beginning of the evaluation period dynamic evaluations have to be based on a ceteris paribus assumption. Compared to evaluations based on scenarios this is a disadvantage. On the other hand, dynamic evaluations have the advantage that they permit relatively safe numerical assessments of the damage already caused but not yet evident. Such assessments have to be carried out regularly on the same object. This evaluation will also yield conclusions improving the assumptions on which scenarios of future developments are based.

- Using such instruments as biometry and forest valuation, the dynamic evaluation also permits a relatively reliable assessment of the objective damage relating to the direct economic effects of the forest (production of forest products).

The fact that forest damage affects the direct economic effects of forests, in particular the timber trade, is important and raises special problems. The international timber market e.g. is an almost completely free system that is governed by the laws of supply and demand. Scenarios showing the influence of forest damage on the timber market may, therefore, lead to reactions which might even aggravate the damage already done to the market and/or completely change the market due to the protectionist measures that might be taken. For purposes of translation into monetary terms, such reactions cannot be taken into account.

- The inclusion of the indirect economic effects of forests - e.g. drinking water supply and drinking water quality - calls for assumptions that are comparatively unsafe. We have hardly any experience accumulated in the damaged forest areas which are currently the subject of evaluation. Thus, it cannot be denied that the damage may be grossly underrated.

- As far as the subjective damage to non-economic effects of the forest is concerned, e.g. the impairment of its recreational or scenic value, there are limits to the evaluation, since market prices do not exist. Although there have been methodical attempts to express the actual social value of these effects of the forest in monetary terms (e.g. by asking people hiking in the woods or by adding up all costs incurred by those looking for recreation in the forest), it has not been possible to present a complete picture. Merely simulating a translation into monetary value, such calculations are bound to lead to a gross underestimation of forest damage.

- When making comprehensive evaluations embracing the national economy, one is tempted into cost-benefit analyses, i.e. the costs arising from forest damage are compared with the costs for emission reduction. Such calculations make sense within narrow limits, e.g. to show that a preventive environmental policy which takes measures in due time would be wise also from the economic point of view. However, from the ecological as well as the economic angle evaluations and, above all, cost-benefit analyses will become questionable, if they permit forest damage to appear as a monetary problem once it has reached the extent of a national catastrophe that can no longer be justified in the interest of future generations. Following this line of thought ardent supporters of the ecological movement indiscriminately reject any economic evaluation of forest damage. This attitude, however, cannot be approved.

5. Summary - Suggestion

Concerning the economic evaluation of forest damage, the following recommendations are made:

5.1 Micro-economic Level

5.1.1 Continuous dynamic evaluation of the objective damage in relation to the direct economic effects of forests.

5.1.2 Extension of the evaluation indicated under 5.1.1 to include the indirect economic effects of forests as exemplified by case studies (e.g. protective function, raw material supply, effects on agriculture, drinking water supply, etc.)

5.2 Macro-economic Level

5.2.1 Aggregation and extrapolation of individual evaluation results according to 5.1.1

5.2.2 Extrapolation of individual evaluations according to

5.1.2 on the basis of a sufficient number of case studies

5.2.3 Calculations based on scenarios should not be called evaluations or translations into monetary terms but should be termed expert estimates of the extent of damage to be expected.
The underlying assumptions with regard to cause/effect relationships and damaging factor trends should be revealed in each case.

7.2 JAPANESE WOOD SUPPLY IN THE FUTURE AND THE EFFECTS OF AIR POLLUTANTS*

M. Amano and I. Noda
Forestry and Forest Products
Research Institute
Tsukuba, Ibaraki 305, JAPAN

1. INTRODUCTION

Policies concerning forest resource management are established using the "Basic Plan". The Government is required to formulate the "Basic Plan" to ensure steady development of the national economy and social welfare through the adequate preservation, cultivation and utilization of forest resources. Simultaneously the Government makes public the "Demand-Supply Prospects" showing the timber demand and supply projection during the period of the Basic Plan. The scope and complexity of the plan and prospects must be viewed from different perspectives. In this way the Forestry Administration Council discusses and achieves the desirable scenario for the final draft of the Basic Plan and Demand-Supply Prospects. Finally 50 year long-term plans at the national level are comprised largely of policy objectives which are changed only as a result of fundamental changes in political, economic and environmental conditions.

Initially, the Government was required to established the plan and prospects in 1966 due to a general shortage of wood during a period of high economic growth. Since then the Government has revised the plan and prospects in 1973, 1980 and 1986. The 1973 revision was brought about by the oil crisis. The 1980 revision was made to adjust the plan and prospects to the stabilized economic growth. The Government has just finished the newest revision under the present depressed timber prices and strong needs to protect a forest ecosystem stressed by a highly industrialized society.

The previous three times revisions were formlated by human wave tactics and simple methods. This time a computer aided perspective model, described here, was useful. This paper gives a procedure for using the model to assess the effect of the forest damage attributed to air pollution.

2. STRUCTURE OF THE MODEL

The model is made up of three submodules which are supply, demand and roundwood market shown in Figure 1.

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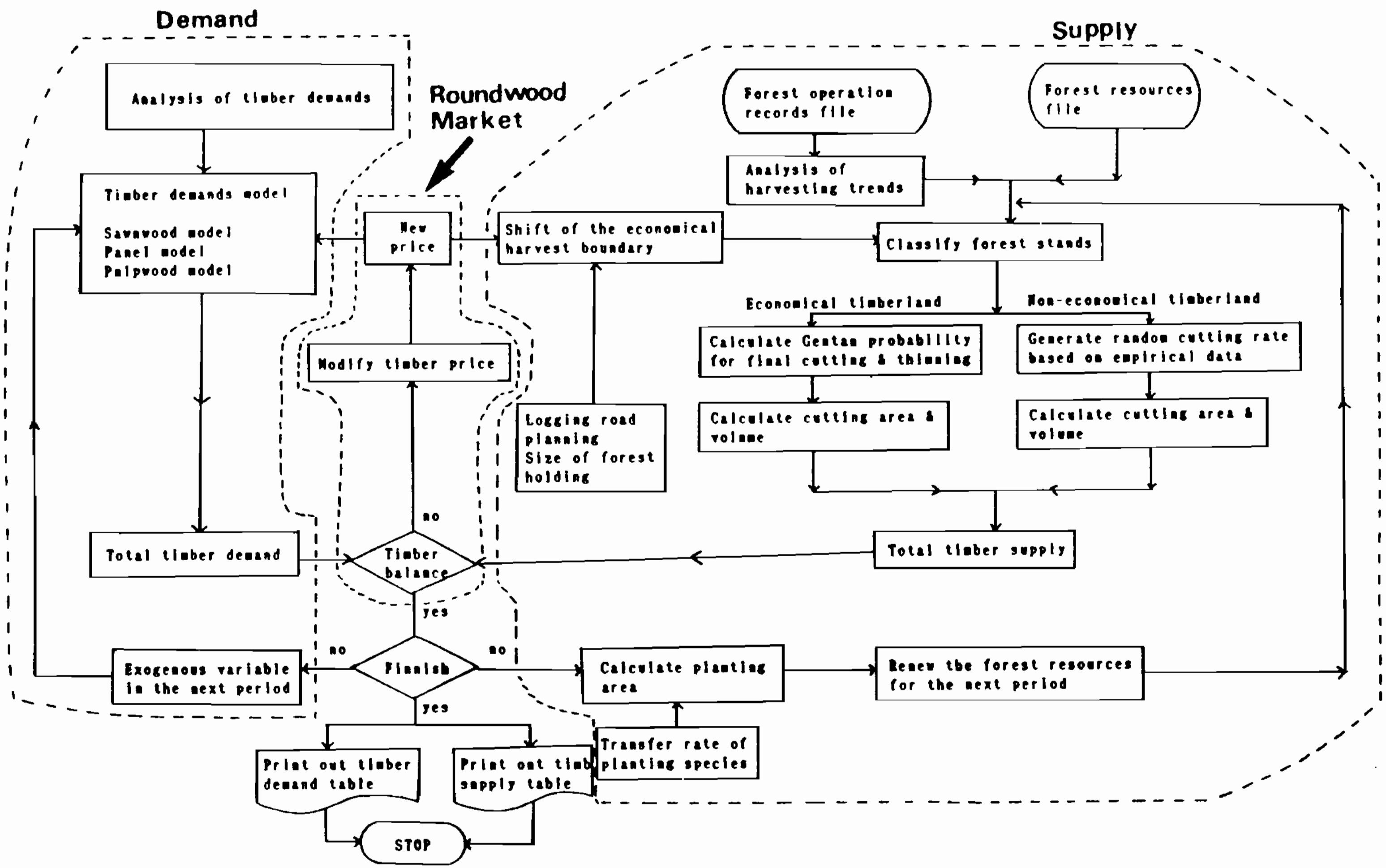

Figure 1. Outline of the Timber Supply-Demand Model for the "Basic Forest Resource Plan" in Japan

2.1 Supply submodule

Table 1 shows how actual harvesting area differed with distance from the road. It can be readily seen that the stands adjacent to the roads (within 500-meter distance) had a significantly higher harvest ratio than those further away. This is just one of the manifestations of depressed demand for forest products over many years where forestry remains fairly active only in locations favorable for logging. Figure 2 shows a similar trend for harvesting in Gifu, a typical forestry area in Japan. In 1975, harvesting increased in the roadside forest but declined in the more remote forest.

Table 1. Harvesting activity according to the accessibility in man-made matured forests in Japan. (1980 - 1984)

Species	Distance from Logging road(m)	Forests older than 50 years(ha)		B/A (%)
		Forested area(A)	Harvested area(B)	
Red cedar	0 - 500	411482	46677	11.3
	500 -	162960	11140	6.8
Cypress	0 - 500	188160	21110	11.2
	500 -	74759	6607	8.8

The above analysis has differentiated forests into two groups, one active and the other stagnant in management. The fundamental assumption underlying this differentiation is explained in Figure 3. The area along a logging road located inside an economical harvest boundary is defined as economical timberland, and the area outside is defined as non-economical timberland. The boundary shifts with the fluctuation of timber price, logging cost, logging road construction and so on. The higher a timber price is, the broader the width of economical timberland is. This boundary is considered as the factor to determine the portion of economical timberland in the total forested area. Figure 4 shows a high coefficient of correlation between the timber price index and the % share of economical timberland of man-made forests in Japan.

A simple equation which takes into account three assumptions is:

RATE.ECON=1.299*PRICE+.573*CONS.ROAD-1.299*LOG.COST-61.683
R=0.99

RATE.ECON=Share of economical timberland
PRICE =Roundwood price index deflated by over-all wholesale price index
CONS.ROAD=New road construction mileage during 5-year period
LOG.COST =Logging cost
CONS.ROAD and LOG.COST are given as exogeneous variable.

Currently the economical timberland is the primary source of domestic timber supply and the amount of this supply in the sum of products of the Gentan Probabilities and the corresponding forest areas by the "Gentan probability" theory (T. Suzuki, 1984). This probability was developed for predicting the timber supply of private forests using the Markov

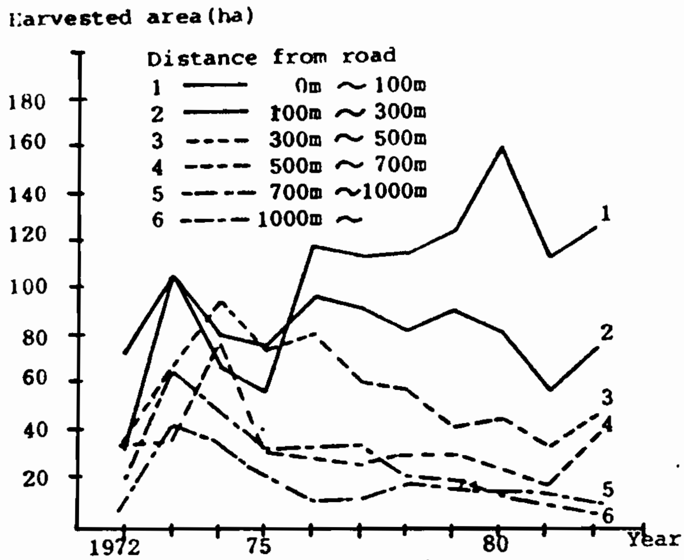

Figure 2. Harvested area according to accessibility of cypress forests in Gifu prefecture.

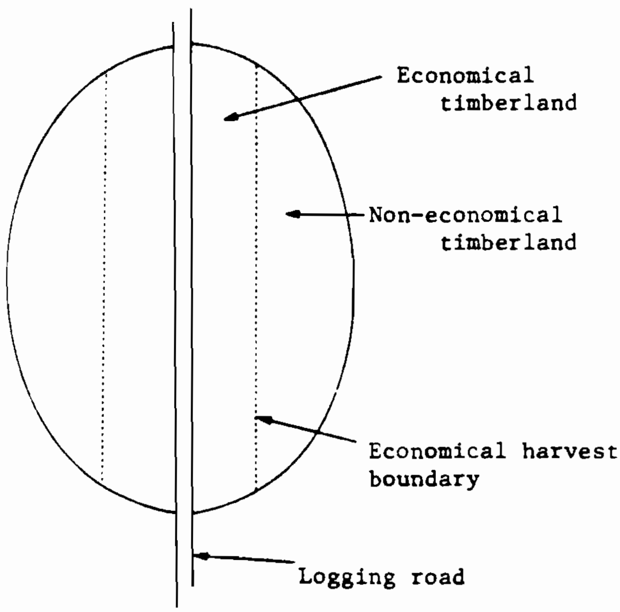

Figure 3. A simple model of economical timberland and non-economical timberland

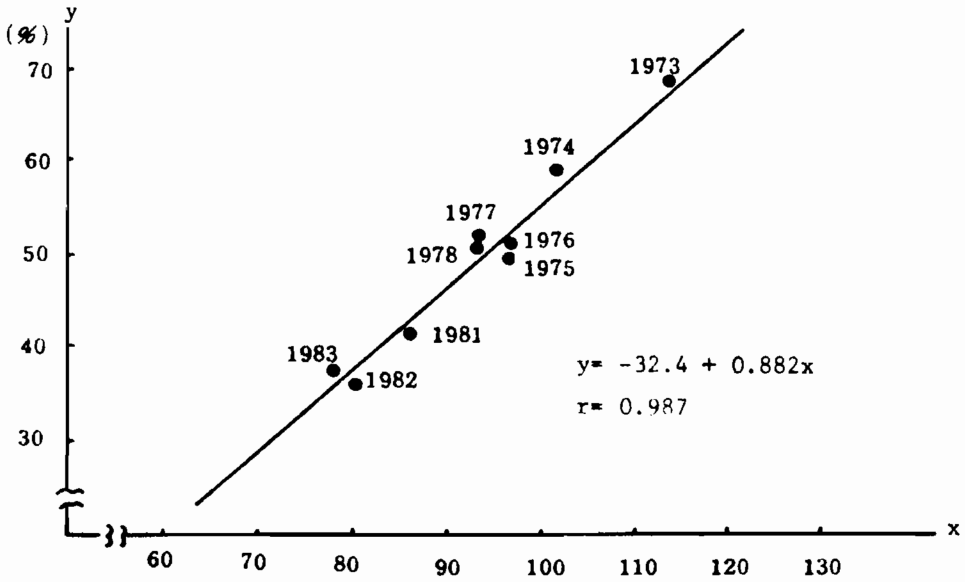

Figure 4. Correlation of the timber price index and the share of the economical timberland.

Process. The forecasting parameters of cutting tendencies are a mean cutting age and its variance. So it is easy to determine scenarios reflecting changes in future cutting activities. Cutting area and volume from the non-economical timberland are calculated by using random cutting rates based on empirical data. However, the amount of such cutting is rather small.

2.2 Demand submodule

Demands for sawnwood, panelwood, and other uses including pulpwood were estimated by ordinary econometric models. As an example, a sawnwood demand function is represented by following regression equation.

WOOD.DEMAND= .9069*HOUSE+.048064*SUBST-.02786*PRICE-.022652*ENERGY.COST
+.003648*CAPACI.PRO-4.2870*IMPORT.PRI+4.6145

WOOD.DEMAND=Amount of domestic sawnwood
HOUSE =Rate of wooden housing starts
SUBST =Deflated real wholesale price index of substitutes.
PRICE =Deflated domestic roundwood price index
ENERGY.COST=Energy cost of electricity and fuel
CAPACI.PRO =sawmill capacity for imported wood
IMPORT.PRI =Deflated price index of imported roundwood

Figure 5 shows the estimated and actual consumption levels. The fitness of this regression equation was fairly good.

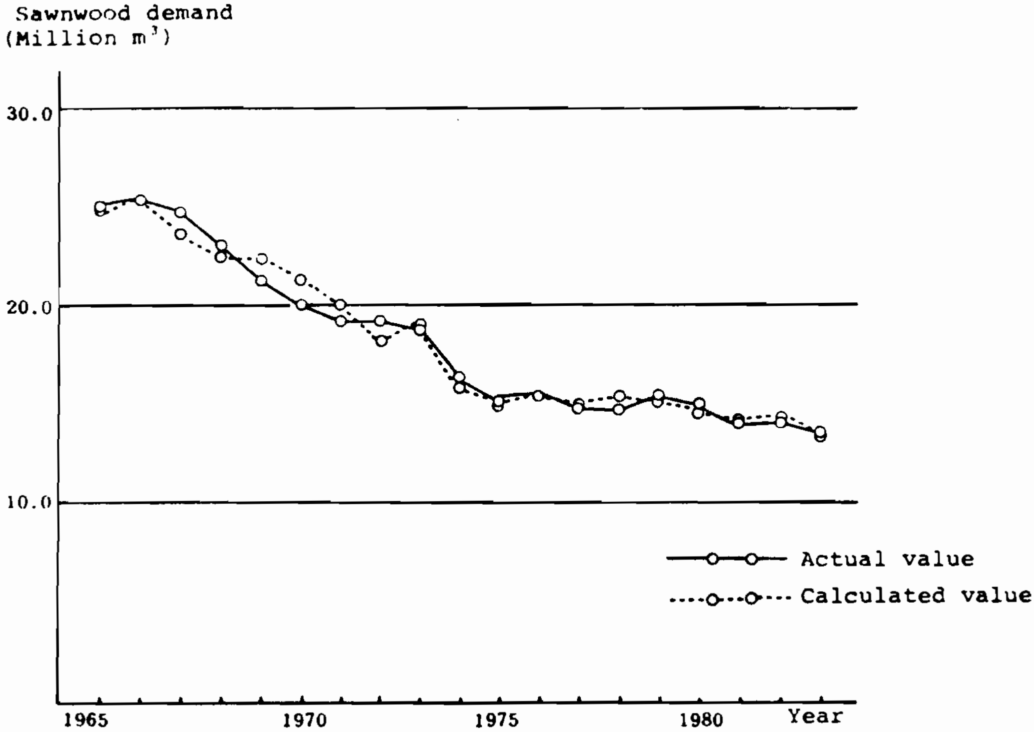

Figure 5. Comparison of calculated sawnwood demand and actual value

2.3 Roundwood market

The demand and the supply submodules are linked through the roundwood market submodule. Demand and supply equlibria are computed for 5- year periods over the projection period. It is difficult to determine an equiliblium point at the quantities of demand and supply. In the model, a temporary timber price is first assigned in the roundwood market and then each submodule calculates demand and supply volumes using this price. If demand and supply volumes are unbalanced, a new price is set and same procedures are repeated. Such feedback iterations proceed in the three submodules until the demand and supply volumes converge upon an equiliblium. Also the demand and supply curves in a given year (t) are functions of exogenous and endogenous variables as well as forest resource structures. Positions of demand and supply curves in a given year (t) are shifted according to these variables.

3. RESULTS

If forest damage attributed to air-pollution is assumed, cutting behavior will change. In this situation the increment of forest will decrease and the final cutting age will be put off several years. Also logging cost will increase, if forest involves a certain degree of damaged trees. The model simulations are conducted to assess the effect of air pollutants under these assumptions.

For illustration, results based on two scenarios are presented here. Assumptions and results are presented in Table 2 and 3. Case 1 takes an optimistic view, that is, forest will be free from air pollutants. And case 2 takes a pessimistic view. Forest damage will occur and cutting behavior will change in this case. The cutting volumes increase in both cases and the effect of air pollutants in case 2 is not clear from this point. These phenomena mean that the potential domestic timber supply is comparatively larger than the capacity of demand for domestic timber. In fact the age distribution of Japanese man-made forests is remarkably skewed toward young ages as Figure 6. In other words, domestic forests will produce a lot of wood in future. So domestic timber markets are expected to expand in future, as these young forests become mature. But the domestic roundwood price index is considerably high compared with case 1. Both cases assume the imported roundwood price will be unchangeable in future. So if the imported roundwood price will follow on the domestic roundwood price, the share of the imported roundwood market must be expanded and this change will hit hard the forest industry in Japan.

Table 2 Assumption of calculation

Constraints	Case 1	Case 2
Average cutting age	52 year	1985-1989 52 year 1990- 65 year
Logging cost	Decrease 1%/year	1985-1989 equal to Case 1 1989- increase 10% comparing to 1985
Merchantable Volume	100%	90% of Case 1
Real economic growth	1985-1989 4.0% 1990- 3.5%	Same
Factors of the demand submodule	Continue the present situation	Same

Table 3 Results of calculation

Year	Harvesting volume Case 1	Case 2 (million m**3)	roundwoood price index Case 1	Case 2
1989	19.0	18.8	0.69	0.73
1994	24.7	23.5	0.71	0.92
1999	30.0	28.7	0.67	0.90
2004	35.5	34.5	0.63	0.86
2009	39.2	38.2	0.57	0.73

4. CONCLUSION

Accuracy with which this model predicts is reviewed using last 10 years data, and the results can be easily explanable. Sensitivity analysis of the model indicates that the supply submodule is stable and the demand submodule is slightly fragile. This difference depends on the methods of constructing submodules. The demand submodule is based on econometrics, so this does not have the ability to forecast for a long term such as 20 or 30 years. On the other hand the supply model is made up using a system dynamics theory to follow the behaviors of forest resource structures, and more suitable for projecting the long term market changes.

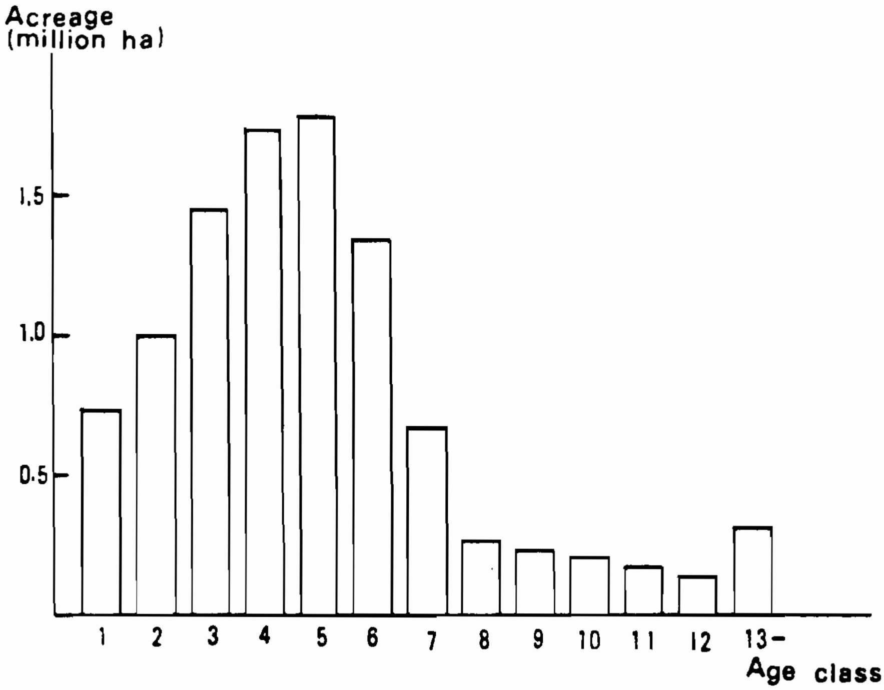

Figure 6   5-year age-class distribution of man-made forest

Also it is desirable to develop the ecosystem submodule to predict the effect of air pollutants on the future supply accurately.

ACKNOWLEDGEMENT

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7.3 POLLUTION RELATED FOREST DECLINE IN THE U.S. AND POSSIBLE IMPLICATIONS FOR FUTURE HARVESTS*

R.A. Sedjo

Resources for the Future
Washington, DC, USA

Forest decline became an issue in Europe in the early 1980s after it was determined that a significant portion of the Central European forest was experiencing damage of an unknown origin initially believed to be associated with "acid rain." In the U.S. the symptoms of forest decline are neither as diverse nor as well developed as those of the forests of Central Europe. Also comparisons between forests of Europe and the U.S. are fraught with difficulty especially due to the differences in forest management practices. Nevertheless, there is growing evidence that forest decline has been occurring in some regions of the U.S. for perhaps decades with the Northeast the most heavily affected region. In this paper I provide a summary of our current knowledge as to the extent of forest decline in the U.S. I then discuss briefly current thinking as to what might be the causes of the decline in the U.S., concluding that the emerging consensus is that a variety of pollutants and interrelations among them are probably involved. Next, I explore some possible long term consequences of forest decline on future harvests and prices of industrial wood worldwide. Finally, I use our recently developed Timber Supply Model (TSM) to explore some of the possible long term consequences of a hypothetical decline in the U.S. of world timber prices and harvests. While the hypothetical example is clearly unrealistic, it does give an indication of the nature of the domestic and international adjustment process.

1. FORESTS IN THE U.S.

The U.S. is a relatively heavily forested country. When the colonists first arrived in America some 350 years ago, it is estimated that the total forested area was a little less than 400 million hectares. This area declined to perhaps 280 million hectares in the 1930s as the land was cleared, largely for agriculture. The forest has subsequently increased to about 300 million over the past 45 years as marginal agricultural land has been abandoned and returned to forest (Clawson 1979). Major forests of the U.S. include the mixed conifer and hardwood forests of New England, the largely hardwood forests of the Lake States, the mixed forests of the South, the Rocky Mountain forests and the conifer forests of the Pacific Northwest. The dominant industrial forests are the pine forests of the lower elevations of the South and the conifer forests of the Pacific Northwest. These two regions account for about 90 percent of U.S. industrial wood harvests. However, significant harvests also occur in parts of all of the other major forested regions.

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2. FOREST DECLINE IN THE U.S.

2.1 Extent of the Decline

While the U.S. symptoms of forest decline are neither as diverse nor as well developed as those of the forests of Central Europe, there is nevertheless a growing consensus that forest decline has been occurring in some areas of the U.S. for some species for a number of years (Figure 1). In New England over the past 25-30 years, high-elevation red spruce forest has experienced a rather dramatic decline in the growth rate for both old and young trees. Data from Mt. Washington, New Hampshire, indicate that red spruce decline may have begun as early as 1960 (McLaughlin 1985). More recently, signs of damage to other species, including red spruce, shortleaf pine, hickory and yellow birch, have been observed in eastern Tennessee (Hileman 1984). In recent years visible and increasing damage has been reported on Mount Mitchell in North Carolina with the number of diseased spruce trees at high elevations increasing from 32% to 59% in a one year period between 1984 and 1985 (World Resource Institute 1986).

While most of the forest decline appears to be in the east and particularly the northeast of the U.S., some decline has been observed elsewhere. In the U.S. west, a comprehensive investigation of the influences of photochemical oxidants on natural forest ecosystems which was conducted in the mountains of California east of Los Angeles in the 1970s, found visible signs of ozone damage as far as 120 km from Los Angeles (Miller 1983). In the South, the U.S. Forest Service reported an approximate 25% slowdown in radial growth in natural pine forests (loblolly) in the Piedmont regions of Georgia (Sheffield and Knight 1983).

2.2 Features of the Decline

Several features of the observed decline are noteworthy. First, most of the damage is found in high elevation forest. For example, Camel's Hump in Vermont, Mount Mitchell in North Carolina and White Mountain in New York all have visible symptoms of crown dieback and the damage in the west also occurs at the higher elevations. Second, most of the observed damage is in the east, and particularly the northeast where there has been increased recognition and documentation of decreased growth and vigor of certain species, particularly red spruce at numerous locations throughout the Appalachian Mountains. Third, while the damage is not limited to high elevation forests, the damage to low elevation forests such as in the Piedmont of Georgia is typically less well documented and more difficult to relate to the potential influences of air pollutants. Finally, thus far most of the observed damage (excepting in Georgia) has occurred in forests that are not particularly important as sources of industrial wood. Hence, up to this time, the forest industry has taken a "wait and see" attitude.

2.3 Causes

While in the U.S. there is no clear scientific consensus as to what is the primary agent triggering the forest dieback, there is broad agreement on at least four points (Hinrichsen 1986):

1) Forest dieback is probably induced by multiple factors involving predisposing and stress-inducing factors followed by numerous secondary effects of biotic and abiotic origin.

2) The primary causes are not due to insect or known forest pathogens alone, although these agents may play a role.

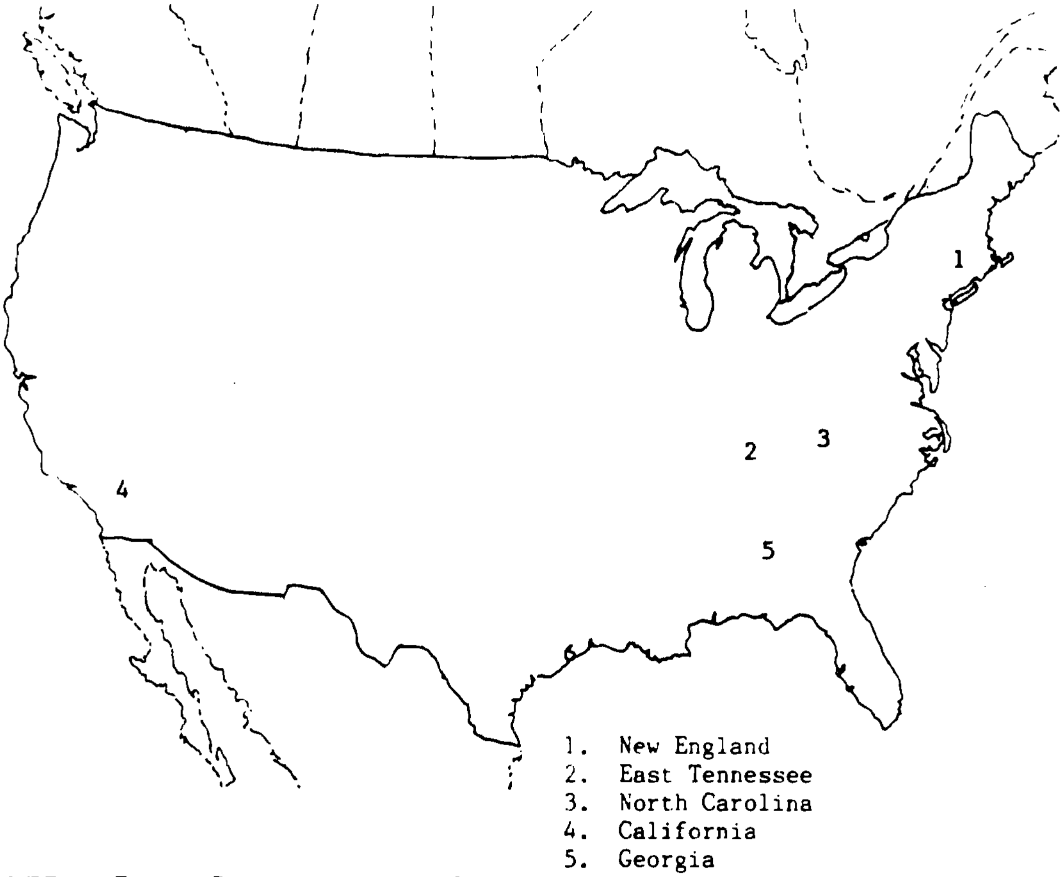


FIGURE 1 Forest Decline in the U.S.

3) Climatic factors such as drought and frost are also involved, but their role is likely to be secondary.

4) Air pollution or pollutant related toxic, nutrient or growth-altering substances are among the primary causes.

In recent testimony before the U.S. Congress, Ellis B. Cowlings, Associate Dean, Research, School of Forest Resources, North Carolina State University (1986), suggested that four forest declines in the U.S. could be attributed to airborne chemicals. These are the ozone damage occurring in large parts of the natural range of white pine in the Northeast U.S. and the ozone related forest damage in the San Bernardino Mountains of California. In addition, there is also growing evidence that the spruce and fir damage at high elevations in the eastern U.S. is associated with ozone. However, the evidence is less compelling that the forest decline of the lower elevation Piedmont forest of Georgia is related to airborne chemicals.

The picture is obviously still somewhat confused. As noted, the problem is more intense in the Northern Appalachian Range of the eastern U.S. than in the the southern part of that range. Furthermore, based on limited laboratory and field studies, there is not good evidence that current levels of sulfur dioxide and nitrogen oxide are high enough on a regional scale to adversely affect forests. Also, studies suggest that acidity per se is unlikely to produce the adverse effects observed. However, not well studied are the effects of acid fogs that occur in high elevation forests nor the effects of acid rain in concert with other pollutants.

In general, the interactive effects of exposure to multiple pollutants is not well understood. There is, however, a growing belief among researchers that ozone and acid acting together cause much of the damage being experienced by the higher elevation forests. The ozone is believed to cause damage to membranes in the cell tissue of the foliage allowing acid to enter the leaves' interior and destroy the tissue. Since higher elevation forests are frequently immersed in mists or fogs that have been found to contain very high pollutant and acidity concentration, they are particularly susceptible to damage.

Furthermore, there has emerged from the research and the debate a clear consensus that the original view of sulfur dioxide as being the single cause of forest dieback is an inadequate explanation of the phenomenon. This view has given way to a much more complex view of an interaction of a variety of other pollutants including sulfur dioxide, the nitrous oxides, heavy metals, hydrocarbons and so forth, with particular attention being given to the role of ozone in the process.

3. IMPLICATIONS OF FOREST DECLINE TO THE FUTURE WORLD'S FORESTS

In a number of recent papers Kenneth Lyon (1983) and I (1983) have examined the long term potential of worldwide industrial wood production using a control theory Timber Supply Model (TSM). Although we have undertaken a number of alternative scenarios, we have not examined explicitly the implications of a serious dieback of European industrial forests due to pollution or other similar causes. In this section of this paper I will first speculate as to the likely long term impacts of a serious dieback under a number of alternative assumptions. Subsequently, I will formally utilize our TSM to explore the long term consequences on worldwide prices and harvest levels of a hypothetical dieback in the U.S.

3.1 Some Consequences

Suppose that the dieback is reflected in higher mortality and lower biological growth in major industrial forests. It is reasonable to assume that the initial impact would be increased harvests as part of a salvaging operation followed by decreased future harvests from the impacted region. Let us assume that while future growth is diminished, it is not totally destroyed and hence some level of future harvest will be feasible.

Let us now consider three scenarios. First, suppose that there were only one major region, i.e., Central Europe, impacted by the pollution dieback. The short-term effect would be an increase in harvests from this region, a depression of world market prices, and the reduction of harvests elsewhere as other suppliers become aware of the higher future prices that are expected once the salvage glut is removed from the market. The near term effect would likely be reduced investments in timber in Central Europe, reflecting decreased economic returns associated with the reduced growth potential and increased investments in timber growing and management in competing non-Central European regions such as the Nordic region, the U.S., Canada, and the emerging regions of the Southern Hemisphere (Brazil, Chile, New Zealand, etc.). In the long term this changed investment structure would be followed in time by increased future harvests from those regions offsetting (but only in part) the reductions in the future harvests of Central Europe. Ultimately, the world market price would be somewhat higher than in the absence of the dieback. The extent to which the price would be higher would reflect the biological potential and investment responsiveness of the other regions to the increased competitive opportunities created by the dieback.

Let us now modify our initial assumption about the area affected by the dieback and reduced future productivity. Suppose that the region affected were much larger, encompassing all of Europe and perhaps the U.S. South which is also a very major producer of industrial wood. In this case the effects would be the same in direction but the amplitudes would be much larger. More salvage would depress initial prices even further. Investment would decrease in the much larger affected area but this would promise even higher future prices, encouraging even greater investments in nonaffected regions. More total dislocations of harvests would occur together with more offsetting investments. In the long term harvests would be somewhat lower and prices higher than in the previous scenario.

In any variant of the above situation the world's industrial wood sector would be expected to respond to a dieback in one or several regions, with a shift of timber growing investments to nonaffected regions. The larger the affected regions, the larger the dislocations and adjustments and the larger the long term impact.

4. FOREST DIEBACK IN THE U.S. AND ITS CONSEQUENCES FOR REGIONAL AND WORLD TIMBER PRODUCTION: A HYPOTHETICAL CASE

Figures 2 and 3 present the price and harvest consequences of the hypothetical case of a forest dieback occurring in only one region, the U.S., with the assumption of no salvage. This situation is, in effect, one in which the long term biological productivity of the forest is reduced. The result will be a decline in future timber harvests due to both lower natural growth and reduced investment in regeneration and management in the affected areas. In this hypothetical example, the U.S. competitive position in timber production declines, resulting in a shifting of the structure of investment out of U.S. forests and into competing timber growing regions.

Figure 2 presents the comparative intertemporal time paths of the real price of timber for the forest decline situation just posited as compared with the situation without forest decline. Throughout the time period the real price of timber will be higher than without the decline. This reflects the fact that the timber resource will be more valuable in a world with less prime timber growing lands.

Figure 3 presents the comparative intertemporal time paths of harvest for the entire system (the world) and for the decline impacted U.S. It should be noted that the decline in worldwide harvests is only about one-half of the decline in U.S. production. The reason for this is that in the fact of expected declines in investments and harvests in the U.S., the non-U.S. competing regions expand their investments in timber regeneration and timber growing thus offsetting much, but not all, of the declines experienced in the U.S.

FIGURE 2

PRICE OVER TIME

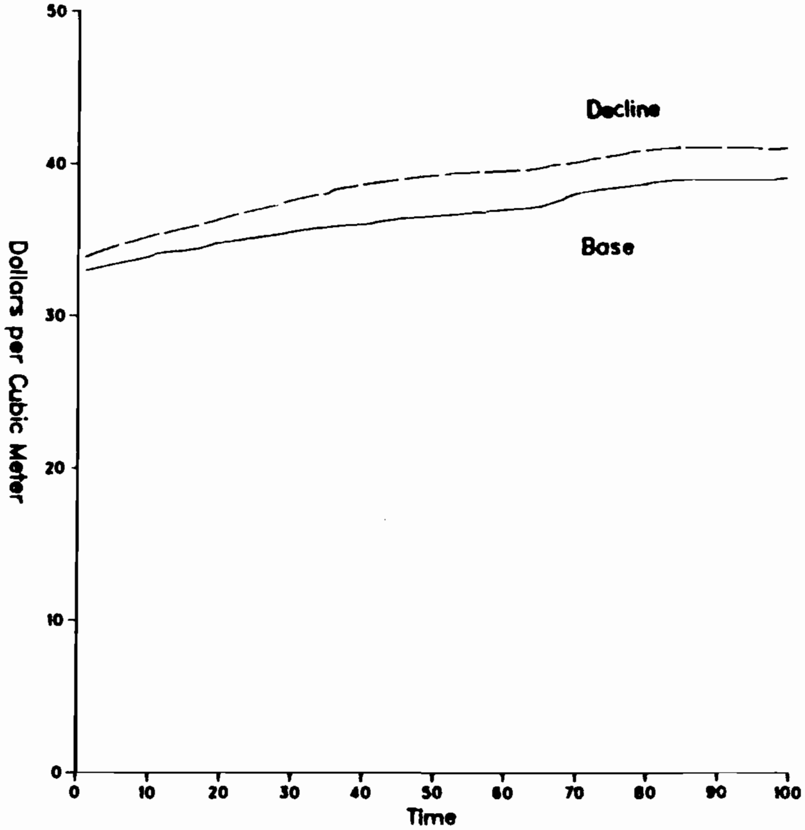
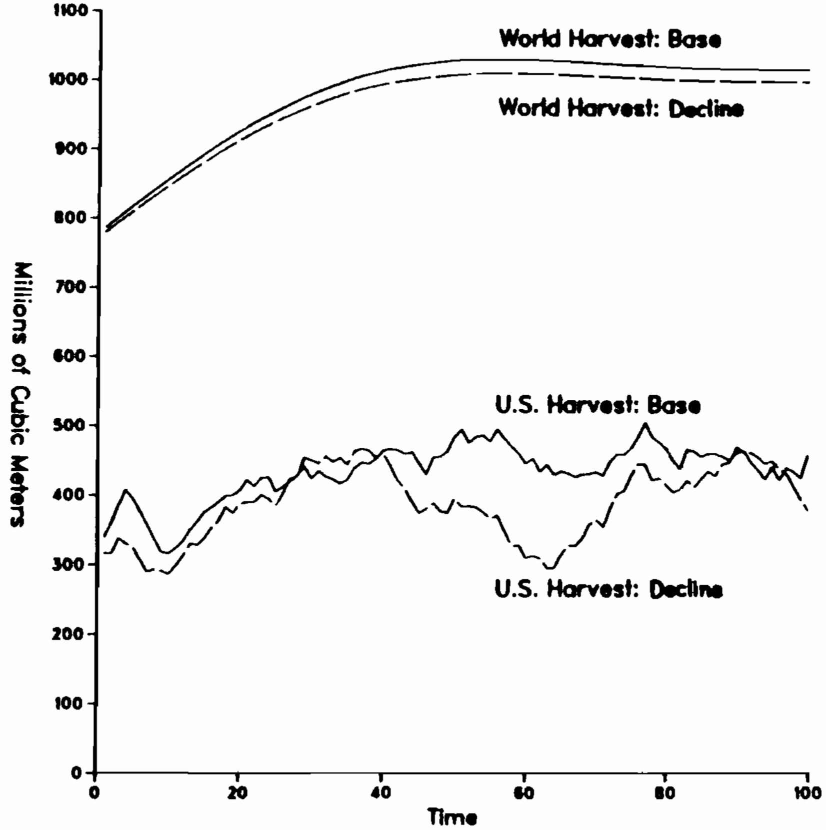


FIGURE 3

VOLUME OVER TIME



5. CONCLUSIONS

It is clear that forest decline is impacting on U.S. forests as well as on the forests of Europe. However, the evidence suggests that while we don't yet fully understand either the extent of the dieback or the full causal relationships, the problem is much less serious in the U.S. than it is in Central Europe with the majority of the damage probably being largely confined to high elevation forests in the northeast. Furthermore, at this point in time the damage appears to be occurring mostly on forests which are marginal as industrial wood producers and so is unlikely to have large impacts upon the industrial wood industry.

Using the Timber Supply Model as a construct, analysis suggests that should a region be severely impacted by forest decline, the consequences would likely go beyond that region and impact the world market for timber. However, a significant share of the long term impact could be expected to be offset by restructuring investments in regeneration and forest management away from the impacted region to competing forest growing regions. Thus, while forest decline would result in decreased harvests and increased prices in the long run, some offsetting market actions can be expected which would mitigate the international impacts.

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7.4 DYNAMICS OF FOREST RESOURCES. THE BURGUNDY REGION EXAMPLE*

J-L. Peyron
Ecole National du Génie Rural, des Eaux et des Forêts
F-54042 Nancy Cedex, FRANCE

1. NATIONAL BACKGROUND

The French forest sector employs about 600.000 people or 2.5 % of the active population. Its contribution to the gross domestic product is 2.5 to 3 %.

1.1. Increasing resources

When considering forests bigger than 0.5 ha and poplar plantations, forest area is quickly increasing :

TABLE 1 Evolution of the French forest area

Year	Area (million ha)	Annual increase (ha)
1892	about 9.5	
		67.000
1974	13.98	
		14.000
1984	14.12	

Sources : Huffel (1904), SCEES (1977), SCEES (1986).

The annual increase has diminished but is likely to keep its level because many lands will soon be abandonned by agricultural activities.

Moreover, other variables than area are interesting for the description of forest resources. Many poor forest stands have actually been planted too so that old forest area is more productive.

For instance since 1947 2 million hectares both of bare lands and poor forests have been planted with grants from the National Forest Fund and they will soon product big quantities of wood.

When considering productive forests only, the evolution of the stumpage volume is given in the following table :

TABLE 2 Evolution of stumpage volume and increment

Variable	Value[a] 1985	Annual growth rate[b]
Stumpage volume	1650 million m^3	+ 1.75 %
Annual increment	61.1 million m^3	+ 2.50 %

[a]Approximately for the stem up to diameter 7 cm. [b] estimation
Source : National forest survey and Bazire (1985).

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These estimations show both an increase of the growing stock and an imbalance in the advantage of low age classes. They allow thus to conclude that this evolution will go on and experts estimate that the allowable cut will be enlarged by 10 million m3 in the next ten years and even more later on.

1.2. Forest dieback

A forest dieback has been noticed in France, especially in the Eastern part. A survey has been started in 1983 with the same characteristics as in other European Economic Community countries. The last results show that the situation does not become worse and worse and the damage is now often steady or even reduced. However, it can increase again and the risk is very important.

From the technical and economic points of view, the forest dieback can decrease the forest growth (but this effect has not been noticed until now) and limit silvicultural choices.

1.3. Forest sector problems

Many wood industries must be modernized and have problems of investments. They have thus some difficulties in being competitive and taking market shares. This can be particularly noticed when estimating the French needs for wood and how they are satisfied.

TABLE 3 Estimation of needs for wood in million m3 roundwood equivalent

Variable	1973	1982
Marketed removals[a]	30.8	28.2
Net imports of roundwoods	0.2	- 1.2
Net imports of bulk products (panels,pulp,sawnwoods,...)	7.7	9.8
Net imports of final products	3.7	4.8
Total net imports	11.6	13.4
Actual needs[a]	42.4	41.7
Apparent consumption of recycled products	8.8	9.8
Total needs	51.2	51.5

[a] non marketed removals are not included ; they can vary between 10 and 25 million m3.

Sources : Guillon (1978), de Naurois (1985).

This table gives several informations : (1) needs have decreased between 1973 and 1982 thanks to recycling (42.4 to 41.7 instead of 51.2 to 51.5 in million m3 EQ) ; (2) marketed removals have decreased more than actual needs and moreover a part of them has been directly exported ; (3) consequently imports of both bulk and final products have increased and reached a high level.

1.4. Necessity of models

On the one hand, the available forest resources are strongly increasing and they are also threatened with the forest dieback ; on the other hand, wood industries are not for the moment dynamic enough to use much more wood raw materials. It appears thus necessary to prepare the future by studying the effects during a twenty year period of several measures and different situations on the forest sector composed with both the forests and the wood industries.

The development of models gives supplementary and efficient tools to decision makers or managers. Such an approach has been started in France. The first model - which must still be improved - has not yet included the forest dieback but could nevertheless be used to evaluate some consequences of such an issue.

This paper will then present regional considerations and describe the main and forest features of a regional model.

2. REGIONAL ISSUES

2.1. Relevance of regional forest sector policies and models

The forest policy has always been run mainly from Paris. The National Forest Fund is an example of its tools. However the economic and social decision-making power of regions is increasing. For the forest sector, this fact can be explained by ecological, political and economic factors.

France has actually a big ecological diversity that influences by the way the effects of air pollution on forest stands. Then, the political power of the twenty two regions has been growing since its creation in 1972 and was recently strengthened especially in the forest sector. Moreover, differences between resources and industrial locations and the economic crisis of the last fifteen years lead some regions to see development and employment possibilities in the forest sector on condition that it will not be too affected by the forest dieback.

These factors are the reasons why many regions want to analyse the future linked evolutions of available forest resources (the supply) on the one hand, industrial capacity and characteristics (the demand) on the other hand, in regional forest sector models.

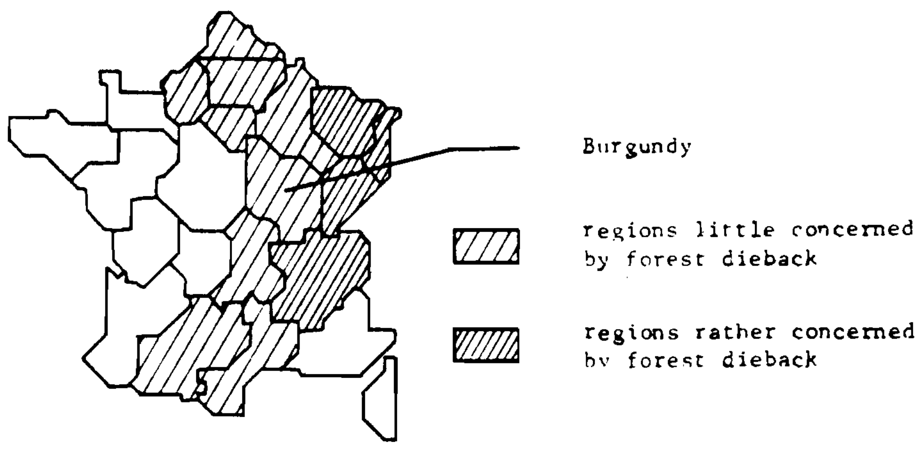

FIGURE 1 French regions and forest dieback

2.2. The Burgundy example

Ten years ago, the economic situation of Burgundy was rather good but it has quickly changed as it can be shown when considering unemployment :

TABLE 4 Unemployment evolution in Burgundy

Year	Active population	Unemployment	Unemployment in France
1975	625 000	2.83 %	3.86 %
1982	678 000	7.82 %	8.53 %
1984	690 000[a]	9.5 %[b]	9.6 %[b]

[a] extrapolation [b] approximation

Source : from INSEE.

On the contrary, the forests are developing and productive ones have the following characteristics :

TABLE 5 Forest area, volume and increment in Burgundy in 1986

Variable	Non conifers	Conifers	Total
Area value (million ha)	0.80	0.15	0.95
annual growth rate (%)	- 0.1	2.2	0.2
Volume value (million m3)	103	16	119
annual growth rate (%)	2.3	5.7	2.6
Increment value (million m3)	3.1	1.2	4.3
annual growth rate (%)	0.7	9.9	2.2

Source : extrapolation from National Forest Survey.

The distribution of forest areas between State, Communities and non-industrial private owners is 10 %, 21 % and 69 %.

The forests are mainly broadleaved but many coniferous plantations have been made since the second world war and will soon reach their production phase. Among broadleaved trees, oak is the main species and represents 78 % of the area, 61 % of the stumpage volume and 50 % of the increment.

The stand structure is often coppice with standards and so, uneven aged :

TABLE 6 Stand structures areas in Burgundy (in %)

Stand structure	non conifers	conifers
High forests	8.9 %	11.5 %
Coppice with standards	66.4 %	-
Other structures	11.3 %	1.9 %

Source : National forest survey.

Forest dieback is surveyed but just a very small damage has been noticed.

As generally in France, most of roundwood is sold on stumpage and a large part of it is bought directly by sawmillers. There is thus no roundwood market. The marketed removals have decreased for hardwoods but increased for softwoods :

TABLE 7 Marketed removals evolution 1974-1984 (thousand m3)

Wood qualities	Year	non conifers	conifers	total
Sawtimber and veneer timber	1974	654	106	760
	1984	571	114	685
Pulpwood	1974	328	72	400
	1984	294	122	416
Other industrial wood and fuel wood	1974	-	-	262
	1984	-	-	167

Source : Ministry of Agriculture

No pulp and paper industry is located in Burgundy. Two important board industries are working but their production cannot be given (statistical secret).

Sawmills are numerous, small and their mean production is increasing slowly :

TABLE 8 Number and production of sawmills in Burgundy

Year	Number	Production (thousand m3)	Mean production (m3)
1969	297	336	1 131
1974	283	355	1 254
1979	246	322	1 309
1984	200	277	1 385

Source : Ministry of Agriculture

As for secondary industries, most of the wood they used comes from outside Burgundy (Fleury 1986) and it is difficult to analyse precisely their wood consumption.

Finally, the Burgundy forest sector gives a good example of national issues.

3. PURPOSES AND STRUCTURE OF FIBRE MODEL

3.1. Purposes

It is desirable that a forest sector model can be applied to the whole of a region. The methodology must also be applicable to other regions. The model must illustrate possible consequences for the forest sector under investigation of different measures for achieving, in various situations, an increased industrial utilization of the allowable cut for hardwoods and softwoods respectively.

This model is mainly intended for administrative and political decision makers, but it could also be of value to industrial managers when they have understood the extent to which such a model can be useful.

Burgundy has been chosen as the first area for implementing a model, and the investigation period is 1975-2005.

For the moment and for reasons directly linked with the above description, the only industries represented in detail in the model are sawmills but links with the rest of the sector including pulpwood, fuelwood and residues are obviously taken into account.

3.2. Situations and measures directly simulated

The different situations that appear concern (i) the sawnwood demand, (ii) sawnwood prices, (iii) labour costs, (iv) labour productivity, (v) sawmills miscellaneous costs, (vi) exchange rates the effects of which can be tested through assumptions made for prices (see (ii)).

Measures that can be taken by decision makers in these situations are changes of (i) taxes and charges, (ii) subsidies, (iii) the prime rate, (iv) the life time for capacity and (v) investments that can be tested through the above variables.

Other circumstances can obviously but less easily be simulated by changing parameters of the model.

3.3. Model structure

FIBRE model runs on a personnal computer belonging to IBM PC and true compatible class, with a Dynamo compiler.

It is composed of several submodels or modules :

- a core module which organizes links between other modules,
- a policy module where scenarios - that is to say different measures and possible situations - are defined,
- five modules describing the forest sector :

. the demand and market module calculates the potential demand for sawnwood in Burgundy by multiplying the French apparent consumption of sawnwood by the Burgundy market share on the national market.

. the industry module calculates the sawmills capacity, the financial flows, the revenue and production costs, the sawnwood production, the potential demand for sawtimber and the employment.

. the roundwood market module estimates prices, potential demand and supply of roundwoods and the actual cut calculated as the minimum value of the last two variables taking trade into consideration.

. the forest management module is relative to harvesting costs and employment in logging activities.

. At last, the forest module which describes the forest growth.

- two data modules of which one for forest data.

3.4. Treatment of regional features

At the regional level, problems with data are emphasized. Many data are actually needed and they can be absent or not reliable. It is therefore necessary to succeed in avoiding these problems.

. final demand : the Burgundy final demand is considered as a share of the total demand in France.

. interregional trade : there is a lack of interregional trade data so that is not possible to treat the region as a nation. It would not be either realistic to do so. The Burgundy industrial production is therefore treated as a market share of the total demand in France.

. wood flows : regional data are used for standing volume, forest growth, actual cut, sawmills production and in a more general way for wood flows.

. costs and prices : national data can often be used for costs and prices because they are more reliable and not very different from regional ones.

4. FOREST GROWTH AND MANAGEMENT

This part of the model consists in monitoring the number of trees in each diameter class, in calculating a potential supply from the allowable cut, and in distributing the actual cut among the diameter classes.

4.1. Principle

Let us consider n successive life stages to which trees can belong. In this case, these stages are diameter classes because of the uneven aged structure of many stands.

Between time t and time t+1, a tree that is in stage i at t has probabilities of $d_i(t)$ of dying and $c_i(t)$ of being cut. Moreover, a tree that stays alive has probabilities of $s_i(t)$ of staying in stage i and $p_i(t)= 1-s_i(t)$ of passing to the next stage. The model needs a final assumption : the coefficients s_i, p_i, c_i and d_i are considered as constants. The process is thus a stationary Markov one.

To calculate volumes, the individual volume v_i of a tree in stage i is needed ; v_i is also a constant. Furthermore, the first stage consists of trees that will pass to the second stage in one year and expresses the regeneration. For the moment, eleven other stages are considered and are all diameter classes from class 10 (7.5 cm to 12.5 cm) to class 60+ (57.5 cm and more).

4.2. Parameter estimation

In France, the National Forest Survey covers about one tenth of the forests, each year, Department by Department. Decided in 1958 but started during the sixties, most of departements have been surveyed twice.

For Burgundy, the dates of the surveys were : Côte d'Or (1971 and 1980), Nièvre (1974 and 1985), Saône et Loire (1970 and 1979), Yonne (1975).

These data make it possible to calculate, by interpolation, data for 1975 in each stage or diameter class for :
- number of trees,
- individual volumes,
- number of dead trees during one year,
- number of cut trees during one year,
- diameter increment Id_i with which it is possible to estimate for a tree the probabilities of staying in the same class or of passing to the next between t and t+1 ($p_i = Id_i/0.05$).

TABLE 9 Forest data for hardwoods in Burgundy in 1975

Stage	Number of trees (in thousand)	volume of a tree (m3 o.b.)	Number of dead trees (1000/year)	Number of cut trees (1000/year)	Diameter increment (mm/year)	Silvicultural coefficients (in %)
R[a]	25 714					
10	400 603	0.028	749	4 909	2.36	7.9
15	102 025	0.099	154	2 161	3.18	13.6
20	39 777	0.206	46	718	3.50	11.6
25	21 195	0.352	28	292	3.73	8.9
30	14 687	0.553	17	130	3.69	5.7
35	9 936	0.822	10	72	3.89	4.7
40	7 323	1.180	10	55	3.96	4.8
45	4 804	1.620	5	43	3.97	5.8
50	2 863	2.056	1	27	4.33	6.1
55	1 562	2.561	1	16	4.24	6.6
60+[b]	1 563	3.882	2	59	4.52	24.3

[a] annual recruitment [b] trees with higher diameter than 57.5 cm
Source : from National Forest Survey.

Stumpage volumes measured in forests are a little different from those supposed to be used by industries and households ; in this model, these volumes have been adjusted with coefficients taking branches and bark into account.

4.3. Mathematical formulation

. monitoring the number of trees

Let $x_i(t)$ be the number of trees in stage i at time t, $y_i(t-1,t)$ and $z_i(t-1,t)$ the number of cut and dead trees between t-1 and t :

$$x_i(t) = p_{i-1}\,(x_{i-1}(t-1)-y_{i-1}(t-1,t)-z_{i-1}(t-1,t)) + s_i\,(x_i(t-1)-y_i(t-1,t)-z_i(t-1,t))$$

. calculating annual increment

The annual increment I(t-1,t) between t-1 and t is calculated from the standing volumes V(t-1) and V(t) at t-1 and at t, from the actual cut C(t-1,t) and the mortality D(t-1,t) between t-1 and t.

$$I(t-1,t) = V(t) - V(t-1) + C(t-1,t) + D(t-1,t)$$

. calculating the allowable cut

Let A(t,t+1) be the allowable cut between t and t+1. Q is a coefficient that can be 0.4, W(t) is the volume of trees bigger than 42.5 cm and T the time corresponding to a growth from 42.5 cm to 62.5 cm :

$$A(t,t+1) = Q \times I(t-1,t) + W(t)/T$$

The potential supply is a constant share of the allowable cut.

. distributing the actual cut

The actual cut C(t,t+1) between t and t+1 is calculated from the corresponding potential demand and supply taking trade into consideration. If r_i is the share of cut trees noticed by the national forest survey, the actual cut is distributed among the diameter classes according to :

$$Y_i(t,t+1) = \frac{r_i}{\mathrm{SIGMA}\,(r_j\, v_j\, x_j(t))}\; x_i(t)\; C(t,t+1)$$

The coefficients r_i, are important because they express silvicultural activities ; they are now considered as constants but could be changed ; their reference values are presented in percentage in TABLE 9 for hardwoods.

4.4. Interests and limits of the model

In this kind of rather global model, a simple forest module is needed and the example presented above can be sufficient. Nevertheless this part must be improved by considering more diameter classes. Several other aspects of the model must also be improved, especially the estimation of some parameters. They are thus able to make forestry economics progress.

This model can also be a starting point for discussions inside a regional forest sector and be applied to special situations. It could for example be used to simulate the evolution of the forest sector taking into account effects of forest dieback such as changes in diameter increment, in silviculture or in mortality.

5. CONCLUDING REMARKS

An analysis of the national forest sector has led to regional approaches and models based on dynamics of forest resources on the one hand, on industrial capacity and competitiveness on the other hand. The FIBRE model that has been first developed for Burgundy fulfill the objectives. It can be applied to other regions and used with some adaptations in forest dieback conditions.

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7.5 WOOD FORMATION IN DECLINING FORESTS AND THE CONSEQUENCES FOR WOOD QUALITY*

A. Frühwald and J. Bauch
Institutes for Wood Technology and Wood Biology
Hamburg University
D-2050 Hamburg
FEDERAL REPUBLIC OF GERMANY

1. INTRODUCTION

Forest decline has become a serious problem in many countries of the northern hemisphere. Particularly since the late 1970's. The diseases of fir and spruce but also the damage to pine and hardwood species like beech and oak have initiated research efforts in many countries. In the Federal Republic of Germany research began around 1975 and aims to understand the causes of forest decline and its effect on the formation of the wood tissue. Although knowledge of the causes of tree disease are not completely understood now, the relationship between tree disease and wood quality can be interpreted comprehensively. Interdisciplinary and interinstitutional cooperative research has contributed important results within a reasonable time.

In this respect, knowledge of wood formation under stress caused by local industrial pollution was very helpful, because the methods for the investigation had already been developed. It is known from these studies that a distinct growth reduction occurs (Vins 1962, Pollanschütz 1971). In some cases anatomical alterations of the wood cells were described (Liese et al. 1975, Grill et al. 1979, Kartusch and Halbwachs 1985). Reduction of latewood density was found with a moderate impact on density and mechanical properties as well (Eckstein et al. 1981). However these results were not relevant to the new problem of forest decline, because the die-back of the forests occurred far from industrial pollution sources.

For evaluation of the possible impact of die-back to the forests three major questions arose:

(1) Are there any biological and chemical alterations initiated in the cambium at the time of wood formation?

(2) Is there any secondary damage in the wood tissue of the diseased trees such as chemical changes and occurrence of microorganisms?

(3) Is there a predisposition in the wood of diseased trees toward quality loss during log storage or a higher sensitivity to fungus and insect attack during use?

Preliminary results on the alterations of wood from damaged forest sites, published by Bauch et al. (1978) and v. Aufsess (1981) were concentrated on fir because of its heavy decline during the mid and late 1970's. Along with other tree species intensive research was extended to spruce (Bauch and Frühwald 1983, Frühwald et al. 1984, Schulz 1984, Knigge et al. 1985, Schulz (ed.) 1985, Fengel 1985, Puls and Rademacher 1986, Pozgaj and Kurjatko 1986 and others) and pine (Frühwald et al. 1986). Since 1985 in

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the FRG major work is concentrated on beech (Frühwald 1986, Wahlmann 1986, Rademacher 1986, Frühwald et al. 1987 a) and in 1986 projects were started dealing with the wood quality of oak. In other European countries most emphasis is still given to softwoods because of their more severe decline and their greater economic importance compared to hardwoods.

2. MATERIAL AND METHODS

The investigation of wood from damaged forest sites relates to the wood quality immediately after the felling of the trees. For this purpose a number of trees (up to 20) of the various stages of disease as well as healthy appearing trees were selected from the same site[1]. Some studies only dealt with trees from one site whereas others (i.e. Schulz (ed.) 1985 for spruce, Frühwald (ed.) 1986 for pine) included several sites with different natural stress and immission of pollutants. Normally discs were cut from the trunk of the tree at different heights for the determination of width of growth rings, biological (i.e. fiber dimensions, water content, pH-value) and chemical properties of the wood. Samples from short logs of 0,5 m and from logs up to 4 m in length were taken for testing physical (density, shrinkage) and technological properties (modulus of elasticity, various strength factors, gluability etc.) The properties of the wood were tested, from the outer and inner sapwood and outer and inner heartwood. Logs were also kept in storage (forest log yards, under sprinkling water, in log ponds) to study the effect on quality during storage.

3. RESULTS OF THE VARIOUS INVESTIGATIONS AND DISCUSSION OF PRESENT KNOWLEDGE

From more than ten years experience with quality research on wood of declining forests in the Federal Republic of Germany the following report is based on results from several projects.

3.1. Growth ring analysis

On some sites of the FRG, Switzerland and Yugoslavia (e.g. Bauch et al. 1979, Schweingruber 1986, Torelli et al. 1986) the start of growth depression of heavy diseased fir trees dates back to the 1950's although the disease only became visible in the crown many years later. Spruce followed this pattern with a delay of several years, but in many cases a close correlation between needle loss (and damage class respectively) and growth reduction is not obvious (Kenk et al. 1984, Bauch et al. 1986, Schweingruber 1986). This is also valid for pine (Frühwald et al. 1986), where a growth ring depression on some sites started around 1960 whereas on other sites no growth reduction could be determined (Fig. 1). Growth ring analysis for beech and oak reveals a rather confusing result. Some trees of higher damage classes may have a small but significant reduction, but as a rule there is no depression in ring width. A few heavily diseased beech and oak trees even show an increase in growth. These findings have been confirmed by Rademacher (1986) and Wahlmann et al. (1986). The influence of climatic parameters on the growth of softwoods and hardwoods in relation to forest decline was studied by Kienast (1982), Eckstein et al. (1983) and Greve et al. (1986). It was found that a drought year can decrease the ring width but it is not the main cause for decline.

1) The classification of damage classes was carried out according to the concept for the visual "Waldschadenserhebung" in FRG. The problem of this classification is not discussed in this paper although classification is the key to interpretation of test results.

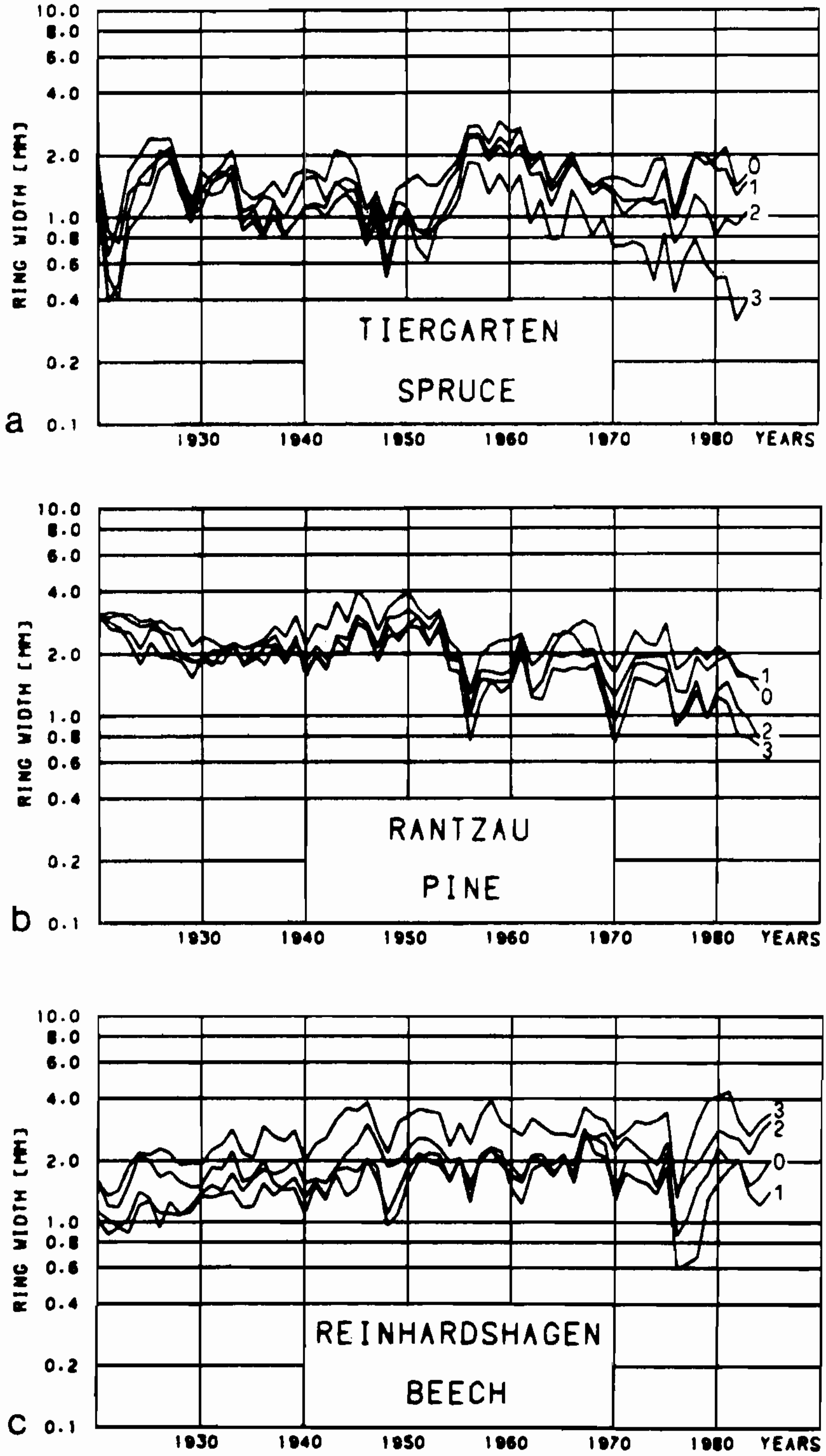

FIGURE 1 Growth ring width at breast height for spruce (a), pine (b) and beech (c) from three different locations of the FRG.

3.2. Early- and latewood percentage

In narrow rings of diseased trees the proportion of earlywood and latewood may either be the same as in healthy trees (Grosser et al. 1985, Eckstein et al. 1981, both for spruce) or the latewood percentage is increased (Eckstein et al. 1981 for fir, Liese et al. 1975 for spruce). In very narrow rings of fir the latewood portion decreases (Bosshard et al. 1986). These changes have, of course, an impact on density but they are in the normal pattern of the relationship between ring width and density.

3.3. Tracheid dimensions

Ring width and tracheid length can vary within a wide range. Measurements from 12 spruce trees of different damage classes from the northern part of the FRG showed no relationship between ring width and tracheid length (Göttsche-Kühn 1987). Grosser et al. (1985) confirmed this result with wood grown in the south of the FRG. Bosshard et al. (1986) reported shorter tracheids in heavily diseased spruce whereas he found an increase in fiber length in two diseased fir trees as compared with healthy ones. Aszmutat et al. (1986) and de Kort (1986) found shorter tracheids in diseased spruce than in the healthy ones. Histometrical measurements of lumen and wall diameter give information on alterations in wood formation. The cross-sectional area of the earlywood tracheids can be considerably reduced in damaged trees mainly due to the reduced radial cell expansion during cell development. The wall thickness of latewood tracheids of spruce can be reduced by up to 30 % in very advanced stages of disease (Bauch et al. 1986). Larson (1973) found for young healthy conifers that tracheid diameter was mainly influenced by the amount of auxin reaching a developing tracheid whereas wall thickness appeared to be related on the soluble sugars available at the cambial zone. Puls et al. (1985) found the absolute content of soluble sugars to be reduced in heavily diseased spruce trees. Göttsche-Kühn (1987) found for similar diseased trees that the activity of the cambium was delayed in spring and stopped earlier in late summer compared to healthy trees. Supplementary observations with the electron microscope by Fengel (1985) and Sachsse and Hapla (1986) confirm that the packing density and fine structure of the cell wall are unaltered.

3.4. Water content

The water content in the active phloem and cambial tissue was at the same level in healthy and diseased trees. In sapwood of spruce moisture content decreases parallel to the advance of the disease (Fig. 2). However, in fir wetwood may spread out irregularly into the sapwood at a late stage of disease. For spruce a corresponding development of the wetwood is not seen. For beech and oak so far no difference could be determined either with regard to distribution of moisture content or with regard to irregular heartwood. But many foresters believe that in heavily affected stands of beech older than 120 years a irregular heart develops faster and more severe than in healthy trees. This will be a subject of research within the coming years. Reduced sapwood width as in spruce and to a lesser extent in pine (Fig. 2) and moisture content of softwoods are important because of the development of discoloration caused by fungal attack during storage of logs. Heavily affected trees contain less water and reach a critical moisture content for fungal attack earlier than healthy trees. Discoloration may start earlier and more intensively, which may be important for storage of wood (Göttsche-Kühn und Frühwald 1986).

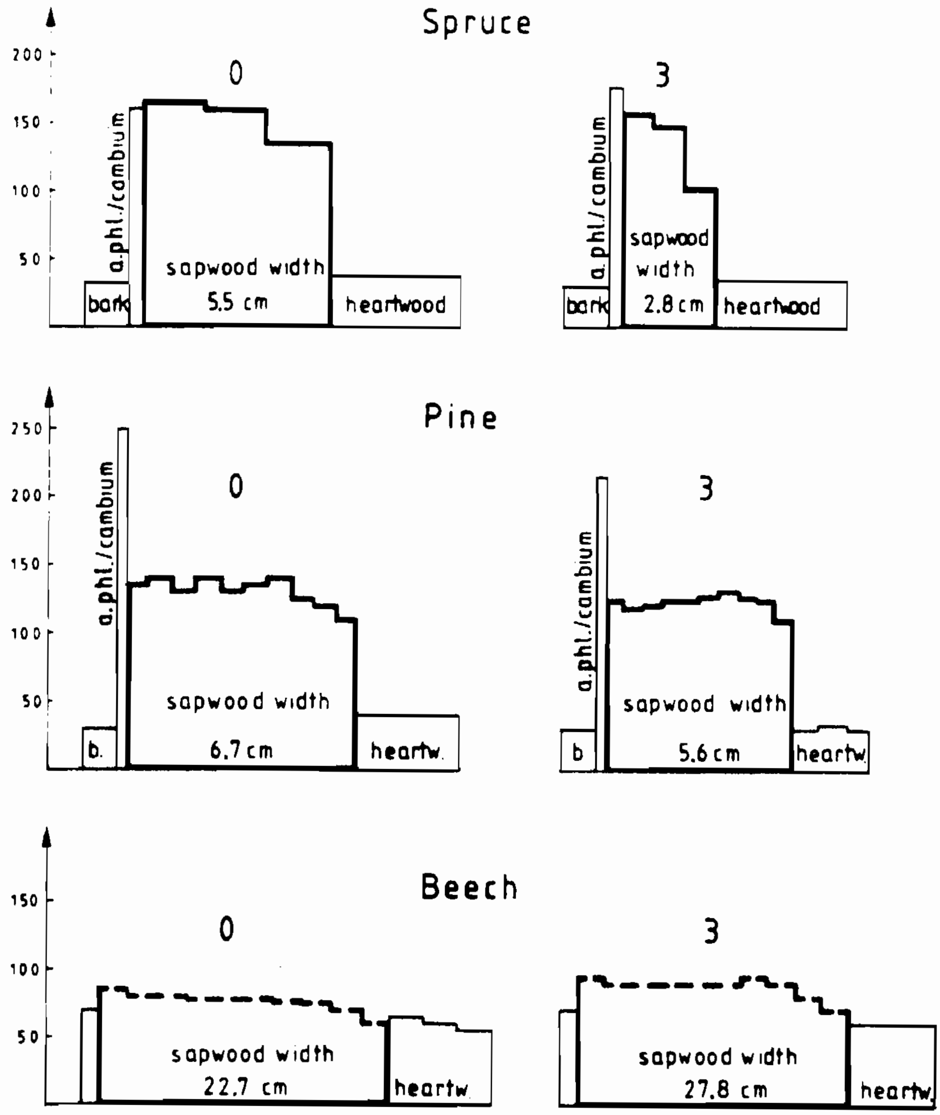

FIGURE 2 Moisture distribution (percentage of ovendry weight) over the cross section of the trunk at the time of felling. Mean values for five trees of each damage class 0 and 3; a. phl. = active phloem.

3.5. Chemical composition of the wood tissue

The percentage of soluble sugars (glucose, fructose, sucrose) is higher in diseased spruce trees than in healthy ones (Fig. 3). This is true for the last 5 - 15 growth rings. But the total content of sugars is reduced in diseased trees because of the smaller growth rings. The quantity of starch amounts to only 30 % in affected trees compared to the control trees (Puls and Rademacher 1986). Fink (1986) confirmed this finding and found a lower enzyme activity of ATP-ase and phosphatases. These results show the necessity of further comprehensive physiological studies to understand the response of wood formation of declining trees. The main components of the wood cellulose, hemicellulose and lignin remain unchanged according to results

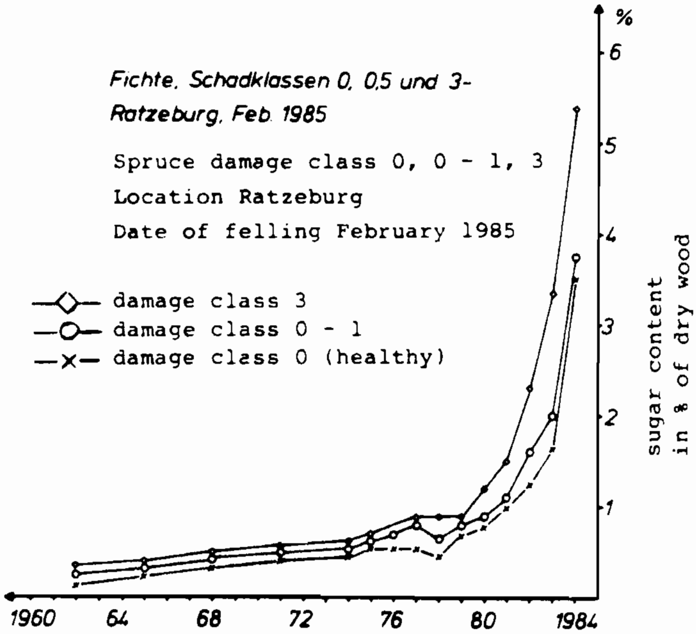

FIGURE 3 Content of soluble sugars in the wood of the growth rings 1968 - 1984 of spruce trees.

reported by Fengel (1985) and Puls and Rademacher (1986). The pH-value of squeezed sap of highly diseased (almost dead) spruce trees is slightly reduced (Fengel and Schulz 1986) whereas for beech of different damage classes Frühwald et al. (1987 a) could not find any differences.

3.6. Occurrence of microorganisms

Trees with a decreasing level of physiological activity are liable to higher risks for microbial attack. Brill et al. (1981) found several strains of bacteria in fir trees. Corresponding microbial investigations with spruce were carried out by Schmidt (1985), v. Aufsess (1986) and Schmidt et al. (1986). Logs of healthy trees were scarcely colonized by microorganisms. In diseased trees the microbial flora increased and in addition to bacteria, yeasts and fungi imperfecti also stereum species were identified.

3.7. Density

From numerous measurements it appears that in diseased trees the density can either slightly increase as soon as the latewood portion goes up or slightly decrease when the wall thickness diminishes in extremely narrow rings of softwoods (Frühwald et al. 1984, Schulz 1984, Bosshard et al. 1986). This is also valid for pine (Frühwald et al. 1986). For beech and oak no influence of disease on the density could be observed.

3.8. Mechanical Properties

Although testing of mechanical properties occupies a major part of the experiments the results can be described briefly. No difference has been found for any of the properties and tree species between healthy and diseased trees or between the inner part of the cross section and the outer sapwood. Of course, mechanical properties are very much influenced by wood density and this correlation was accounted for by regression analysis to eliminate the influence of density (Schulz (ed.) 1985, Frühwald et al. 1986, Frühwald (ed.) 1987). After adjusting the mechanical properties to a constant density no difference occurs between the damage classes from a single location. It is obvious that material from different locations shows different properties. An example for the relationship between density and bending strength for spruce is given in Fig. 4. The outer sapwood (So) grown under influence of pollution shows the same quality as the other parts of the trunk.

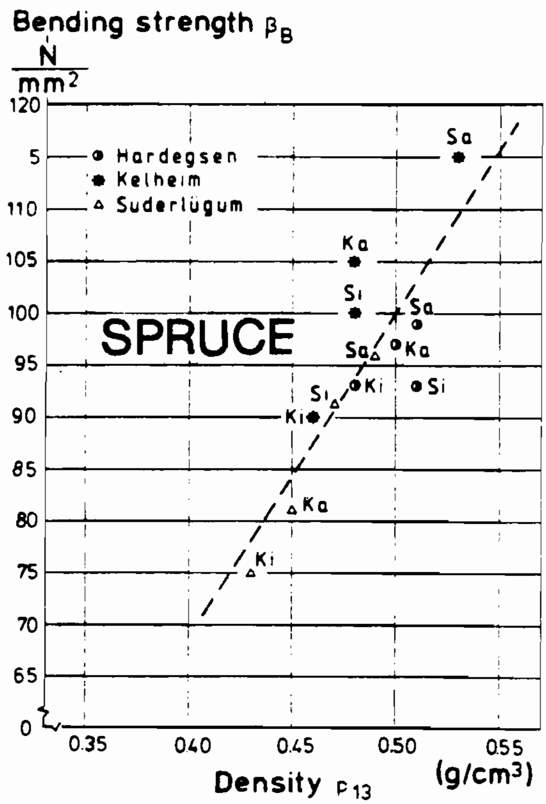

FIGURE 4 Bending strength and density in healthy (Δ) and diseased (*, o) spruce trees from three locations in the FRG.

Table 1 lists the various properties for pine according to damage classes. Neither the mean values nor the coefficient of variance indicates that wood from diseased trees is of lower quality. The conclusion that mechanical properties of the wood are not affected by the disease of the trees was confirmed by Glos and Schulz (1985), Frühwald et al. (1985), Grammel et al. (1986), Schulz (1986), Aszmutat et al. (1986) and Böttcher (1986). Frühwald et al. (1987 a) tested beech and found no differences relating to tree di-

TABLE 1 Wood properties of the outer (So) and inner (Si) part of the sapwood of pine at two height levels (low, high) of the trunk. Values of properties adjusted to a density of 0,51 g/cm³

		Damage class 0				Damage class 1				Damage class 2				Damage class 3			
		low		high		low		high		low		high		low		high	
		So	Si	So	Si	So	Si	So	Si	So	Si	So	Si	So	Si	So	Si
location Forchheim																	
Modulus of elasticity	N/mm²	10800	11200	10800	10800	9700	10000	10200	10200	11000	11400	10700	10800	10900	11200	11100	10900
Bending strength	N/mm²	91.3	93.5	93.8	94.0	84.9	85.7	89.4	89.7	93.0	92.5	93.5	94.7	94.0	95.8	94.5	94.3
Compression strength	N/mm²	49.4	50.3	48.3	50.0	45.4	46.2	46.5	47.6	49.2	49.2	48.7	49.9	48.3	49.7	49.5	51.2
Impact bending	kJ/m²	49.5	44.7	42.5	40.9	43.7	44.2	41.2	39.0	47.1	44.3	43.8	40.5	49.5	46.9	44.6	39.1
Torsion strength	N/mm²	15.5	15.3	14.3	14.5	13.9	14.0	14.2	14.2	14.5	13.2	14.7	14.4	14.8	14.8	14.5	14.7
Shear strength rad	N/mm²	11.6	11.9	12.4	11.9	11.5	11.6	11.8	11.9	11.7	11.9	12.5	12.2	12.0	12.2	12.3	12.2
Shear strength tan	N/mm²	9.9	10.0	10.5	10.8	10.3	10.2	10.0	10.5	10.1	10.2	10.4	10.6	10.3	10.5	10.2	10.5
location Wildbad																	
Modulus of elasticity	N/mm²	10900	10700	10500	10600	9400	9700	8800	9400	9800	9800	9400	10200	10000	9800	10500	10700
Bending strength	N/mm²	95.6	93.5	94.2	93.6	81.6	81.9	78.8	84.2	86.8	86.9	87.0	92.4	88.3	90.5	93.5	97.6
Compression strength	N/mm²	47.5	48.2	47.8	50.2	43.4	44.7	41.0	44.6	44.0	44.5	44.9	47.2	44.6	45.4	46.8	49.4
Impact bending	kJ/m²	43.1	42.6	40.5	39.8	41.7	41.4	35.7	36.2	42.0	42.3	40.7	39.8	48.6	42.1	40.8	39.5
Torsion strength	N/mm²	15.9	16.4	16.2	16.4	14.0	14.4	13.8	14.4	14.8	14.8	15.2	15.3	15.1	15.5	15.3	15.8
Shear strength rad	N/mm²	11.1	11.5	11.4	11.5	11.1	11.2	11.0	11.4	11.1	11.1	11.3	11.5	11.6	11.8	12.1	11.9
Shear strength tan	N/mm²	10.3	10.5	10.6	10.8	10.0	10.4	9.9	10.7	9.9	10.0	10.0	10.0	10.3	10.6	10.0	10.6
location Rantzau																	
Modulus of elasticity	N/mm²	10000	10000	10400	10400	10000	10200	10100	10100	9600	10200	9800	9800	10500	11000	11000	11000
Bending strength	N/mm²	85.6	83.3	91.2	92.9	86.8	87.1	89.5	90.8	85.6	88.4	88.6	88.2	92.2	94.0	95.5	96.2
Compression strength	N/mm²	43.8	43.6	44.0	45.3	43.8	44.8	44.1	43.8	42.9	44.4	44.8	47.6	47.2	47.8	49.0	49.5
Impact bending	kJ/m²	41.8	41.9	43.0	41.7	38.9	41.4	39.5	39.4	44.6	43.6	40.2	39.3	46.6	45.1	43.1	39.4
Torsion strength	N/mm²	14.1	14.0	14.6	14.4	14.7	14.2	14.6	14.3	15.2	15.3	14.3	15.0	14.9	14.7	14.4	14.7
Shear strength rad	N/mm²	11.0	11.1	11.4	12.0	10.9	11.2	11.0	11.2	11.0	11.0	10.9	11.5	11.2	11.4	11.5	11.8
Shear strength tan	N/mm²	10.3	10.3	10.6	10.9	10.3	10.2	10.4	10.3	9.9	10.1	9.8	10.2	10.4	10.7	10.3	10.7

sease. Glos and Schulz (1986) have tested lumber in larger dimensions, Buchholzer and Harbs (1986) dealt with particle board made of wood from healthy and diseased trees. Both came to similar conclusions.

3.9. Wood Properties of Spruce after Log Storage

After storage of spruce in the forest for a few months, the moisture content of the sapwood decreases considerably (Tab. 2). The results reported by Göttsche-Kühn and Frühwald (1986) are based on the investigation of 6 healthy and 8 diseased spruce trees. After four months the moisture content in healthy trees is about 110 % and still too high for a heavy fungal attack. Consequently the discoloration of the wood is less developed than in diseased trees with only 95 % moisture content (Tab. 3). After seven months at the end of the summer period moisture content of healthy trees was down to 60 %, an optimum for fungal attack whereas the classes 2 and 3 had

TABLE 2 Moisture content in the sapwood of logs from healthy (0) and diseased (2 + 3) trees before and after 4 and 7 months storage in a log yard.

Spruce		moisture content (%) in outer sapwood	inner sapwood	mean
after felling	0	180	155	167
	2 + 3	140	110	125
after 4 months:	0	120	100	110
	2 + 3	100	90	95
after 7 months:	0	60	60	60
	2 + 3	48	36	42

TABLE 3 Percentage of discoloured wood from healthy trees (0) and diseased trees (2 + 3) after 4 and 7 months storage in a log yard (with bark).

Spruce	not discoloured 0	not discoloured 2 + 3	discoloured 0	discoloured 2 + 3	moderately discoloured 0	moderately discoloured 2 + 3	heavily discoloured 0	heavily discoloured 2 + 3
4 months								
outer sapwood	4	8	72	50	23	26	1	16
inner sapwood	34	25	66	62	–	10	–	3
outer heartwood	87	72	13	23	–	4	–	1
inner heartwood	100	90	–	9	–	–	–	1
7 months								
outer sapwood	2	10	25	29	41	44	32	16
inner sapwood	0	9	23	71	50	13	27	7
outer heartwood	15	49	41	32	23	15	21	10
inner heartwood	49	67	31	21	5	10	15	2

only 42 % m.c. which is below ideal conditions for microbial attack. Therefore the wood from healthy trees is even more discolored than wood from the diseased ones. This leads to the recommendation that logs from diseased trees should be processed immediately after felling. However, if for specific reasons storage is necessary for a period of a few months debarking should be considered to accelerate the drying of the sapwood protion (with the risk of surface checks). The strength properties (MOE, static bending and impact bending strength) showed no difference between the fresh and stored condition. Even the strength of heavily discolored wood was not significantly reduced after a 7 months storage in a forest log yard. This corresponds to previous results reported by Pechmann et al. (1967) when after 16 months of storage in the forest the impact bending strength was reduced only by 10 %. It remains to be determined if the occurrence of microorganisms in diseased trees (Schmidt et al. 1986) and the higher concentration of free sugars in the very last growth rings (Puls and Rademacher 1986) might have an influence on the development of discoloration.

The first investigation of the wood from spruce logs which had been stored for two years under sprinkling water shows no significant difference in discoloration between healthy and diseased trees. The moisture content is still high with about 90 to 200 % in the sapwood but is still lower in diseased trees compared to healthy ones. First results for the mechanical properties show a significant reduction for MOE, bending, compression, torsional, and shear strength. But no difference occurs between healthy and diseased trees (Frühwald et al. 1987 b).

4. CONCLUSION

Considering the investigations concerned with the characteristics and quality of the wood from diseased trees in comparison with more healthy-appearing trees it becomes obvious that the understanding of wood formation is of predominant importance. Although minor alterations of certain wood properties have been observed, the macroscopic properties which are believed to play the most important role for timber utilization seem to be unchanged. The main problem is that there are many natural stress factors which cause a response in the cambium of an individual tree in such a way that it is almost impossible to eliminate the impact of stresses caused by environmental pollution.

Further research on the characteristics of wood from diseased forests is highly necessary, especially relating to the formation of wood when the trees are under stress. Until now research is done almost exclusively on old growth, but young growth should be considered also. Comparative studies on old and young growth could indicate what wood quality can be expected if the present stress and pollution input persists into the medium or distant future.

At present most studies indicate that there is no difference in the wood between healthy and diseased trees in so far as the most important wood properties for common utilization are concerned. Mechanical properties remain unchanged, very reassuring information for foresters, the forest products industry and consumers. However, research is urgently needed on the development of discoloration and irregular heartwood development as well as the storage behaviour of logs under various conditions. These studies must have high priority, because many experts assume that in some areas of Europe serious disease (also combined with natural effects - i.e. drought years) may lead to decisions to remove from the forests more than the market can absorb.

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7.6 FOREST DAMAGE SCENE FROM THE FOREST INDUSTRY'S PERSPECTIVE*

L.J. Joukhi and E. Uutela
THOMESTO Group
Eteläesplanadi 18
SF-00130 Helsinki 13, FINLAND

1. INTRODUCTION

During the past five years the forest decline, or "Waldsterben", has progressed irrevocably in Central Europe, and signs of dying forests are also to be seen in the Nordic countries. There are not yet very liable statistics available about the extent of forest damages in different countries, and definitional problems complicate comparisons between the announced figures. According to one of the most recent and reliable studies on the subject (Nilsson 1986), the level of one damage that can be said with a high degree of certainty to be caused by air pollutants, was reported to be 370 million m3 of softwood and 345 million m3 of hardwood trees in only western Central Europe. The average annual fellings of the same region are some 70 million m3 of softwood and 56 million m3 of hardwood trees, the damaged volume being thus five to six times as high as the annual fellings.

So far, no drastic disturbances caused by the fellings of damaged forests are to be seen in the roundwood markets. The total volume harvested in Central Europe has not increased considerably, since the fellings of damaged wood have, to a great extent, replaced fellings from the unaffected forests. However, the stock of sick trees is rapidly increasing in all parts of Europe, and it is obvious that the total annual fellings of wood have soon to be raised to a clearly higher level in order to avoid secondary damages by insects, fungi, decay, etc. affecting also the still sound trees nearby the damaged areas. When these additional wood volumes come into the market, the effects on the market and for the industry may be dramatic.

In the following is an outline of some of the possible effects of increased wood supply due to forest damage on the forest industries and forest products and wood trade. It should be noted that since there is little actual evidence on these effects, the following discussion is based on personal opinions only.

2. EFFECTS ON PRODUCTION LEVELS OF DIFFERENT PRODUCTS

2.1. Importance of Wood Costs

Cost competitiveness is the most important factor affecting production levels and trade flows between countries. The main cost components in the forest industry are the costs of wood or fibre raw material, energy, labour, capital and transportation. Any drastic changes in the prices of these components will directly affect the competetive position of different countries. Since the operating margins in the forest industry are relatively low, even a change of 10-15 % in one of the most important cost

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components has remarkable consequences.

The cost structure and the importance of different cost components vary by product. The sawmilling industry is raw material and labour intensive, the pulping industry capital intensive and the newsprint and other printing paper industry based largely on mechanical pulp, very energy intensive. Thus wood costs have a different importance in different forest product industries. The raw material base used for paper manufacture has substantial differences in most major products in Central Europe and in the Nordic countries (use of recycled fibre in the fibre furnish).

The following products were picked up for further discussion: Spruce sawnwood, bleached spruce chemical pulp, newsprint, LWC, woodfree fine paper, linerboard and folding boxboard. The estimated shares of wood costs in the total sales price requirement of the product, when delivered to the Central European markets, have been compiled in Table 1. Comparisons are made between the Federal Republic of Germany and Sweden, both important producers of all forest products.

It can be seen from Table 1 that the share of wood costs in the end product price varies from 50-60 % in the case of sawnwood to only 9 % in the case of LWC paper indicating thus that the effects of changing wood costs are clearly smaller on more value-added products than on bulky products. It should be noted that there is no wood cost for linerboard in the FRG since all domestic production is based on recycled fibres (testliner) and not on kraft pulp.

2.2. Changes in Cost Competitiveness Due to Lower Wood Costs

In the following a hypothetical example of the effects of decreasing wood costs on product competitiveness is outlined. It is assumed that the wood supply in Central Europe would increase permanently on a sustained yield basis by 30 % from the current level. The effects on the price level of wood raw material are difficult to assess without any estimated wood supply models but it is obvious that the price would decrease by less than 30 %.

The transportation and harvesting costs namely account for a high share of the total wood costs, and in some extreme cases the stumpage price is even negative. With reference to the fact that the forests located at high altitudes in some countries are most sensitive to the forest dieback, it is clear that the cuttings of damaged forests normally involve substantial harvesting and transportation costs. Therefore, it is assumed here that the average wood costs in Central Europe will decrease e.g. by 20 % for logs and 10 % for pulpwood if the price is purely determined by market forces.

However, it is obvious that subsidies will be used to cover part of the harvesting and transportation costs by different countries in order to secure and speed up the removals of damaged forest areas. This is the case already today in e.g. the FRG and Poland. Taking into account the possibility of state subsidizing, the price levels could decrease by more than 20 % and 10 %, let us say by 40 % for logs and 30 % for pulpwood.

It is also obvious that not all of the additional wood harvested in Central Europe will be processed into forest products in the Continental Europe. Part of logs and pulpwood will likely be sold in countries where there is industrial capacity available. The transportation costs and bottlenecks from the Continental Europe to e.g. Sweden have to be considered. But again it is possible that also wood exports will be subsidized by the states of the exporting countries. For the cost calculations it is here assumed that, without subsidizing, the wood costs for imported wood from the Continental Europe would be the same or above the current wood costs in

TABLE 1 Estimated Share of Wood Costs of the Sales Prices of Different Forest Products Delivered to the Western European Markets

Product	Share of Direct Wood Costs in Sweden	FRG
Spruce sawnwood	50-60 %	50-60 %
Bleached softwood pulp	50	50
Newsprint (purch.chemical pulp)	26	16
LWC (purch. chemical pulp)	9	9
Unc. woodfree (integrated mills)	27	27
Linerboard	52	-
Folding boxboard (purch.chem.pulp)	10	10

Source: Jaakko Pöyry

Sweden. In the case of subsidized exports from the Continental Europe it is assumed that the costs of imported wood at the Swedish mills would be some 10 % less than the current wood costs of both sawmills and the pulp and paper industry. The hypothetical effects of changing wood costs other things being equal, on the cost competitiveness of different products, are compiled in Table 2.

It can be concluded that the effects of increasing wood supply and hence the assumed decrease in wood price will be important to the cost competitiveness of sawn softwood and substantial also to that of bleached softwood pulp, whereas the effects on newsprint, LWC paper and folding box-board are minimal. In the case of uncoated woodfree paper the calculated relative benefit of 5 % of the German producers (when subsidies are used) may also have some importance although other factors, such as the higher integration degree and bigger average paper machine size of the Nordic paper industry, can to some extent counterbalance the situation.

In the production of kraftliner the Swedish producers would possibly have even a small relative benefit against the German testliner producers through the subsidized lower prices of imported wood, since there is no direct reflection of the lower wood prices on the prices of recycled fibres in the FRG.

TABLE 2 Hypothetical Effects of Changing Wood Costs in the Forest Industries of the FRG and Sweden

Product	Changes in Cost Competitiveness (%)					
	Cost decrease without subsidies in		Relative benefit of FRG (+)	Cost decrease with subsidies in		Relative benefit of FRG (+)
	FRG	SWE		FRG	SWE	
Spruce sawnwood	-10-12	-	+10-12	-20-24	-5-6	+15-18
Bl. softwood pulp	- 5	-	+ 5	-15	-5	+10
Newsprint	- 2	-	+ 2	- 5	-3	+ 2
LWC	- 1	-	+ 1	- 3	-1	+ 2
Unc. Woodfree	- 3	-	+ 3	- 8	-3	+ 5
Linerboard	-	-	-	-	-5	- 5
Folding boxboard	- 1	-	+ 1	- 3	-1	+ 2

2.3. Reflections to the Location of Production

The effects of wood cost change presented in Table 2 can be considered equal to the situation if the German mark would be devaluated against the Swedish krona with the same percentages. It is obvious that for sawnwood a shift of 10 up to 18 % in the comparative costs would also mean considerable change in the supply sources. Production increases in Central Europe do not necessarily mean that many new sawmills should be built as the capacity of sawmills is flexible and can in many cases be doubled or even tripled by simply adding a second and possibly third working shift. Currently there are still a lot of sawmills in Central Europe operating in one shift only. So far the shifts in production have been relatively small (Table 3).

The only remarkable change between 1980 and 1984 has been the drop of the Finnish sawnwood production by 2.0 million m3. This has been only partly compensated by the production increase in Sweden. In the four Central European countries included here the sawnwood production increased moderately by 2 %. When taking into account that the consumption of sawnwood in Europe was some 5 % lower in 1984 than in 1980, it can be argued that the Central European producers have gained some market share from the Nordic producers. This tendency is expected to continue, and some estimates for the Finnish sawnwood production expect a further drop to some 6 million m3 within a few years (Ehrnrooth 1986). In Sweden the last devaluation improved the competitiveness of sawnwood producers temporarily, but a decrease in production may also be expected, let us say some 10 million m3, if the wood prices will develop as outlined and subsidies are paid.

In the pulp production a relative change in production costs of 5 to 10 % will not be enough to make the construction of new large-scale pulp mills in Central Europe feasible. The high capital intensivity and the comparative advantage of countries basing their pulp production on wood from fast-growing plantations will obviously be too high risks for companies to build new chemical pulp mills in Central Europe. Even if the pulp mill projects were subsidized by Governments, the risks involved might prevent new big investments.

TABLE 3 Production of Sawn Softwood in Selected Western European Countries 1980-1984

Country	Production of Sawn Softwood 1980	1984	Relative Change in 1980-1984
	mill.m3		
Finland	10.15	8.15	- 20
Sweden	11.08	11.79	+ 6
Sub-total	21.23	19.94	- 6
Austria	6.30	6.31	+/-0
FRG	8.36	8.32	+/-0
Czechoslovakia	4.00	4.30	+ 8
GDR	1.83	1.98	+ 8
Sub-total	20.49	20.91	+ 2
GRAND TOTAL	41.72	40.85	- 2

Source: FAO Yearbook of Forest Products

In the paper and board production the differences in competitiveness due to lower wood costs are so small that no major effects in production levels can be expected. In the production of uncoated woodfree paper, where the cost benefit with subsidized wood price is the biggest, it should be noted that an effective mill would require integration to an existing pulp mill. In the western Continental Europe there exist only few market pulp mills that could be integrated (e.g. Pöls in Austria). In eastern Europe there are some market pulp mills which could be integrated with woodfree paper production (e.g. in Czechoslovakia). However, the high investment costs of building new big wood free paper machines are again the main hindrance for realizing these plans.

3. WOOD QUALITY

The wood quality of raw material delivered from the damaged forest areas is a major concern of the industries using or considering the use of this resource. Dead trees which have possibly been attacked also by insects or fungi can find their use only as fuelwood. For quality reasons part of the logs may not be suitable for sawnwood production, even if the trees are not yet wholly dead. Fresh wood is also required for mechanical pulping, and so far it is not totally clear how much of the pulpwood affected by the forest dieback can be utilized in the groundwood and thermomechanical pulping. In chemical pulping possibly less problems will arise, provided that the totally dead dry rot material is not cooked.

The wood quality aspects of the wood from forest damage areas have so far got too little attention by the researchers. There are some studies where these problems have been approached from a wood technologist's point of view (Thörnqvist 1986). Sawnwood has been the main subject of these studies. However, a comprehensive study on this subject starting from the properties of end products and quality requirements of end users would be required to answer to the questions raised by the industrial wood users. It would also help in formulating the pricing principles for the wood from the damaged areas although in many cases it is not a question of price but a necessity.

4. EFFECTS ON THE TRADE OF WOOD AND WOOD PRODUCTS

4.1. Wood Products

The effects on wood product trade flows are naturally closely related to the production levels of different products and different countries. As a summary, the main changes will be seen in the trade of sawnwood. The traditional big trade flows from the Nordic countries to the Continental Europe will likely decrease, and the trade within the Continental European countries increase. On the other hand, for many years already, there has been the tendency to export more and more sawnwood from the Nordic countries to the Near and Middle East and North Africa. It is likely that the Nordic sawmills are also in the future obliged to seek markets for an increasing share of their production in the overseas countries.

4.2. Logs and Pulpwood

There are good grounds to expect that the forest decline in Europe will have a positive effect on the quantities of roundwood traded internationally. It will take time to build new domestic industrial capacity and in many cases it may be more advantageous to sell the wood there where the processing capacity is already available. Transportation of wood raw material takes, however, considerable volume in vessels, which drastically reduces the profitability of the business. Therefore, subsidies are often needed to make the trade feasible.

It is obvious that especially the trade in pulpwood and chips will grow considerably within the next few years. Logs will more likely be processed at sawmills in the Continental Europe, though part of logs may be transported e.g. to the southern parts of Sweden which can utilize direct deliveries, by e.g. railways, from the Continent. Part of the logs will also be used as pulpwood by pulp mills.

Another question is whether pulpwood will be transported as roundwood or is it first processed into chips before transportation. Today most of the European pulpwood trade is roundwood, but it is likely that deliveries of chips will grow remarkably. Pulp mills locating on the coastal areas of the Nordic countries may have the biggest advantage of the increasing pulpwood trade. It is impossible to estimate how much the traded volume of pulpwood and chips will grow, as it essentially depends on how much the trade is subsidized by exporting countries. The trade may grow also within a country as it is likely that wood from the coastal areas will be increasingly exported and this removing wood supply at the domestic mills replaced by deliveries from the interior parts of the country.

5. EFFECTS ON THE FOREST POLICY AND FOREST INDUSTRY STRATEGIES

5.1. Forest Policies

The foreseeable changes in the forest products markets have also reflections in the forest policies in the big exporters of forest products, particularly the Nordic countries. The demand prospects for sawnwood are relatively poor, and the expected changes in the cost competitiveness of spruce sawnwood production will further complicate the situation. It is obvious that there will be an oversupply of spruce logs in the Nordic countries, particularly in Finland. By using the current pricing principles it is not reasonable to use this part of logs as pulpwood, if the price is tied with the sawlog prices. In Finland today smaller diameter logs are sawn than e.g. in Austria or the FRG, and thus it is likely that the definition between logs and pulpwood has to be changed when the oversupply of spruce logs will grow considerably.

There is also the question about change of forest policies for balancing the short-term oversupply with a long-term deficit between countries. For example, the Nordic countries may be forced to reduce the harvests during next 20 years. That will change the whole forest policy. The policy is today starting from the assumption that x million m3 should be harvested. But if we have to reduce the harvests by 20-30 %, the policy must be changed.

If the Nordic countries have to reduce the harvests by 20-30 %, there are direct reflections in the forest growing and plantation programmes. Sawlog production should be concentrated on those forest areas that naturally are the most suitable ones for pine log production. At the same time part of the best forest land areas could be utilized for growing spruce and birch pulpwood for the needs of the pulp and paper industry by using shorter rotation periods, say 40-50 years. This would change the traditional principle of dividing the tree into the log and pulpwood parts to correspond better to the requirements of the most viable part of the forest industries in the Nordic conditions.

5.2. Forest Industry Strategies

Forest industry is capital intensive, thus all major strategies are built from investment decisions or divestment decisions. A systematic analysis of business strategies requires that strategies be categorized in a meaningful way. Here I have chosen a single simple matrix of categories instead of a more detailed, individualistic one. The business framework for a base industry such as the forest industry justifies this choice.

A decision is the end product of a business strategy.

1. STRUCTURAL STRATEGIC DECISIONS (SSD): These are singular, non-recurring decisions which require a rather large degree of freedom. In the forest industry such decisions include location decisions, product line or industry branch decisions, acquisitions, mergers and divestments.

2. NORMAL STRATEGIC DECISIONS (NSD): These are highly relevant decisions usually with significant later impact. In the forest industry such decisions precede all major investments in plants and machinery and determine later market mix.

3. The three basic elements for a company in both SSD's and NSD's are
   * markets
   * internal resources
   * raw materials

The forest damages can strategically influence industrial decisions through wood trade flows both in volume and quality, both long and short term, although short term does not very much affect (by definition) the forest industry strategies. By definition long term here equals to NSD life cycle. Here it must be, pro primo, emphasized that the overall fibre availability, both today and in the future, has far greater impacts on the NSD's and SSD's than forest damages through wood trade flows. Based on the afore, following scenarios can be sketched:

Base Scenario

There is a general trend of growing international wood and fibre trade flows, anyway, e.g. from both the Soviet Union and overseas sources. These flow potentials have been taken into consideration in NSD's and SSD's. The possible increase in trade flows caused by forest damages will not in any drastic way inspire new NSD's or SSD's. All it does is that it lowers overall wood prices, especially pulpwood prices, thus promoting paper industry's competitive edge towards other information media industries. The downward trend in wood prices is further advocated by the pressure from lower class logs as the need for basic building materials in Europe declines and only the best of logs is used as refurbishing material. Overall the growth estimates for graphic papers can be pushed a tiny bit upward, maybe almost back to the percentages of the early 70s and late 60s.

In the Base Scenario the total import volume to the Nordic countries could be in the region of 15 million m3 p.a. (Figure 1)

Scenario 2

Logistics bottlenecks - harbours, transportation systems, harvesting, manpower questions, etc. are not taken care of - and political inefficiencies do not allow the wood raw material to enter into the commercial raw wood market in any significant way. This alternative has shown to be

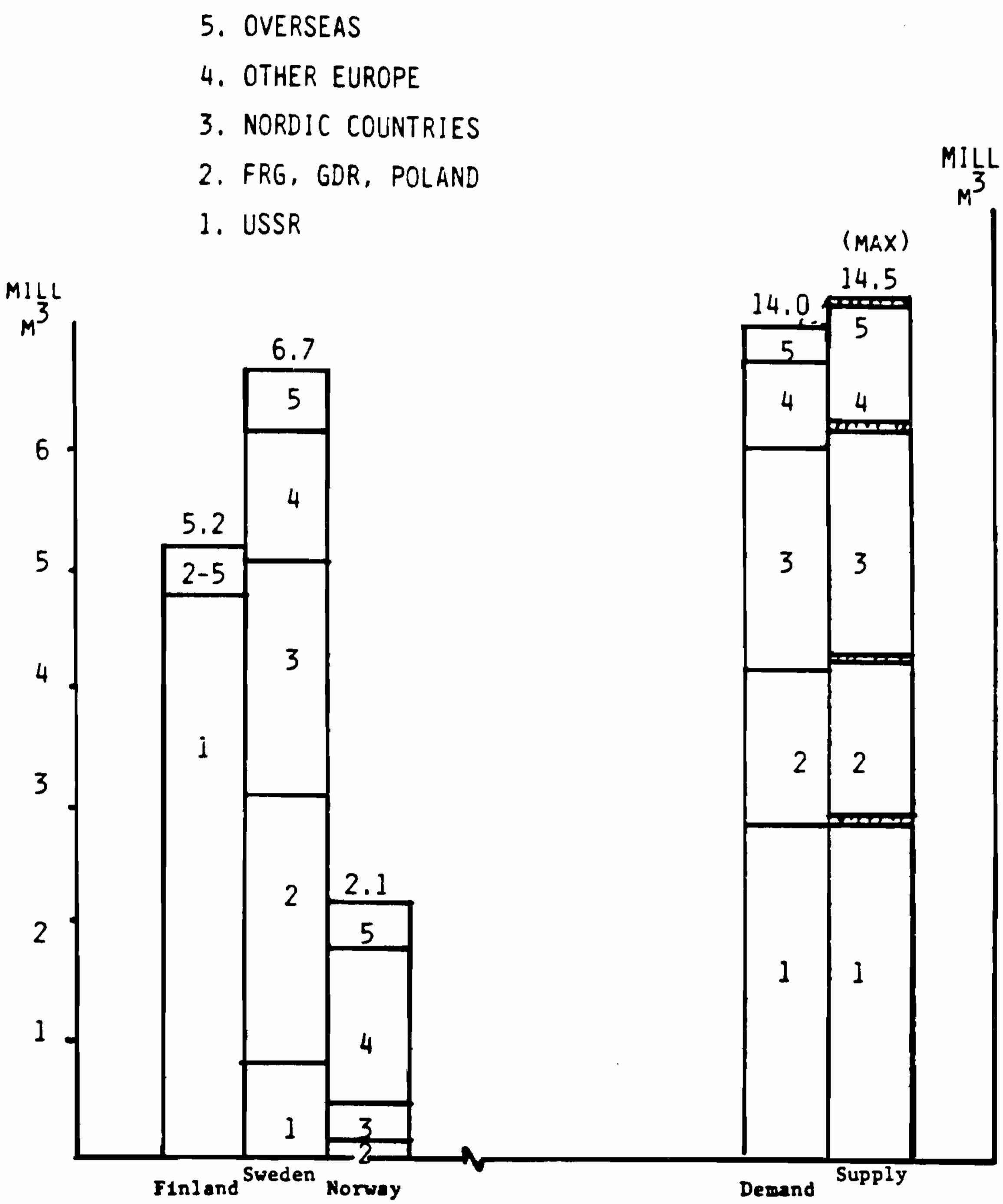

Figure 1. Consumption, supply and balance of imported wood - Finland, Sweden and Norway, 1986.

possible and marginally cuts off from the edge of competitiveness, pushes wood prices upward but at the same time stimulates other wood trade sources. The sourcing potential is definitely there. - Here only 10 million m3 p.a. (Figure 2) imports can be expected.

Scenario 3

There are no physical limitations in the logistics systems in the international wood trade flows. In this scenario the total imports to the Nordic countries could be as high as 20 million m3 p.a. (Figures 1-2). Some long-term NSD's would be done in the Nordic countries (2-3 extra pulp mills). Industry's competitive edge sharpens while other things remain equal.

Future Future Scenario

It seems like the key questions will be not today's forest resources, nor forest damages but what will be the level of sustained yield 50 years from now, if the forest decline proceeds, not only in the continental Europe but also in other parts of the world. If the forest growth in general is irrevocably hurt we will have to expect rather drastic NSD's and SSD's in the next 20-30 years to come.

It is the real long term that counts and although we do see very, very little of it, the prospects may be very dismayal if strong actions are not taken in short term!

Summa Summarum

Forest Damages and Forest Industry Strategies

* More international wood trade flows - more practical things to be done immediately
* Pulping methods will be improved
* Increased investments in logistics
* Wood quality problems
* No large-scale NSD's nor SSD's because of forest damage
* Wood price structure changes
* Very long-term scenarios dangerously interesting, situation has to be monitored continuously
* Here the question is "to be or not to be" for the forest industry and not for the forest industry only
* Nordic forest products industry ought to watch more sustained yield fibre sources from overseas in all different forms (pulp, paper, wood products).

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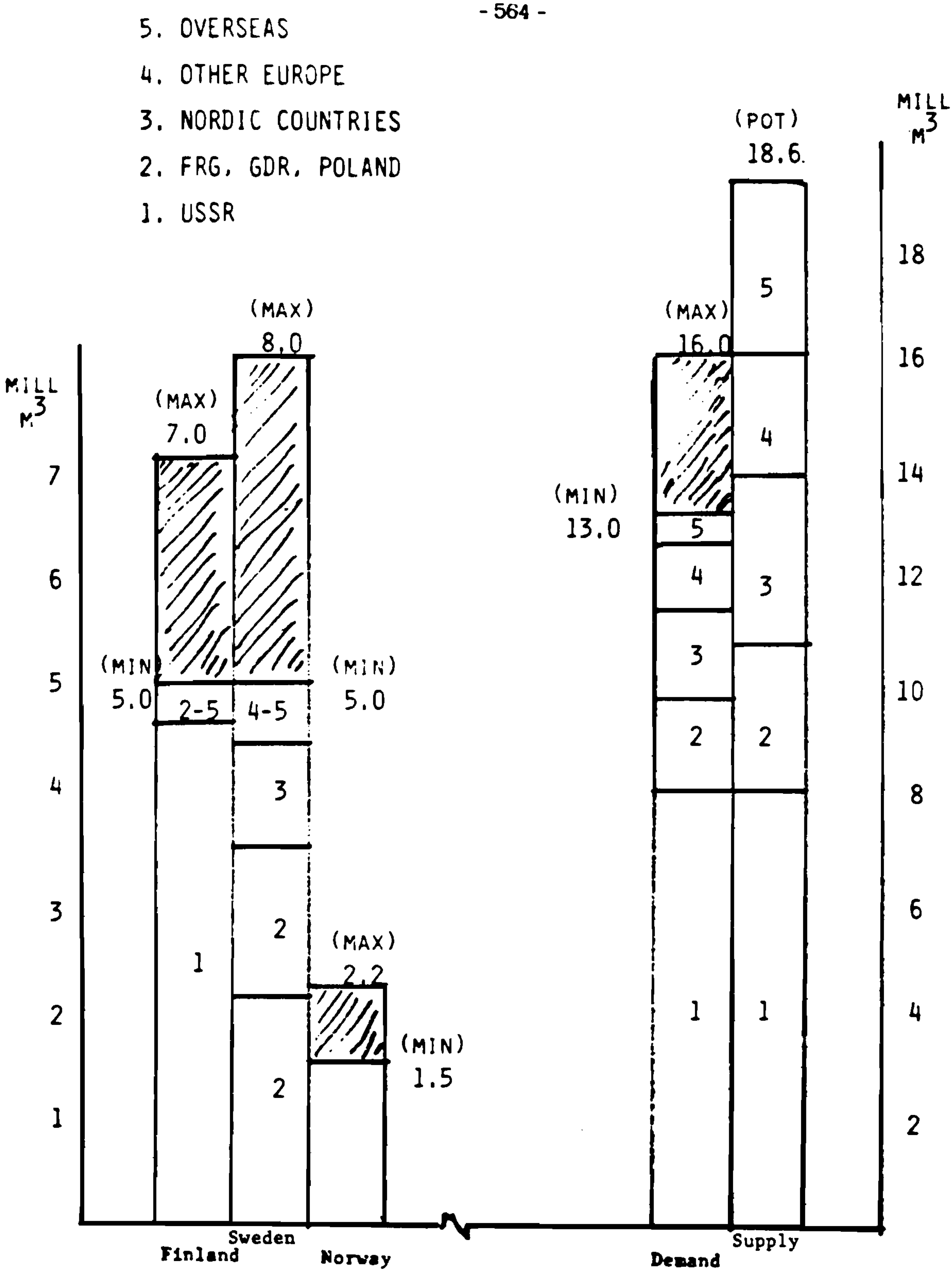

Figure 2. Consumption, supply and balance of imported wood - Finland, Sweden and Norway (in 5 years' time).

7.7 EFFECTS OF FOREST DAMAGE ON THE FOREST INDUSTRY AND THE RURAL COMMUNITIES – SOME EXAMPLES*

L. Lönnstedt
Faculty of Forestry
Swedish University of Agricultural Sciences
S-750 07 Uppsala, SWEDEN

1. INCREASED WOOD SUPPLY?

Every year the European air is the recipient of about 30 million tons of sulphur - the main part coming from coal and oil burning. Some forest areas of the Federal Republic of Germany (FRG) have received 100 kilos sulphur or more per hectare and year for half a century. From time to time we can read alarm reports. For example an article signed by Johansson (1983) said: "Half of the FRG forest will die within 20 years, if not the enormous emissions of sulphur from the industry are reduced... Already now the forest die back has affected one tenth of the FRG forest".

Quantitative estimates of forest damage are uncertain and must be treated cautiously. An estimate made for the Timber Committe by a group of specialists on possible market problems of air pollution damage to forest is that about 7.0 million hectares of the European forest area have been affected by air pollution (Schotte, 1985). Of this area 5.9 million hectares are located in seven geographically closely related countries - Austria, the FRG, the Netherlands, Luxemburg, Poland, Switzerland and Czeckoslovakia. However, it is known that damaged forests also exist in the German Democratic Republic (GDR). Of the above mentioned area about 2.0 million hectares are estimated to have moderately damaged, dying, or dead forest. Another way of measuring the extent of the damages is to look at the standing volume. About 2.800 million m^3s are estimated to be damaged. This corresponds to about 5-7 normal annual removals in Europe.

Around 1984 more than 10 per cent of the total annual removals in countries with heavy damage are estimated to be forced (op.cit). The estimate for the total of Europe is 3.5-4.5%. (The total removals for Europe are about 500 million m^3s ub). Most of this "extra" supply is in the form of saw logs because most of the damages are to be found in older forest. So far, official sources in different countries are stressing that there has not been any effect on the roundwood markets (Nilsson, 1979).

In many countries one tries to reduce the removals from healthy stands. This strategy can perhaps be followed for five more years or until the beginning of the 1990's. Then one or two decades with excess supply of wood, mainly saw logs, may follow. As a result a period with shortage of wood will follow in the beginning of the next century.

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The purpose of this paper is to highlight the possible consequences for the forest sector and the rural communities of a change in the wood supply due to forest damage. The consequences will be highlighted through such variables as gross profit margin, production capacity, number of employees and number of plants. Two different forest sectors will be studied, one exporting (for example Canada and the Nordic Countries) and one importing sector (countries in Central Europe), respectively.

The result is not an attempt to produce forecasts. On the contrary! The intention is to illustrate how necessary it is for the policy makers to take action so the future development will be another one.

In the next section will be showed how the development of rural employment opportunities generated by the forest sector could be analyzed. The following section presents a tool for generating possible developments of the forest sector. At the end this tool is used for producing a scenario of the possible impact from forest damage on the forest industry and the rural communities.

2. RURAL EMPLOYMENT OPPORTUNITIES

The possibilities and problems of the forest sector as a rural employer can be analysed by using the following equation (Lönnstedt, 1984).

$$\underset{\text{(persons)}}{\text{employment}} = \frac{\underset{(\text{m}^3/\text{year})}{\text{production}}}{\underset{(\text{m}^3/\text{person} \cdot \text{h})}{\text{productivity}} \cdot \underset{(\text{h/year})}{\text{working hours}}}$$

Thus, the employment opportunities within the forest sector are dependent on (i) production, (ii) productivity, and (iii) working hours.

The main interest in this article is concentrated around forest damages which have an indirect effect on the industrial production via the wood supply. There is also a link between wood supply and change in the industrial production on one side and productivity on the other. It is easier to introduce new processes for an expanding industry than for a stable. A quick introduction of technological changes means a more favourable development of productivity and thus an improvement of the competitive situation.

Taking Sweden as an example the development of the variables in the equation and their impact on the employment will be discussed in the following text.

Production

In Sweden, saw mills were established during the middle of the last century. At the end of the century the pulp and paper industry was established, compensating the decline of the saw mill and utilizing thin tree dimensions. During the 20th century total wood removals were rather constant up to the end of the Second World War, when a rapid increase of wood removals and consumption of the forest industry took place. Since the beginning of the 1970's the capacity expansion of the pulp industry and the saw mills have more or less come to a stand still. Meanwhile the stock of standing forest is growing.

Productivity

One way of reducing the effect on the production cost per ton or cubic metre of increasing costs per working hour is to increase productivity. This is done by introducing machines and automation. This strategy has with success been followed by the Swedish forest industry during the 1950's and 1960's. The value of capital stock employed per man hour has increased substantially. Economics of scale has caused a centralization of production. The number of production units has declined. This has caused great problems for many rural communities.

Working hours

A part of the increase in the material standard of living made possible by productivity is realized as leisure time. The working hours are becoming shorter, the holidays longer. In Sweden, the practical working hours nowadays amount to some 1.700 hours a year. This is a decrease of about 30% during the last 75 years.

Employment

The Swedish case shows that the number of working places and employees within the forest sector grew rapidly during the expansion of the forest industry. However, this growth phase was transformed into a decrease because productivity increased faster than production.

Employment within the Swedish forestry sector peaked out at the end of the 1930's. Since then the reduction has amounted to about 2% yearly, in spite of wood removals increasing by about 1% a year until the beginning of the 1970's. Employment within the forest industry reached its peak in the middle of the 1960's. Thereafter, the number of employees has decreased somewhat despite an average increase in the production volume of about 4% per year between 1965 and 1975. After the mid-1970's and until the beginning of the 1980's, the weak world economy and low demand for forest products have caused both production and employment to decrease. The Swedish devaluations in 1981 and 1982, and the high exchange rate for the U.S. dollar totally changed the situation since 1982. Today Sweden has a competitive forest industry. Will a new threat for the industry and the rural communities be forest damages in Central Europe?

3. THE FOREST SECTOR

A forest sector model will be used to illustrate the possible consequences from forest damage on the forest industry and the rural community. The model will thus among other things calculate employment, production and productivity (compare with chapter 2). The model that will be used is a simulation model developed by Lönnstedt (1986). The model was developed to analyse the impact of cost competitiveness on the structural change of a domestic forest sector.

The model consists of two symmetric, competing forest sectors - one for the domestic forest sector and one for the competing forest sectors of other countries. Each forest sector covers all activities, ranging from timber growth to the consumption of forest industry products such as paper, sawn wood and panels (Fig 1).

In principle, each sector is defined by domestic long-term demand and supply of forest industry products. Trade is introduced by linking the two sectors so that imports of forest industrial products and roundwood are introduced on the international product market and the domestic roundwood market, respectively. At the same time the forest sector under study can export its products. The exogenous variables are exchange rate, price of input factors, and technological change.

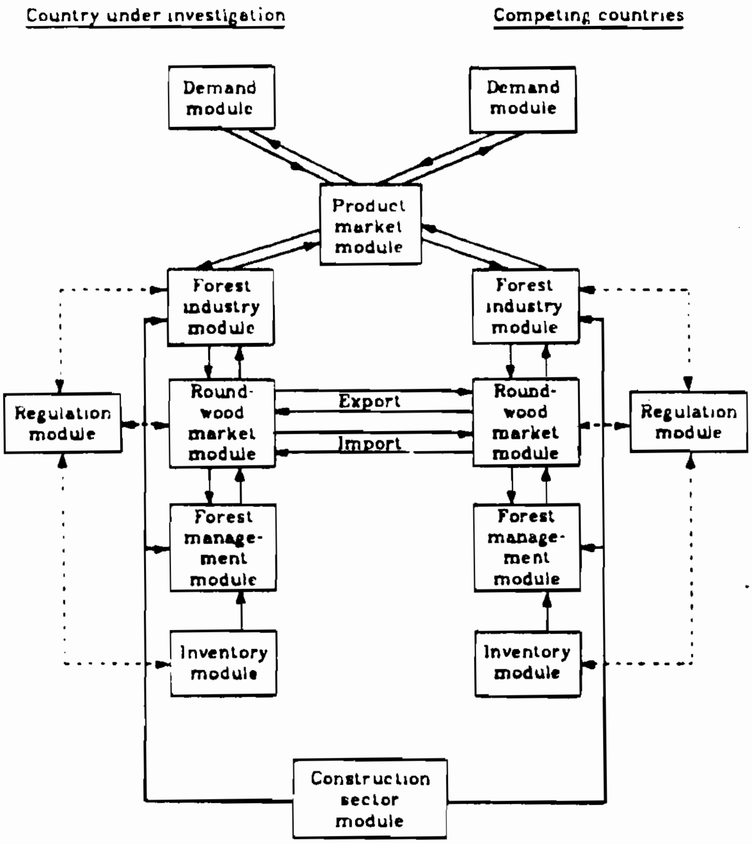


Figure 1. Outline of a domestic forest sector under investigation and competing forest sectors. The linkage between the modules consists essentially of price and quantity information. New capacity is received from the construction sector module. The regulation module specifies quantitative restrictions (marked by dotted lines).

4. A POSSIBLE FUTURE DEVELOPMENT

4.1 Assumptions

In this section the model will be used to illustrate the possible impact of forest damage on soft wood saw mills and rural communities during the coming 2-3 decades. This development will be compared with that of a basic run.

The assumption for the forest-damage-run is that the supply of wood in Central Europe will increase due to the effects of forest damage while the forest in the exporting region is assumed to be uninfluenced. As was mentioned in the introduction the effect in Central Europe can already be seen. However, for the whole of Europe it is marginal. In this scenario the forced cuttings are expected to increase slowly during the rest of this decade. During the 1990's a major increase is asssumed to take place. In the beginning of the next century the forced cuttings will start to decrease. Around 2010 the supply will be at the same level as during the 1980's and will continue to decrease (but this lies outside the model run).

The change in wood supply is expected to have direct effects on the price of wood and thus change the cost structure of the industry. The price of wood will decrease and be quite low during the 1990's due to the increased supply. Nilsson (1987) refers to a study of Bavaria in which the sawn wood prices are estimated to decrease with 20%, if a substantial increase of the cuttings will take place. At the turn of the century, when the forced cuttings come to an end, the prices will start to increase. Meanwhile the saw mill capacity has expanded which means quite a high demand of wood.

In both runs a slow increase is expected for the Western European consumption of soft sawn wood. (About 80% of the European consumption concists of soft sawn wood.) According to a forecast from Jaakko Pöyry (1985) the consumption is expected to grow from about 53 million m^3 around 1985 to about 57 million m^3 about the turn of the century (Table 1). This means an average annual increase with 0.5%. Thus the market can be expected to tough and the competition hard.

Table 1. Historical and forecasted consumption of soft sawn wood in Western Europe.

Period	Consumption mill m^3	Average annual change %
1970-75	54.2	
1976-80	54.7	0.2
1981-85	52.9	- 0.7
1986-90	54.2	0.5
1991-95	56.0	0.7
1996-00	57.0	0.4
2001-05	57.0	0.0
2006-10	57.0	0.0

Another assumption is that the factor costs (excluding wood raw material) in nominal terms, as an average for the decades to come, will increase somewhat more slowly in the importing region than in the exporting region. The technological development and the possible development of the working productivity will be the same for the two regions. Thus the inflation rate will be higher for the exporting region than for the importing one. As a consequence the competitiveness of the exporting region relative to the importing region will gradually deteriorate. To compensate for this it is assumed that the politicians of the exporting region decide to devaluate their currency 1990 and 2000 respectively.

4.2 A Base Scenario

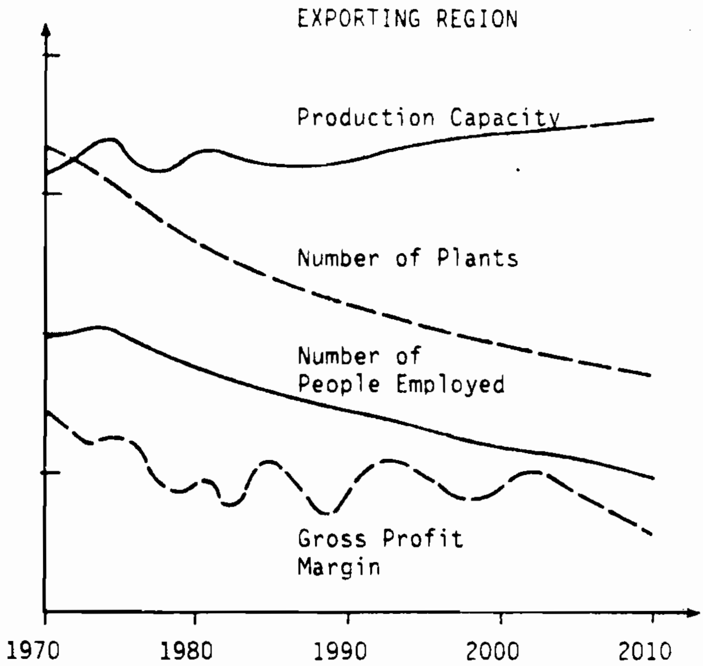
The base scenario shows a slow expansion of the saw milling capacity in the importing region as well as in the exporting region (Fig 2). As a consequence of this the production capacity also increases somewhat. The investment strategy of the model mills is to try to keep their market shares if the profit level allows it. The gross profit margin improves after a low level in the middle of the 1980's for some years in both regions. In the model run the development of the profit margin in the exporting region is getting worse during the 1990's and the beginning of the next century while it is quite stable in the importing region. The explanation is the relatively higher cost increase of the exporting region which however from time to time is taken care of through devaluations.

As the analysis of section two shows the consequence of a slow increase of production combined with improved working productivity will be decreased employment. This happens also in the model run (Fig 2). The number of saw mills also decreases which means that the average size increases (economics of scale).

4.3 A Forest Damage Scenario

The assumption in this model run about increased forced cuttings in the importing region as a consequence of forest damage mainly during the 1990's will have dramatic effects for the saw mills in the exporting region (Fig 3). Even if it takes some years the capacity will decrease drasticly as well as the employment and number of plants. The main reason is the low gross profit margin or for some years loss. This is a consequence of the increased wood supply in the importing countries which reduces the wood prices but also the sawn wood prices. Even if the saw timber prices as a consequence of this are reduced in the exporting region the reduction is not at the same size as in the importing region. At the beginning of the next century the profit margin improves because the supply of wood in the importing region is supposed to decrease. The saw milling capacity starts slowly to recover in the exporting region.

In the importing region the saw milling capacity increases quickly during the 1990's. The number of employees is more or less stable while the number of saw mills continues to decrease as a consequence of the assumption of continued increase of economics of scale. In the model run the profit margin increases dramaticly during this period.



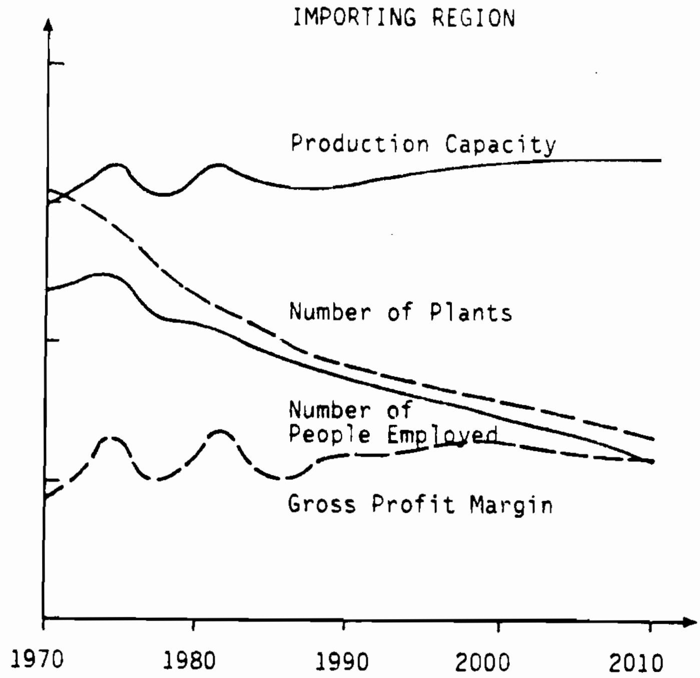
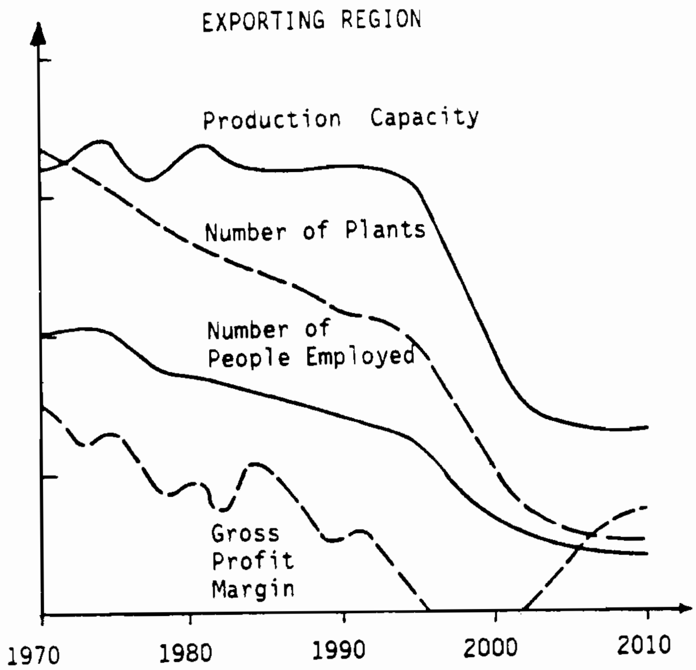


Figure 2. A base scenario for soft wood saw mills in an exporting and in an importing region, respectively. The development of the variables is smoothed through a moving average.



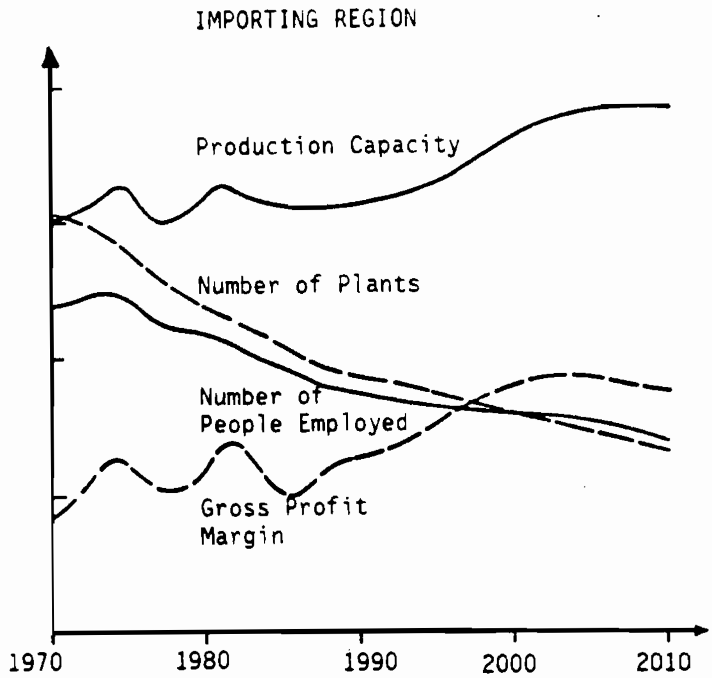


Figure 3. A forest damage scenario for soft wood saw mills in an exporting and in an importing region, respectively. The development of the variables is smoothed through a moving average.

5. CONCLUSIONS

The period when forest damage first is observed and forced cuttings take place will be characterized by confusion and irresolution. Probably one will try to export at least a part of the forced cuttings. After this "wood export period" an investment period will probably follow because the short sighted increase of the wood supply as a consequence of forced cuttings will result in lower wood prices and make investments in saw mills more profitable. After this investment period a wood shortage period will follow characterized by the reduced inventory of standing timber. Forced cuttings are not necessary any longer. Forest reconstraction will take place.

Table 2. Possible effects of forest damage on the forest industry and the rural communities.

Time horizon	Region: Importing	Region: Exporting
Short run	+	-
Long run	-	+

Thus when analysing the possible developments it is important to distinguish between short and long run and between importing and exporting regions (Table 2). In the short run there may be an advantage for the forest products industry, workers and rural communities in the importing region as a consequence of increased supply due to forest damage. This possibility is a threat for exporting countries such as Canada and the Nordic Countries. However, in the long run the picture may be the reverse.

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7.8 REGIONAL EFFECTS OF FOREST DAMAGE ATTRIBUTED TO AIR POLLUTION*

H. Steinlin
Institut für Landespflege
D-7800 Freiburg
FEDERAL REPUBLIC OF GERMANY

1. INTRODUCTION

The effect of forest decline is not confined to forest owners and forestry as such. Of course, forest owners suffer directly from the depreciation of the capital invested in the forest enterprise, from reduced production potential, lower prices for harvested timber as well as from higher costs etc. due to continuing decline of the health-status of their forests and the constraint to cut unmature timber in order to prevent further damage by pests and insects. The consequences are most severe for private forest owners, and among them especially for those who live from their forests or those who depend from their forests as a source of supplementary income to an other activity such as farming under marginal conditions. In the FRG 41 % of the whole forest area is privately owned by more than 450 000 owners; in some regions the share of private forests reaches 90 % of the total forest area.

In this paper major emphasis will be put on the regional effects of forest damage i.e. on the living conditions of the whole population and the consequences for the regional economy. It is well known and does not need further explanation that forests have many different functions and that these functions are not confined to the owners of a forest. Severely damaged or even dying forests are unable to meet with the legitimate society's expectations for protection against avalanches and erosion, prevention of floods and pollution of drinking water, recreation, amenity of the landscape etc. Forest damage entails at least a loss of quality of life for parts or the entire population, but in many cases, it entails also the need for technical measures such as artificial defense against the formation of avalanches, tunnels for endangered roads and railways, erosion control, dikes against floods, treatment of drinking water etc. Many of such measures are very expensive, require big investments an permanent maintenance costs, which were unnessessary as long as the forest existed and was vigorous enough to replace them.

More difficult to assess are the consequences of forest decline for the regional economy. Reduced income of forest owners, loss of working places in forestry, recession of wood based industries due to lack of raw-material, decline of tourisme and other possible developments affect nessessarily the regional Gross Domestic Product. Reduction of quality of life and deterrioration of the economic situation may lead to the emigration of parts of the labour force, reducing the population or, at least, changing the agestructure with all corresponding consequences. The more important forests, forestry and forest industries are and the weaker the general economic situation in a given region is, the bigger are the possible effects of forest decline on the whole regional economy. A high percentage of forest cover in a region is in general coupled with marginal agricultural conditions, small

*In: **Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

population density, rather difficult terrain conditions and often with a comparatively poor economic structure. These regions are also the most affected by forest decline and the most sensitive to any kind of economic regression. The effects of forest damage may well be of comparatively minor importance for the whole nation, but they can be, and often are, vital for some regions in the same country. A regional approach is therefore nessesary.

2. METHODOLOGICAL PROBLEMS

2.1 Definition and Delimitation of a region

A region is understood here as a section of the biosphere which in itself is homogeneous under certain aspects and to a certain degree, but differs under the same aspects from neighbouring regions. There are always many possibilities for the delimitation of a region following different criteria e.g. physical (natural) boundaries such as topography, climate, watersheds, altitude, sea-shores etc., political or administrative borderlines, historical or socio-economic boundaries etc. Which of the criteria suits best a given case depends on the purpose of the delimitation. When most emphasis lies on ecological or geographical aspects, natural boundaries are most appropriate. In the case of economic and social analises, administrative or political borderlines have the advantage of easier access to statistical material and socio-economic data. Administrative borderlines, however, reflect very often historical conditions which are not relevant any longer and cut through modern organic economic an social units. In such cases it seems preferable to search out new delimitations which reflect the present-day conditions. Any analysis of regional effects of forest damage deals with ecological as well as with socio-economic aspects. This fact makes the delimitation of a study-area a very difficult task. In most cases only a compromise between different criteria allows for a suitable solution. But such a compromise entails often many difficulties in the collection and interpretation of data.

A region as a section of the biosphere is a complex system which comprises natural ecosystems as well as human fabrics, activities and social systems. Nevertheless a region can be seen as an ecosystem itself, comprising a number of subsystems with all their relations and interactions. A region is always an open system interacting with neighbour regions and underlaying the same influences as each other ecosystem. Research on effects of forest damage therefore has to use the tools and follow the principles of systems analysis. In principle it is possible to build mathematical models of a region. In view of the complexity of an entire region such models tend to become very complex. Many of the links are difficult to assess and not yet well known. Much more problematic is, however, the procurement of empirical data fitted for the mathematical model. Some of the related problems will be dealt with in the next sections.

2.2 Nature, State and Evolution of Forest Damage

The effects of forest damage in a region depend on the nature, the state and the evolution of forest damage. Neither nature and state nor evolution of forest damage are easy to assess. The wide-spread forest decline in highly industrialised countries is not identical with the well known damage to forests caused by SO_2-loaden smoke for centuries. Of course, such damage exist still and in some regions it is the main reason for forest decline and can be attributed to specific sources of emissions. In other regions the phenomenon is much more complex. It becomes increasingly clear that the mechanisme of forest damage is not the same under all circumstances. Site-conditions, weather, tree species and probably also temporal and spatial variations of pollutant concentration and composition lead to different reactions of the trees and to different nature of damage. It is, therefore, not easy to transfer experiences from one region to another and in many respects the mechanisme of forest decline is not yet completely understood. This makes also the assessment of the effects very difficult.

The same applies for the establishment of the real state of health of a forest. We have to rely for practical reasons on visible or at least photo-optic parameters. Such parameters are loss of needles and leaves, colour of leaves and remission of radiation. It is at least doubtfull whether these parameters reflect the real health of a tree or a whole forest stand. It is also not well known which degree of needle loss or leave colour corresponds to a certain level of vitality of a tree. More sophisticated methods such as examinations of roots or measurments of metabolisme of trees are time-consuming and expensive and cannot be used for big scale inventories which are indispensable for regional assessments of the state of forests.

Even more problematic are all forecasts on the evolution of forest decline and the temporal and spatial progress of damage. As the phenomenon is new and without any historical parallels, we are unable to assess the further development through any kind of analogy or past experience. The observation time is also far to short for the establishment of trends and their extrapolation into the future. The continuing yearly inventories in some countries suggest moreover that forest decline progresses in waves and often differs in a given year from one region to another and even from one stand or tree to another, periods of fast progress alternating with stagnation or even partial and perhaps temporary recovery. This leads to the conclusion that numerical forecasts or prognoses are impossible, the only solution being the construction of scenarios with a set of assumptions.

2.3 Damage by Polluted Air to other Ecosystems than Forests

When speaking of regional effects of forest decline we have always to bear in mind that not only forests are concerned and that damage to other ecosystems, caused by the same phenomenom, may well increase and amplify the multiple effects on the whole regional system. Such ecosystems are lakes, rivers, groundwater, but also agricultural land, bogs and other specific biotops which are important for the survival of endangered animals and plants. Except for lakes and rivers much less is known about the reaction of such ecosystems to polluted air, but should be known for a true regional assessment.

2.4 Ecological Implications

The ecological implications of forest decline cannot be generalized. They depend essentially on the situation of a given region, its topography, its climate, bed-rock, regime of precipitation, existing forest area and its repartition, other land-uses, function of forests etc. The assessment of ecological impacts of forest damage in a region asks therefore for a thourough case study in the region itself. Main topics of such an impact study are in most cases the effect on micro- and mesoclimate, waterregime, soil erosion by wind, water and snow, living conditions for animals and plants etc.

2.5 Economic Effects

In contrast to ecological effects, economic effects normally are expressed in monetary units. Money is the usual common denominator for all kind of economic effects. The modern welfare-economy offers quite a number of tools which can and should be used for the assessment of the consequences of forest damage. It is not the scope of this paper to enter into a discussion of the aspects and problems related with the valuation of specific effects by individuals and the collectivity as well as the problem of pricing immaterial goods and services.

The expression of all the regional effects of forest decline in terms of money is also important from a political point of view. Most politicians are used to think in terms of money and judge the importance of a problem according to its financial aspects. Investments in measures to control or reduce pollution and the running costs of such measures are normally also expressed in terms of money and the question of the relation between costs of pollution control and the benefits of it is regularely raised. The answer can only be given if the effects of pollution can also be expressed in terms of money.

Most of the problems encountered by the assessment of economic effects are not specific for the case of forest damage. Some need, however, special attention as they play a certain role when approaching regional analyses of the impact of forest decline and will be discussed in more detail.

2.5.1 Regional Input/Output Tables

The impact of forest decline in a region on the various sectors of an economy in the same region depend very much on the forward and backward linkages between the sectors. For the purpose of national economies so called input/output tables are a useful tool to evaluate indirect effects. For an entire national economy sufficient statistical material exists and such tables have been constructed or can be constructed. The task is not so easy for parts of a country. Nevertheless it had been solved in some cases for bigger areas, in the FRG for instance for the whole state of Baden-Württemberg. For smaller regions which are of special interest in view of forest decline one meets with enormous difficulties because sufficiently specified statistics are lacking. Our efforts to get the necessary figures directly from enterprises in the region failed inspite of a lot of goodwill and readiness to cooperate from the contacted firms and their associations because the enterprises themselves do not dispose of statistics which show the part of material and goods purchases or sold in the region itself. The use of nation-wide results for a much smaller region with specific economic conditions is very problematic.

2.5.2 Rate of Interest

Many effects of forest decline are not felt immediately but persist over years or become even perpetual. Others are to be expected in the future or appear only periodically. The same applies for the measures of pollution abatment. These measures are introduced step by step over many years and the full effect on forest ecosystems is only reached after several years. Economic effects in terms of money need to be expressed for a given moment. Anticipated effects in the future should be discounted to this moment. The choice of the rate of interest depends on the time-preference, i.e. the relation between the present value at current prices and the same sum becoming effective in 10 or 20 years. A time-preference of zero means that a future effect has the value in terms of money as the to-day effect. In this case no discount is calculated, the rate of interest is zero and values can be added irrespective of the moment they become effective. The higher the preference for a present effect in comparison with the same effect in the far future, the higher is the rate of interest. Over long periods the rate of interest adopted plays an enormous role in the results of economic calculations, and economic assessments can be much manipulated by the choice of the rate of interest. There is no general aggreement among economists and politicians over the adequate rate of interest in such cases. (By the way, this problem bothers forestry since more than 200 years!)

2.5.3 Assessment of the Impact on Recreation and Tourism

In many regions with a high percentage of forest cover, forestry recreation and tourism play an important role. This is especially true for Central Europe and many parts of the Alps. Recreation and tourism may generate up to 40 % and more of the entire employment in a region and the contribution to the GDP is considerable. In general the part of tourism in a regional economy is rather well documented for the prevailing present conditions by a set of available statistics.

The role of forests in regions where recreation and tourism are important is manyfold. In the higher mountains whre winter sport prevails the protection function of forests is primordial. Many of the villages and tourist resorts owe their existence to the forest which protects houses, roads, teleskis, ski-grounds and walking trails from avalanches and rockfall. The importance of protection forests increased dramatically in the last 20 - 30 years because of the extension of settlements into land which formerly was only used for farming and therefore less sensible to avalanches and rockfall, as well as because of the dense traffic in and between the settlements, while in former times the indigenous population remaind in their sheltered houses during dangerous periods and traffic interruptions over several days or even weeks were accepted as inavoidable. A new and formerly unknown risk is also the crowd of tourists moving everywhere around the area. The whole touristic infrastructure and touristic life depends therefore on the protection by forests. Severe damage or even disappearance of the forests would have catastrophic consequences for the whole region. Many valleys in the Alps would become inhabitable and the whole economy disrupted. The replacement of protection forests by artificial means of protection is practically impossible for economic and financial reasons. Solid calculations in Switzerland came to the result that the replacement of 1 hectar of protection forest by artificial protective constructions asks for an investment of about 1 million Swiss Franks (about US $ 250 000.- per acre!).

In other tourist regions the importance of the protection by forests may be much smaller but forests play a big role for recreation and tourism itself because a considerable part of recreational activities is located in and around the forests or because the forest is considered as a constitutive element of the landscape and dead forests or lacking forests would completely change the character of the land and influence its suitability for recreation and tourism.

While it is not so difficult to assess the physical consequences of the disappearance of specific protection forests and its impact on safety or to document the alteration of the visual aspect of a landscape due to forest damage, enormous problems appear when we try to assess the reaction of people to these alterations. Will they continue to frequent a region, will they adapt their activities to the new situation, will the structure of the visitors (age, social classes etc.) and therefore their demand for activities and infrastructure change? It is well known that recreation and tourism are not only or even not overwhelmingly influenced by economic and technical factors but to a high degree by psychological aspects, custom, tradition and personal perceptions. How do people or does the majority of people react to the new situation in a region? Which role plays the gradual adaptation to a new situation, which role plays the picture given by the mass-media for the decision of an individual? How will people react to a factual or imagined higher risk e.g. for wintersport in specific alpine regions? There is almost no serious empirical material available to answer such questions and it is of course very difficult to get reliable answers through enquiries, polls and questionaires as it had been tried sometimes. Such inquiries are even more doubtfull if one has to ask for future reactions under hypothetical circumstances!

The previous reflections show how precarious an assessment of impacts of forest decline on recreation and tourism is. We need nevertheless some indications when we want to quantify the effects of forest decline on the regional economy in those cases where recreation and tourism are important economic activities in a region. The only way which seems to be possible consists again in the construction of scenarios with certain assumptions, however questionable they may be. But by using a set of scenarios with different assumptions one can at least indicate some limits within which the real development may move.

2.5.4 Future Price of Timber

The price of timber is most relevant for all considerations and calculations of economic effects of forest damage in a given region. It has to be expected, however, that timber prices themselves will be influenced by forest decline. A wide-spread increase of removals from severely damaged forests may well lead to a decrease of timber prices if the surplus cannot be compensated by reduced removals in not or less affected forests. The price-elasticity in timber- and woodproduct-markets is very restricted and a surplus in other regions or even other countries influences also distant regions. It is therefore extremely difficult to predict future prices of timber in a regional study. It seems also likely that an increase of damage in one region or country will be followed by similar tendencies in other regions or neighbouring countries. The consequences of such developments are nearly impredictible, in as much as timber prices may also be influenced by interventions at the national or international level. Extent, kind and success of such possible interventions are evenly difficult to predict. Timber price is therefore another unknown and makes judgment difficult when assessing the economic effects of forest decline in any region.

3. EXAMPLES OF REGIONAL STUDIES ON THE EFFECT OF FOREST DAMAGE

Inspite of the many methodological difficulties just discussed, different studies on the impact of forest decline on whole regions have been undertaken. Two studies in the FRG will be mentioned here.

3.1 The "Report on Methodological Problems of Monetary Evaluation of Complex Damages - The Example of the Forest Damage in the Federal Republic of Germany"

This voluminous report has been published as No. 4/86 of the reports of the "Umweltbundesamt", the Federal Office dealing with the environment. This report had been prepared by a team of specialists headed by Prof. Dr. H.J. EWERS from the Technical University of Berlin. Prof. Dr. H.D. BRABÄNDER and Prof. Dr. H.-M. BRECHTEL with some of their collaborators participated as specialists for forestry in the team.

This comprehensive study evaluates the social costs of forest damage for the whole FRG. Manyfold methodological aspects are discussed in depth. The background of the study was the need for arguments in monetary terms concerning the political discussion on costs and benefits of measures against air pollution. The monetary value of the forest damage should be compared with the costs of specific prevention measures in industry, energy production and traffic.

From the methodological point of view the study is characterized by the use of a combination of expert surveys (Delphi-method) and scenario techniques. Three main scenarios are used:

- a so called "reference scenario" i.e. the development path of forestry as if no air pollution existed (assuming that the conditions of the years 1930/39 persisted
- a so called "status quo scenario" i.e. assuming that present (1984) state of emissions and immissions continued
- a so called "trend scenario" i.e. assuming strong but possible reductions of SO_2 and NO_x emissions during the simulation period. In 1990 SO_2 emission should be reduced by 40 %, NO_x by 30 %, in 2060 SO_2 emission should be only 25 % and NO_x emission 35 % of the 1984 level.

The time horizon of the 3 scenarios is very far, namely the year 2060. This extremely long period shows very well the development of the forests under the various assumptions. On the other hand it makes the evaluation of effects in the far future rather problematic. The scenario of the forest development is based on production tables and growth-models for Norway Spruce (Picea abies), the most important tree species in the FRG. The results for spruce had been adapted for the other relevant species.

There is no attempt to a regional differenciation. The model for the forest development, as well as pollution figures and the estimations of damage are given as global figures for the whole FRG. The damage is calculated as the difference between the "reference-scenario" and the "status quo" and the "trend scenario" respectively over the whole period.

The results of the forest development scenarios are frightening. Even under the assumption of the trend scenario the area of regularely managed production forests will diminish from present 6.3 million ha to 5.5 million ha in 2060. The part of spruce and pine will diminish in favour of some broad leave trees, especially oak and poplar. The reduction of standing volume is dramatic. Following the trend scenario, spruce will have only half of the 1984 volume, following the status quo scenario only 20 % of the present level. The age-structure in both scenarios differs very much from the reference scenario. Following the trend scenario there will not be any stands of spruce with more than 80 years left in 2010 and there will not be any stands of more than 80 years rebuilt by 2060. The consequences of the present damage will persist over the year 2060 and a full revolution period would be needed to restore the forests according to the reference scenario.

The total damage is calculated as the sum of the damages in the forest enterprises (only loss of volume and increment plus costs for regeneration, forest protection, fertilizer etc.) on the basis of constant timber prices and the damage in the sectors "recreation and tourism" as well as "soil and water". It is assumed further that there will be no impact on the forest industries. This assumption is, of course, questionable.

The damage is expressed in annuities using discount rates beween 0 and and 3 %. In the final conclusions an interest rate of 2 % is proposed as adequate. The influence of the discount rate is considerable. The total damage is calculated as 4.3 - 11.4 billion DM per year for the "trend scenario". The lower figure corresponds to the rate of 3 %, the higher figure to a rate of 0 %.

It cannot be the scope of this paper to go into the details of this comprehensive and interesting study. The main results are the following:

	trend scenario billion DM	status quo scenario billion DM
damage in forest enterprises	1.4 - 4.8	2.3 - 6.3
recreation and tourism	2.3 - 6.3	4.2 -11.3
soil and water	0.3 - 0.4	0.4 - 0.6
TOTAL	4.3 -11.5	6.9 -18.2

At an interest rate of 2 % the total damage reaches 5.5 billion DM/ year for the trend scenario and 8.8 billion DM/year for the status quo scenario. The discounted present (basis 1984) net value of the damage is 211 billion DM for the trend scenario using a 2 % discount rate and 344 billion DM for the status quo scenario. So a national investments of about 133 billion DM for pollution control measures would be economically justyfied, not taking into account other possible effects such as human health, other vegetation than forests and buildings.

3.2 The Study on the Effect of Forest Decline in the "Region Südlicher Oberrhein" by an Interdisciplinary Working Group of the Akademie für Raumforschung und Landesplanung

This study is underway and not yet completed. It aims atacase study analysis of the effects of forest decline on the whole nature and economy of a smaller region and the consequences to be drawn for the regional planning. The object of the case study is the "Regionalverband Südlicher Oberrhein" one of the 12 intercommunal planning authorities in Baden-Württemberg. The main task of a "Regionalverband" is the coordination of the communal planning in order to attain a balanced development of the whole region and to plan the regional infrastructure in accordance with the goals set by the state gouvernment. The "Regionalverband Südlicher Oberrhein" covers an area of about 4000 km² with a population of about 850 000 in the South-West of the FRG, comprising parts of the Black Forest and the Rhine-Valley. The town of Freiburg i.Br. (175 000 inhabitants) is the administrative and economic center of the region. Forests cover roughly 46 % of the total area; in the Black Forest even 63 %. A 2/3 of the forests are coniferous forests, 1/3 broad leave forests. Altitude 150 - 1 500 m a.s.l. Forests are owned by state, communities and privates. Forestry, saw-milling and tourism are important sectors of the regional economy, mainly in the Black Forest. Forest damage is severe, especially in the higher parts of the Black Forest.

The working group set up by the "Akademie für Raumforschung und Landesplanung" consists of members of the academy, among them geographers, ecologists, economists, forest scientists, planners and some guest-members from other disciplines. The group is headed by the author of this paper and started its work in 1985. The main purpose of the work is not so much the concrete case-study but the development of an adequate methodology for such regional studies. The final objective is to demonstrate what is happening within the regional system in the field of ecology, economy and social aspects when forest decline continues and what consequences can be drawn and which tools can be used by planners to alleviate the situation and to avoid catastrophic ecological, economic and social developments. The work concentrates, therefore, less on the evaluation of damage in terms of money as in the study of the Umweltbundesamt than on the assessment of interactions within the regional system and the consequences for the various sectors of economy. Special emphasis is given to labourmarket, income, living conditions, migration, traffic etc. as basis for planning decisions, such as creation of new working places, structural adaptation in the agricultural and industrial sector, housing, traffic etc.

In view of the specific goal of the study the time horizon is rather short, 1995 i.e. 10 years. The basis of all considerations are scenarios for the development of the health status of the regional forests. The scenarios depart from the damage inventories which have been made in 1983,1984, 1985 and 1986. They give sufficiently reliable figures for the 3 subregions Rhine Valley, foot hills of the Black Forest and Black Forest itself. Three different scenarios have been constructed, an "optimistic", a "pessimistic" and an "intermediate" scenario. For these scenarios it has been assumed that all the trees with more than 60 % needle-loss will not recover and die within 5, 10 or 15 years according to the 3 scenarios. The number of trees expected to enter each year the class of more than 60 % needle-loss has been calculated on the basis of the results of the annual inventories. Three assumptions have been made, a pessimistic using the transfer figure to the class 60 % needle-loss and more from the year with the fastest progress of damage (1983/84), an optimistic, using the figures of the year with the slowest progress of damage (1984/85) and an intermediate using the average figures 1983/86. The "pessimistic" scenario combines the short dying period of 5 years with the fastest yearly progress, the "optimistic" scenario the long dying period of 15 years and the slowest progress. The intermediate scenario combines the 10 years dying period with the mean progress of damage over the 4 years. The calculation have been made separately for all important tree species.

The results of the 3 scenarios differ very much from each other. They give the expected removals caused by forest damage for each year in the 3 subregions separately for species and assortments. To these figures an allowance for other unavoidable removals (wind, snow, insects) and not deferrable silvicultural interventions has to be added. In the optimistic scenario the removals do not exceed the normal annual harvest of the past period, but there is a slight shift in the repartition of assortments. The intermediate scenario lies around the normal annual removal, the pessimistic scenario however superates by far the normal level alone for unavoidable removals.

Based on these seenarios the area to be planted or regenerated yearly, the number of man-days needed in the forest, as well as the offer of specific assortments to the forest industry in and around the region can be calculated. Based on these figures and assuming various timber prices and developments costs, the revenues of the forest enterprises have been assessed.

Further steps in the study investigate the consequences of the anticipated development for the forest industry (capacity, market, labour force etc.), the farmers households, tourism and the other sectors of the regional economy. This part of the study is in full swing. Comprehensive results are not yet available, but it is already clear that under some assumptions especially farmers will be seriously affected. Many of them are owners of forests and a part of their income is generated by forest work and sale of timber. As they work in agriculture under marginal conditions in the region the 10 - 20 % of their income derived from forestry is vital for superating the indispensable level of family income. Without the income of forestry many farms will not any longer be viable, specially as they are hit at the same time by quota on milk production due to EC agrarian policy. The consequences for the whole region will be very serious when forestry, farming and tourism as important sectors in the regional economy simultaneously will enter into a crisis.

In the sector of ecology a comprehensive and very interesting preliminary study has yet been accomplished. It shows that liquid and dry depositions of polluted air on non forest land together with the consequences of forest decline threaten many important and rare biotops in and outside the forest and many endangered species will come under supplementary pressure. A hydrological study which used to a large extent satelite imagery showed that under certain assumptions of forest decline the maximum discharge of some rivers will grow considerably and threaten especially settlements and very fertile agricultural lands at the foot of the Black Forest and in the Rhine Valley. The existing dams will not suffice and have to be reinforced and elevated.

4. CONCLUSIONS

The preliminary experience and the preliminary results of this study lead us to the conclusion that inspite of a multitude of difficulties and obstacles investigations on a regional basis are possible and usefull. They ask for an interdisciplinary approach and a good collaboration between specialists of many fields. Such investigations help to understand what is really happening in the regional system, what can and must be done to alleviate the consequences of forest decline. It will, however, never be possible to predict what will really happen, but we can see and show what could happen under certain circumstances and what could or could not be done when the anticipated situation becomes a reality. Finally, such investigations procure a lot of arguments to convince people and politicians of the necessity to abate pollution by showing a realistic picture of what might happen when needed measures are not taken in time.

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7.9 POSSIBLE REGIONAL ECONOMIC CONSEQUENCES OF FOREST DIEBACK – NORWAY AS AN EXAMPLE*

S. Navrud and B. Solberg
Department of Forest Economics
Agricultural University of Norway
N-1432 As-NLH, NORWAY

ABSTRACT

Dramatic forest decline due to air pollution is not expected in Norway, but effects of episodic high ozone concentrations along the southeastern coast need further investigation. Two types of consequences of possible forest decline are discussed: (i) Consequences on the industrial forestry and forest industries; and (ii) consequences on non-timber values i.e. recreation, wildlife, aesthetics etc.

The regional economic consequences on industrial forestry and forest industries could be severe, especially in the long run if the forest growth declines significantly. Non-timber values could also be drastically reduced. These values may constitute a large part of the total economic losses from a possible forest decline, especially in Norway where 1/3 of the population live near and use the forest area threatened by ozone damages.

1 INTRODUCTION

The main objective of this paper is to discuss possible regional economic consequences in Norway of forest dieback or declines. Although we have at present no statistically significant evidence of a decline in forest production in Norway, the situation may rapidly change. Besides, the forest dieback in Central Europe is very important to the Norwegian forestry and forest industries.

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As air pollution most likely represents the most serious factor in a possible forest decline, this paper will focus on air pollution aspects.

Two types of concequences are discussed: (i) Consequences on the industrial forestry and forest industries, and (ii) consequences on non-timber values - e.g. recreation, wildlife, aesthetics. In addition, a brief account is given in Ch. 2 regarding the probability of a dramatic forest decline in Norway caused by air pollution.

2 THE FOREST DAMAGE SITUATION IN NORWAY - A BRIEF ACCCOUNT

The alarming reports of forest declines in Central Europe, especially during the last 3 - 5 years, have caused major public concern also in Norway. The concern was further accentuated by reports from southern Sweden in the autumn 1983 that similar decline symptoms were developing as in Central Europe. Quite detailed empirical studies were undertaken in Norway, including special inventories with the National Forest Survey, tree ring studies, etc.

The field observations which have been reviewed give no clear evidence of forest decline or forest damage in Norway related to regional air pollution. The concern about the forest declines in Central Europe poses, however, the question of whether similar declines could occur in Norway in the near future. The following points speak against dramatic changes, given that the declines are caused by air pollution (STRAND 1980, ABRAHAMSEN et al. 1983, TVEITE 1985):

1. The concentration of gaseous air pollutants do reach such levels in forest areas of Central Europe that direct damage can be expected. The concentrations in Norway are much lower and apart from ozone the probability of vegetation damage seems very small.

2. Central Europe has over a much longer time had substantially higher depositions of air pollutants. It is therefore not very likely that the Norwegian forests will be damaged at approximately the same time as in Central Europe.

3. In old mining areas melting of mineral ores containing sulphur has caused forest destructions - most probably because of high SO_2-concentrations. It is reasonable to assume substantial dry deposition of sulphur in such areas and that increased soil acidification has been the result. Forest have nevertheless

normally reinvaded the areas when the sulphur emissions stopped, apart from areas with high concentrations of heavy metals. The site productivity has probably been reduced, but trees can still grow normally.

4. A number of experiments to study effects of artificial acidification on tree growth have been carried out in the last 10-15 years. Some of the experiments have shown reduced growth when large amounts of sulphur as diluted sulphuric acid have been applied. But only a few experiments using extremely high concentrations have shown damage symptoms somewhat similar to what has been observed in Central Europe.

5. The forest decline in Central Europe are found on both rich and poor soils. If the damages are mainly caused by soil acidification it is difficult to understand that the damages do also occur on soils rich in calcium and magnesium.

6. The quite detailed study of tree vitality in 1984 in Norway showed no clear relations to the regional pattern of air pollution.

TVEITE (1985) concludes that dramatic forest decline due to air pollution is not expected in Norway, but effects of episodic high ozone concentrations along the southeastern coast need further investigation. Figure 1 shows a tentative map of the probability of high ozone concentrations for southern Norway.

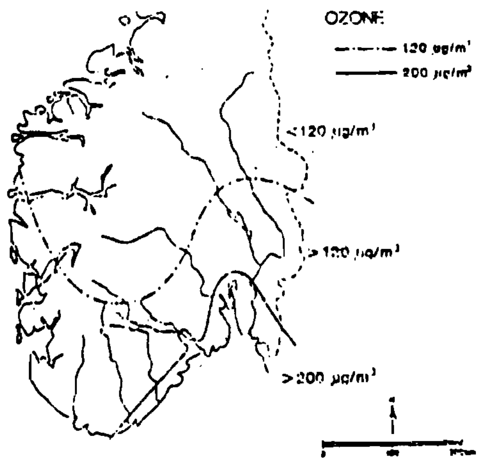

Figure 1. Areas with an estimated 50 % probability of the maximum hourly ozone concentration to exceed 120 µg/m³ and 200 µg/m³ during a summer (From SCHJOLDAGER 1984).

One should note that there is consistent evidence that ozone in Norway is partly a long range transport air pollutant and partly formed on a local scale (GRENNFELDT & SCHOLDAGER 1984).

3 REGIONAL ECONOMIC CONSEQUENCES IN NORWAY

3.1 Consequences on industrial forestry and forest industries

3.1.1 General discussion

Regarding consequences on industrial forestry and forest industries one has to distinguish between two situations:

Situation A: Norway is not hit by forest decline, but other forestry nations in Europe are.

Situation B: Norway is hit by forest decline caused by air pollution together with other European countries.

Consequences of situation A

The consequences for the Norwegian forestry and forest industries of situation A will mainly be the following:

* The world market prices of roundwood and forest industry products will decline in the short run as the supply of roundwood from damaged forest stands in Central Europe will increase. Rational expectations among the Norwegian forest owners will most likely imply that the short run Norwegian timber supply will decrease, as it is rational to expect that in the future (when the damaged stands in the other countries have been cut, and the forest capital then decreased) the roundwood prices will increase.

  This will most likely give lower employment and lower income from forestry in all forestry regions of Norway in the short run.

* The Norwegian forest industry will be influenced by several factors. First, the price of import roundwood is likely to decrease in the short run. This will be counterbalanced by lower world market prices on forest industry products. The total effects of these two factors on the Norwegian forest industry will depend on the price elasticities of demand of forest industry products, the transport costs of roundwood, and the roundwood supply price elasticities. In addition, substitution effects are likely to occur - partly because of different demand price elasticities for forest industry products and partly because different species could be differently hit regarding air pollution damages (for example could birch be less damaged than spruce or pine). These substitution effects could be estimated through studies of the cross price elasticities.

* The long term consequences of alternative A on the Norwegian forestry and forest industries will most likely be rather positive as the domestic timber supply is intact and the world market prices of forest industry products will increase in the long run due to less quantities of roundwood in Europe. Improved growth caused by genetic improvement of the next tree generations could, to some extent, counterbalance this effect.

* Some Norwegian forest industries have been worried about increased production of forest industry products in Central Europe because of the lower roundwood prices in the short run. This fear of competition is, in our view, not particularly relevant if we assume free international trade. First, the cheaper roundwood in Central-Europe could be bought by the forest industries in all countries, and then, as today, only the production and transport cost and foreign exchange rates will be different for the domestic forest industries compared to the foreign one. Secondly, the lower price of forest industry products should give a relatively low rate of return on new investments. Third, lower forest industry product prices will increase the demand of these products. Only two main factors could change this picture - (a) subsidies and regulations of free trade are introduced, and (b) idle capacities in the existing forest industries are significantly different in Norway and Central Europe. The last point is not very likely. Point (a) is possible, but how likely?

* A final point which should not be forgotten, is that other countries outside Europe (and North-America, which also may be severely hit by air pollution), will react on higher prices on forest industry products in the long run, increasing their export of forest industry products. This will work <u>against</u> drastical changes in the price level.

<u>Situation B</u>

In situation B one would have all the effects caused by the foreign countries as described above in situation A. In addition, the roundwod situation in Norway in the short run will be characterized by increased supply of the roundwood damaged by air pollution, and most likely (because of rational price expectations) less supply of roundwood not being damaged. The short term consequences for the activity in the Norwegian forestry and forest industry will highly depend on the absolute size of the forestry damage and its regional distribution. Less domestic timber supply of certain roundwood assortments could be counterbalanced by increased roundwood imports to Norway, so the forest industry activities would probably not be very much affected in the short run.

The long run consequences will most likely be larger as the physical forest capital will decrease and the annual growth per area of forest could be less than today because of air pollution. Also here genetic improvements could counterbalance some of this effect.

3.1.2 Numerical estimates

In Norway no studies exist which explicitly estimate the regional economic consequences of air pollution damages on forestry. The following should be regarded as rough attempts to get an idea of the size of the consequences involved.

Situation A

The short run consequences in Norway of price changes because of forest decline in Central Europe, could be illustrated by using the IBRD-model described in GUNDERSEN & SOLBERG (1984 a). This is a regionalized optimization forest sector model[1]. In GUNDERSEN & SOLBERG (1984 b) the model is used for estimating the regional consequences in Norway if the prices of sawnwood in 1990-95 dropped by 15 % relative to a "most likely" base scenario[1].

The main results of this comparison are:

* The total annual cut decreases by about 3 %.
* In the regions Nord-Trøndelag, Sør-Trøndelag and Southwest-Norway the annual cut will decline by about 10 % relative to the base scenario, because of high logging and road transport costs in these regions.
* A considerable part (about 30 %) of the available sawlog quantities is used as pulpwood. The reason for this is that it is assumed that the prices of pulp and paper are not decreased - it is only the sawnwood prices which are decreased. (Alternatively, one may say that relative to the base scenario the sawnwood prices are decreased 15 % compared to the prices of pulp and paper products). The transfer from sawlog assortment to pulpwood takes place in all regions except those where the sawlog quality is higher than average or where the distance to major sawnwood markets is short.
* The capacity of the pulp and paper industry increases slightly, mostly in the areas with already established capacity, but also in West-Norway.

The long run regional effects of situation A for the Norwegian forestry and forest industries decribed in Ch. 3.1.1 have not been analysed numerically. As mentioned above they are likely to be advantageous.

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[1]The model has 14 forestry regions and about the same number of forest industry- and market regions. The objective function is to maximize the surplus in the forestry logging operations and forest industries seen together.

Situation B

One gets an indication of the short run consequences of situation B when looking at the results in GUNDERSEN & SOLBERG (1985 b:21-24) from the alternative where all old forest of Norway spruce in the country is cut in 20 years time. This alternative is below referred to as scenario B, and represents a 15-20 % increase in the total cut in Norway relative to the base scenario referred to earlier.

Relative to this base scenario, scenario B gives the following characteristics in the period 1990-95:

* The regional forestry activity (e.g. income and employment) increases in all areas except West-Norway, roughly in the same order as the increase in the annual cut. (Note that here the forest damage is assumed not to give reduced quality of the timber felled).

* New investments are done in the forest industries increasing their capacity by 10-15 %.

* The production of sawnwood increases by about 15 %. The major part of this is exported - i.e. the export of sawnwood is increased by about 50 % relative to the base scenario.

The long run potential forestry effects of air pollution are, as mentioned above, caused by two main factors: Decreased stock of mature forest, and second, reduction in the annual growth per forest area. Using SOLBERG & GJØLBERG (1981) one get an idea of the possible size of the first effect[2]. If all the present mature forest in Norway of spruce and pine were cut in a 20 years period and nothing happens with the annual growth (i.e. no reduction in the growth potential is assumed), the highest sustained yield at the end of that period will be about 20 % less than the sustained yield without air pollution.

This will in itself create severe regional consequences for income and employment. If, in addition, the annual growth per ha is reduced due to air pollution effects, the marginal consequences will be still worse, depending on how much the annual growth is reduced and

[2]This report deals with Hedmark county, but that area has about the same age structure and species distribution as the forest for the whole of Norway.

what time profile one gets on the cutting. For example if the annual growth is reduced by 25 %, a rough estimate of the long term reduction of the industrial forestry and forest industry activities would be in the same order.

3.2 Consequences on recreational and non-use benefits of forests (non-timber values)

3.2.1 Description of non-timber values

Apart from producing timber the forest also "produces" recreational opportunities (use values) and non-use values.

The use values result from recreation opportunities like hiking, fishing, hunting, observation/photography of wildlife, and nature/ wilderness experience in general. The demand for and value of these recreation opportunities are very much dependent upon the scenic beauty of the forest, especially "near-view" scenes that focus on physical forest characteristics, but also "far view"-scenes (WALSH & OLIENYK 1981, BROWN & DANIELS 1986).

The non-use values can be divided into option value and existence-/ bequest value. Option value is the value people place on keeping the option to undertake recreational activities in the future, although they don t do it now or are planning to do it. Existence_ value is the value people place on the existence of the forests without physically using it. This includes the aesthetic value of forest as an important element in the landscape, the cultural and symbolic value of the forest and the value of the forest as a crucial part of our terrestial ecosystem and as a large genetical reservoar. The value of delivering this existence to future generations is the bequest value.

3.2.2 Methods for estimating non-timber values

These non-timber values can be considered as public goods in the sense that consumption by one individual does not prevent consumption by another individual, and in the sense that these public goods are nonexcludable in Norway ("allemannsretten" - i.e. everybody has the right to walk on private forest land).

These public goods have, in opposition to private goods, no real market price. To solve this problem, several methods for estimating the economic value of such non-market goods have been developed over the past 25-30 years. The non-market values can then be included, and not ignored, in the decision-making process. This is necessary if we want to find the total economic losses from (possible future) forest dieback due to air pollution.

There are two major types of methods for evaluation of the public goods associated with forest areas:

1) Travel Cost Method (TCM)
2) Contingent Valuation Method (CVM)

Both methods are based on the affected individuals willingness-to-pay (WTP) for the public good or to get/avoid a marginal change in the quality/quantity of the good.

TCM is an indirect method, in the sense that it is based on the idea that a certain private good (here: the cost of travelling to the forest area) is complementary to the public good in question, and that the observed demand for the private good can be used to estimate the value of the non-market, public good.

CVM is a direct method where you try to construct a hypothetical market for the public good through interview techniques.

Another important difference between the two methods is that TCM only calculates the recreational or use value of the public good, while the CVM has the potential of getting the total WTP for all the affected individuals. That is, CVM estimates not only the use value, but also the non-use values.

Empirical studies have shown that these non-use value may be 2-3 times larger than the use values (STRAND 1981, GREENLY, WALSH & YOUNG 1981, NAVRUD 1987), and it is therefore important to include them in the value estimate. In situations with a large degree of uncertainty about the effects, which characterizes the possibility of forest decline in Norway, one should expect large non-use values motivated by risk-averted behaviour.

Both TCM and especially CVM are based on several strong assumptions and have many potential biases. Despite some continuing controversies and unsettled points, CVM-studies of recreational use benefits of familiar environmental goods have performed reasonably well when compared to available empirical evidence from travel behaviour (TCM), actual cash transactions, and controlled laboratory experiments (CUMMINGS, BROOKSHIRE & SCHULTZE 1986). Levels of accuracy have been reasonable and consistent with levels obtained in other areas of economics and in other disiplins.

The accuracy of non-use benefits is more uncertain, but CVM-studies that have focused on this yield much the same results.

This accuracy should in most cases be sufficient to give an approximate size of the value of the public goods. In cases where decision-makers quite simply have no idea as to the economic value of preserving environmental quality, such information is, in out view, preferable to complete ignorance.

3.2.3 Empirical results

In Scandinavia there has been no study on how the non-timber values are/will be affected by a marginal reduction in forest quantity/quality due to air pollution.

However, one TCM-study in Denmark (CHRISTENSEN 1984) and one TCM- and CVM-study in Sweden (BOJÖ 1985) found the recreational value of visiting a forest area to be approximtely NOK 10-35 ($ 1.50- $ 5.00) per visitor day at 1986 price-level. Because these estimates are based only on non-residents, this must be viewed as a minimum estimate.

Forest decline may also affect the recreational value of activities like fishing and hunting, because the quality of the natural scenery is a very important factor in these recreational experiences. In Norway three TCM-studies have found a recreational value of fishing per visitor day of 244 NOK ($ 35) and 128 NOK ($ 18) (1986-prices) for Atlantic salmon and Brown trout respectivly. This difference is consistent with similar American studies and is due to the fact that salmon fishing is a more specialized activity and a "luxury good" (NAVRUD 1986).

Apart from the methodological uncertainties, these unit day values may also vary substantially with different forest quality, substitution possibilities (other available forest areas and alternative recreational possibilities), and the socio-economic characteristics of the regional population. The total recreational value of the area depends very much on the number of potential users.

This last factor is very important in Norway, where about 1/3 of the population (i.e. 1.4 million people) live along the south-eastern coast where forest decline might occur (see Figure 1). These forest areas are intensively used for recreation and are also an important landscape element. Ozon damages may therefore drastically reduce both use and non-use values of this forest area.

The only empirical study we know about regarding this particular subject is CROCKER (1985). He employs CVM to estimate the economic value of visible forest damage from air pollution (needle mottling and drops) to recreationists in the San Bernadino National Forest, Southern California. CROCKER op.cit reports a mean WTP of $ 2.09 per trip in additional access fees to obtain forest quality represented by colour photos depicting a low injury level of 4.5 on a 35 point scale. This WTP was three times greater than the WTP for moderate and severe injury environment (with corresponding scale values 18 and 32). Note that this is only the WTP for the recreational users.

In USA there have been several other studies on the WTP for marginal changes in the forest quality, but in most cases that is due to pine beetle damages. However, the effects on the forest quality and on the use-/non-use values may be somewhat the same. AIKEN (1985) and WALSH (1986) reports the results of a pilot CVM-study exploring the value of forest quality to a sample of the general population, including recreation users and non-users. A sample of households representing the population of Colorado, reports an average WTP of $ 47 per year to protect forest quality in the state at optimum levels of tree density depicted in colour photos. Recreational value represented only 27 percent of this total value. WALSH, WARD & OLIENYK (1986) gives a good review of these and other, similar studies.

4 CONCLUDING REMARKS

Using the IIASA trade equilibrium model for forestry and forest industry products DYKSTRA (1986) reports of consequences of changes in timber supply in Europe because of acid rain, assuming:

(a) the timber supply between 1985 and 1995 in Eastern and Western Europe increases with 20 % above a most likely base scenario;

(b) from 1985 and onwards the rate of forest growth in Eastern and Western Europe measured as a percentage of growing stock volume, would be reduced by one-third compared to the growth rate of the base scenario.

The price effects of these assumptions relative to the base scenario are:

- Between 1985-1995 the price of pulpwood decreases by about 10 %, the sawlog prices decrease by 1 % and the price of forest industry products decreases by 0-2 %.
- Between 1995-2010 the prices increase by 7-11 % on coniferous pulpwood, 7-18 % on coniferous sawlogs, 3-11 % on other forest industry products.

Although burdened with considerable uncertainty, this work indicates that for Norway the short term negative effects of situation A defined in section 1 would be rather modest, and that long term positive effets could be some higher for most forest products.

The negative consequences of situation B could be severe, depending on the size of the reduction of the forest growth in Norway due to air pollution.

Compared to most countries in Europe, Norway has a great advantage in that we can learn from the history of the air pollution effects in Central-Europe and certain areas in North-America.

Non-timber values could be drastically reduced because of air pollution, especially in the South-East part of Norway threatened by high ozon concentration. These values may constitute a large part of the total economic losses from a future forest decline as 1/3 of the Norwegian population live in these areas.

In Scandinavia, and in the rest of Europe, there is a great need for data and empirical studies on how non-timber values are affected by forest decline. Doing WTP-studies of reductions in non-timber values due to air pollution is an important task. Such studies should be done in cooperation for several countries which are differently hit by forest damages. In this way one could get comparable results of considerable interest for policy makers. This could be an important task for IIASA/IUFRO to coordinate.

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8. MANAGEMENT AND POLICY RESPONSES TO FOREST DECLINE

8.1 EXPERIENCE ON FOREST REGENERATION OF POLLUTION-DAMAGED FORESTS IN THE GDR*

H. Thomasius
Technical University of Dresden
DDR-8223 Tharandt
GERMAN DEMOCRATIC REPUBLIC

1. Introduction

The reconstruction of low-productive forests has already been dealt with in earlier papers and a method designed to make objective decisions was deduced (THOMASIUS 1973 a, b, c; 1978, 1980). However, in the foreground of these investigations stood damage from storm and snow in spruce forests growing in the montane regions. But here it is intended to describe the regeneration of pollution-damaged forests. The question first arises how these different problems can be attributed to a common basis and wherein the specific character of the reconstruction of pollution-damaged forests consists as seen from the methodical viewpoint. In a second part it is intendad to describe in detail the results obtained in reconstruction activities over a period of 25 years in the SO_2-polluted forests of the Ore Mountains (Erzgebirge, GDR).

2. Reconstruction strategies

According to an already formerly published definition (THOMASIUS 1978) under reconstruction we understand the short-term (by clearcutting) or long-term conversion (by selection cutting) of low-productive forest stands into such promising a considerably higher productivity. The necessity of such a measure follows from the difference between the production potential L_p of the

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site in question and the productivity L_a of the present stand

$$\text{that is } \Delta L = L_p - L_a,$$

whereby felling produce (mean annual increment), monetory returns or also beneficial effects can serve as evaluation criteria. If this difference exceeds a definite threshold value S following from forest-political considerations, that is

$$S > \Delta L = L_p - L_a,$$

then the necessity of a stand reconstruction is given. In our previous papers on the conversion of low-productive stands we could start from the supposition that the given site with its ecological coordinates $x_1, x_2, \ldots, x_n$, the herefrom resulting climax $y = f(x_1, x_2, \ldots, x_n)$ and its substitute in the commercial forest respectively as well as the production potential L_p to a large degree represent constants. However, this prerequisite does no longer hold, if the forest sites are subjected to permanent inputs of atmospheric pollutants that cannot be compensated as observed in Central Europe on large areas. Consequently, the herefrom resulting change of the ecological coordinates leads also to a change of the resultants, i. e. potential climax, its substitutes and the production potential L_p (fig. 1). This is demonstrated by the Saxon Ore Mountains. Here, under the conditions of clean air the mountain forests of spruce (Piceetum hercynicum) in the oreal belt and mixed forests of spruce, fir, and beech (Abieti-Fagetum luzuletosum) in the montane belt were the dominating climax communities. According to HOFMANN (1985) their production potential amounted to about 5,5 t $a^{-1}ha^{-1}$ (Piceetum) and 7 to 8 t $a^{-1}ha^{-1}$ (Fagetum) aboveground dry matter. In the commercial forests these climax communities were substituted by spruce forests on large areas. Already in the course of several decades the naturally acid sites at medium altitudes have been changed on large areas by immissions of SO_2 and other pollutants (particularly the chemical climate) to such an extent that to-day one has to reckon with a mountain-ash forest growing on crest sites and conifer-poor beech forest at medium altitudes constituting a climax, which is the result of human activities. The transition from the originally conifer-rich climax communities to the pollution-affected subsequent communities that are poor in conifers is connected with disequilibriums between natality and mortality of various species (change in the tree species spectrum), production and decomposition of organic matter (change of bio-mass production and accumulation) as well as disturbances in various feed-back mechanisms what inevitably leads to instability. Naturally, together with the retreat or disappearance of various tree species there is also a change in the possibilities for climax communities to be substituted by forest communities in the commercial forest. In this change of the environmental conditions, their respective climax communities and substitution possibilities the methodical problems connected with the reconstruction of pollution-damaged forests lie. Taking the long production periods in forestry into consideration the following points seem to be necessary for scientifically-based decision making:

- knowledge of the changes already happening or to be expected in the next decades in the ecological coordinates
- knowledge of the structure and function of climax communities which adapted themselves to the altered environmental conditions
- knowledge of the substitutions of these man-made climax communities by forest communities as are possible in commercial forests.

We must confess that our knowledge of these points is still very gappy. However, as it is impossible in practice to wait until all these questions are answered in case of urgent decisions to be made with regard to the reconstruction of pollution-damaged stands definite assumptions have to be taken as a basis.

1. The present extent of pollution will decrease in a foreseeable time ($t \ll t_u$) and it can predominantly be reckoned with a regeneration of the concerned sites as well as surviving stands.

2. The present extent of pollution will decrease in a foreseeable time, however, it must be reckoned with long-term changes of the site and corresponding climax modifications.
3. The extent of pollution will continue for an unforeseeable time so that new site conditions will develop that lead to considerably altered climax and forest communities.

It is obvious that the necessity, urgency and character of the reconstruction to a large degree depend upon the question which of these three possibilities is in conformity with reality or will be selected as a basis for decision. For this reason, we need a reliable prediction on the basis of scenario analysis. In the first case, one will endeavour to assist the present stand, particularly the younger and generally more stable stands, in overcoming the critical years by adopting conservation measures. In places where forest restoration measures are necessary, the usual target stand types will be adhered to also in future.

In the second case the task consists in investigating when the present degree of pollution will decrease and with which remaining site changes one has to reckon. On the basis of the therefrom deriving hypothetical climax communities the likewise hypothetical stocking targets for reconstruction measures are then taken. In the third case the degree of the supposed pollution, the therefrom resulting site change and the tree species spectrum that is considered suitable under these conditions have to be investigated.

In the reconstruction measures hitherto carried through in pollution-damaged areas in the GDR the present extent of pollution and the present state of site without extrapolation to pollution decreases and regeneration or progression of pollution and further degeneration were taken as starting points. However, it has to be checked when and where one can proceed from the variants 1 and 2.

3. Conservation and reconstruction measures to be taken in pollution-damaged spruce stands growing in the Ore Mountains

In general, the management of pollution-damaged spruce forests serves the aim to retard progression of damage, maintain the forest and its beneficial effects and ensure forest restoration taking the given conditions into consideration. This general objective may be attributed to two major tasks.

1. An as long as possible conservation of the living pollution-damaged forest stands up to the time of their planned felling when normally managed. This is necessary in order to ensure continuity of the productive and protective effects of the forests and to maintain a satisfactory arrangement in space and time for the future.
2. Gradual reconstruction of the spruce forests growing in the most severely polluted areas (zone 1) and no longer maintainable by immediate clear felling or gradual conversion into stands which besides a relatively high productivity and beneficial effectiveness are more resistant against air contaminations. In addition to this, seen also from the general viewpoint of economy, reduction of the area proportion of spruce in the montane regions of medium altitude in the GDR should be striven for.

3.1. Conservation of pollution-damaged spruce stands

The common state of health of the forests is to a high degree the resultant of numerous factors affecting them. This general statement applies also to forests growing in polluted regions. Therefore, it is necessary to make the effect of all ecological factors as favourable as possible and that to an extent, to which the latter are open to influence. Also concerning all other adverse factors, such as storm and snow, insects and fungi, a high stability should be attained.

3.1.1. Thinning of pollution-damaged spruce stands

In the pollution-damaged spruce stands growing in the Ore Mountains regulation of stand density with special reference to forest-sanitary viewpoints is a major task in thinning. In this context, two opposing viewpoints have to be taken into consideration and brought in harmony with each other. The first viewpoint reveals itself in the aspiration for keeping the spruce stands as dense as possible in order to attain utmost calm in the air within the crown and avoid physiological wind damage that is recognizable nearly everywhere at stand borders. It must be added that the larger tree number connected with a high stand density embodies a selection reserve for the further tending of stands.

This viewpoint is contrasted with a lower vitality and stability of individual trees, grown up under the conditions of high density, due to restriction and shortening of the crown with a correspondingly diminished needle mass. This comprises also the stability of trees and stands to snow as required in the pollution-damaged regions. Both these viewpoints can only be brought in harmony by intensive educational measures to be taken in young stands and moderate low thinnings in older stands (beginning from 3rd age class). One should also look to it that each single tree possesses a well-developed grown in the juvenile phase and that stands at the old-timber stage have a closed canopy. Longer thinning intervals and severe encroachments should be avoided. This mode of treatment corresponds to differential thinning. Admixed tree species which in spruce stands distinguish themselves nearly always by a higher resistance to SO_2 should possibly be exempted from felling in thinnings. Besides these general viewpoints some other special characteristics have to be taken into consideration in the various damage zones. In the most severely polluted zone (I) which is characteristic of a high pollution-related mortality thinning operations to a high degree embody advanced sanitary fellings. Here, the main task is to keep the bark-beetle under control. If there is the danger of opening up of stands weakened trees, too, must be maintained as long as possible. This applies particularly to pollution-exposed stand borders.

In principle for the damage zone II the abovementioned viewpoints apply. Here, opening up of stands should be avoided too, particularly at stand borders. Stands belonging to damage zone III are to a large extent treated in accordance with the regulations for low thinning as generally applied.

When planning intermediate fellings the increment losses which are differentiated according to damage zones have to be considered.

3.1.2. Edges of forests and stands

In the case of immissions edges of forests and stands manifest particular zones of damage. This is obviously to be attributed to the fact that these border regions which are exposed to immission on the weatherside are first and most severely hit by drifting air masses containing SO_2. It must be added that at the edges of forests and stands a number of further adverse factors are particularly effective among them above all wind as a factor causing physiological and mechanical damage, high solar radiation to the stand border causing bark blister and drought-injuries as well as hoarfrost during the winter months. In the Ore Mountains, the south-west, south and south-east sides are most seriously affected by these phenomena. These sides are, at the same time, open to the attack of immission currents.

Based upon this summed-up effect the forest and stand margins of the abovementioned expositions are especially endangered in the Ore Mountains. Under otherwise equal conditions the borders of older and consequently highly sensitive spruce stands suffer most.

The degree of damage diminishes in the direction from the border to the inner part of the stand. The width of the more severely damaged border strips are under otherwise equal conditions to a high degree dependent on the thinning grade of the stands. One can suppose that this phenomenon has to be attributed first of all to the decreasing wind velocity and the therefrom resulting physiological consequences.

Therefore, special attention must be devoted to forest and stand margins in pollution-damaged regions. This is done by maintaining and rendering assistence to available shrubs and admixed species as well as avoidance of opening of canopy by thinnings. If it is impossible to stop or retard the progression of damage on the weather side of forest and stand margins, then mangling of entire felling series on the side away from immissions will be the result. In the Ore Montains this process runs just against the normal progression of felling. Likewise, consolidations of scattered lots and straight-line fellings should not be undertaken from this side!

3.1.3. Progression of felling as well as form and dimensions of area in final fellings

The importance of the mutual protection of individual trees in a stand has already been depicted. In addition to this there are protective effects between neighbouring stands within a compartment. When conducting and planning fellings in pollution-damaged regions special attention has to be paid to the relations between space and time emerging from such a situation.

In pollution-damaged regions progression of felling with a close-to-normal arrangement in space and time is possible only, if the felling front lies in the immission lee. In this context and in the interest of favourable ecological conditions to exist on the prospective planting area the width of the felling area should not exceed one to two tree-lengths depending upon the tree species. For ecological reasons the subsequent felling is allowed to be made only after the establishment of the adjacent young plantation, i. e. not earlier than after 6 to 8 years.

All felling fronts that are exposed to immissions or orientated to neighboured expositions have to be halted in the interest of protecting the stands lying behind, even if this should lead to deviations from the normal rotation age. All subsequent felling operations only precede the die-back process caused by pollution on the exposed side thus standily ensuring an acceptable state of sanitation in the forest. Only if one cannot expect that protective effects from a whole or partial stand offer shelter to the stands lying behind, stripwise fellings are justified. This is the case, if in the given region the degree of stocking has fallen to $B < 0{,}4$.

Besides these general rules the following specific features have to be attended to: in the damage zone of category I (extreme damage), where the spruce stands die-back from the inside and shelter has become ineffective reconstruction measures have to be taken, if the degree of stocking falls under its critical value. Here, one has to take advantage of all the possibilities for a well-timed planting under cover, advance and subsequent planting of immission-tolerant tree species that are not suitable for cultivation in open fields.

3.1.4. Applying fertilizers in stands

It has already been mentioned that the general state of health of forest stands - in pollution-damaged regions too - depends upon the effect of numerous factors. Hence it follows that the greatest tolerance against pollution can be expected under otherwise optimal environmental conditions and that every change in important environmental factors toward the ecological optimum enhances the probability of an increase in resistance. If this hypothesis is as well applied to the nutrient supply in trees, then it follows that application of deficient nutrients contributes directly to an improvement of the stability of forest stands that are liable to injuries from pollution. In this context, the prospects of success are the greater, the more pronounced a nutrient deficiency is. The results of numerous laboratory experiments, outdoor trials and large-area application of fertilizers in forest stands confirm this supposition. In this way, many pine stands growing on nutrient-poor old-pleistocene sites in the Düben-Forest and Lower Lusatia and being heavily damaged by air pollution have been sanified and stabilized. Here, it must be emphasized that these measures have to be substantiated by the results of needle analyses, as excessive nitrogen dosages (by fertilization or input from the atmosphere) can lead to growth depressions.

Unfortunately, in the SO_2-polluted spruce stands growing in the Ore Mountains application of N did not prove as successful as in the abovementioned case.

a) Fertilization measures are ineffective
   - on crest sites, as the climate here is the all-deciding and growth-limiting factor. Here, under the prevailing climatic conditions there is no acute nutrient deficiency for spruce
   - in extremely polluted regions, as large-scale revival of spruce is here no longer feasible

b) Therapeutical effects of fertilization can be achieved on SO_2-polluted areas
   - in the montane regions of medium and lower altitude, where the climate is no longer the all-deciding environmental factor
   - in the slightly and moderately polluted regions, in which a possibility for revival still exists
   - in spruce stands on sites for which a growth-limiting nutrient deficiency is characteristic even under the condition of pure air.

3.2. Reconstruction of pollution-damaged forests

Forest stands being severely damaged by pollution or giving reason to anticipate, so heavy damage in the next two decades that will no longer fulfill their tasks in national economy and countryside improvement are gradually reconstructed.

This applies to nearly all spruce stands belonging to the damage zone of category I. In this context, one has to differ between short-term conversion by clear felling, partly with pioneer crops, and long-term conversion by planting under cover, advance and subsequent planting.

When doing reconstruction work a number of problems concerning the priority arise:
- the present degree of damage, the anticipated progression of damage and the presumable expectancy of life of each stand

- the present arrangement in space and time in the given compartment as well as that to be striven for in the future
- the expenditures as well as effects of reconstruction on national economy and countryside improvement
- requirements for the cultivation of the tree species under reconstruction as derived from their ecological demands (e. g. shelter from the side and canopy).

3.2.1. Choice of tree species

In pollution-damaged regions special emphasis has to be laid on the demand for suitability of sites for the species to be cultivated and being generally applied when choosing tree species, as the effects of pollution are overcome in the best manner possible, if all the other conditions for the concerned tree species are favourable, possibly optimal.

When a decision has to be arrived at concerning the choice of tree species in pollution-damaged regions the site factor "immission dose" requires to pay additionally special regard to the property "immission tolerance" inherent in the tree species. As to SO_2 plenty of experimentally and empirically acquired knowledge is on hand. In this connection it is once more pointed to possible changes in the degree of pollution. For example, a significant decrease in the pollution by SO_2 to occur in the course of the next 20 years might already to-day justify the re-establishment of spruce, because this tree species possesses a relatively high tolerance against SO_2 in its juvenile phase and regenerates at a relatively high speed after discontiuance of the SO_2-pollution. Further viewpoints, such as productivity and stability as well as beneficial effects of the concerned tree species, their growth strategy and duration of production, are referred to.

Under close consideration of all these viewpoints and experience collected in site surveys for the choice of tree species tables have been worked out, from which for each site unit with different degree of SO_2-pollution.

Those tree species can be selected that are suitable for cultivation.[1] In this context, it may be mentioned that the scope of possibilities narrows more and more in the Ore Mountains beginning with the lower altitudes and terminating with the crest sites, as there extreme site conditions, maximum pollution and natural occurrence of spruce overlap, the latter being highly sensitive to SO_2.

In the pollution-damaged zone of category I situated at high altitudes and on crest sites this situation compels partly to cultivate woody species which no longer render timber yields worth mentioning and only serve to protect the landscape.

In connection with the choice of tree species mention deserve current investigations made in the GDR with the purpose of breeding resistant species. They serve to improve the immission tolerance of the main tree species and broaden the spectrum of tree species that are suitable for cultivation in the pollution-damaged regions. In this context, lengthening the life duration of spruce and pine by two to three decades is already a great success.

With these objectives in mind research work is done which aims at the selection of SO_2-tolerant spruce provenances and individuals and their autovegetative propagation. Mention deserve also the results obtained in cross breedings with European and Japanese larch. In addition to this, selection and in vitro propagation of aspens and mountain-ashes for cultivation in pollution-damaged regions is practised with good success.

3.2.2. Techniques applied to the establishment of young plantations in pollution-damaged regions

The rules generally holding for the establishment of young plantations apply to a large extent also to the re-establishment of such plantations in pollution-damaged regions. Here,

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[1] For want of space publishment of these tables is, unfortunately impossible. Those wishing to receive these tables can contact the author.

they must be applied with special care, as young plantations which are initiated under extreme environmental conditions in such places should be given conditions as favourable as possible for their start. This aim justifies some additional expenditures for preliminary treatment of the planting area, soil working, choise of the plant assortment, care of the young growth as well as application of fertilizers in the young plantations and amelioration.

In pollution-damaged regions of the Ore Mountains the felling sites and planting areas respectively are often covered with dense and vital crops of Calamagrostis villosa. The latter are combatted in combination with a preliminary treatment of the area with potassium or sodium chlorite and delapon respectively. This facilitates the subsequent case of the young growth considerably, because the use of herbicides after planting is impossible on behalf of the higher-sensitiveness of the cultivated plants to herbicides.

There were particular warnings against complete removal of the live ground cover and entire forest floor in pollution-damaged regions, as on the whole these organic substances are important for the soil microorganisms, subsequent nutrient supply, buffering of acid precipitations and soil fertility. Techniques which are based upon removal of the live ground cover by strips, as is the case when using the forest strip plough "Waldmeister" are by for more advantageous. In this manner the suppressing ground cover is removed (what is necessary particularty in the case of Calamagrostis villosa) and the humus deposited in narrow strips at a distance of about two meters. The humus decomposes only slowly and the nutrients which in the course of several years are gradually released can to a large extent be taken up by the meanwhile grown-up trees.

When restoring the forests with more demanding tree species this kind of soil working is to be combined with an ameliorative application of lime and magnesium, on poorer sites also with an application of phosphorus and potassium. Application of nitrogen can be more appropriate at a later time (after decomposition of the forest floor - needle analyses!).

In pollution-damaged regions, plants as big and vigorous as possible should be used in forest restoration and reconstruction in order to compete successfully with grasses and weeds. In the last years container plants and balled young trees have proved highly successful. A special technique designed to set out balled young trees has been worked out.

On wet sites it is often necessary to carry out hydroameliration by new establishment or reconstruction of corresponding ditch systems. Exempted from it are the high moors which are protected by the nature conservation law.

The majority of tree species envisaged for reconstruction are liable to browsing by game. Therefore, safe protection by fencing is indispensable.

When choosing the planting space a sufficient mortality and selection reserve has to be cared for.

The following quantities can be taken as a guide:

			pieces per ha
blue spruce	without harvesting of decorative trees	2.0 m x 2.0 m	= 2,500
	or	2.5 m x 1.6 m	
	with harvesting of decorative trees	2.0 m x 1.5 m	= 3,300
Serbian spruce	without harvesting of decorative trees	2.0 m x 1.5 m	= 3,300
	with harvesting of decorative trees	2.0 m x 1.0 m	= 5,000
lodgepole pine		1.5 m x 1.0 m	= 6,700
	or	2.0 m x C.75 m	
European larch		2.0 m x 1.6 m	= 3,100
	or	2.5 m x 1.25 m	
Japanese larch		2.0 m x 1.1 m	= 4,500

3.2.3. Long-term conversion of pollution-damaged spruce forests by planting under cover, advance and subsequest planting

For the purpose of reconstructing damaged spruce stands some tree species have been proposed, which are not suitable for cultivation in open fields. This applies above all to European beech, broad-leaved tree species of high value and Douglas fir. In the stands envisaged for long-term conversion the cultivation of these tree species has to be prepared and carried out in due time. There are often also stands that offer themselves for this purpose thanks to their loosening-out after damage by snow or storm.

In this connection some remarks may still be made concerning the inclusion of the mountain-ashes and birches-spontaneously growing in various places - as a pioneer crop when establishing the abovementioned tree species. As the re-gaining for European beech and valuable broad-leaved tree species of many sites can be realized only over a pioneer crop of birch, mountain-ash or aspen greater attention must be paid to this stage of the secondary succession.

4. Projects for managing pollution-damaged regions

Proper management of pollution-damaged forest tracts requires continuous monitoring of pollution, mutual weighing of the various ecological, technological and economical viewpoints, integration of the different activities and flexibly taking measures in response to in part rather quickly changing situations. The results of all these deliberations and conclusions find their expression in projects for managing pollution-damaged areas, e. g. individual forest ranges or districts. At definite intervals, mostly every five years, these projects have to be actualized. This includes:

- collection of data on the state of health of each stand and inference of corresponding decisions to be taken for its special tending
- fixing of measures to regulate arrangement in time and space (e. g. stoppage or continuance of felling fronts, carrying out of liberation fellings, severance fellings etc.)

- planning of measures to regenerate forests
- planning of measures to fertilize and ameliorate
- preparation of combatting campaigns against the bark beetle and other pests etc.

The results of these elaborations are represented on planning cards that - taking the topography into consideration - give an all-round idea of the present state, presumable progression of damage and prospective forest structure.

8.2 FOREST DECLINE AND CHANGES IN FORESTRY*

D. Mlinšek
Biotechnical Faculty
YU-61000 Ljubljana, YUGOSLAVIA

Abstract

Forests are getting ill. Forestry has to change its character completely. The patient forest needs a good hospital. Forestry needs alliance with other branches. Common research of foretsry and medicine could be an important psychological help for changes in man`s polluting technologies.

Forestry and its "modern society" would like to save the dying forests without changing their behaviour and their technologies. The real background for the appearence of inappropriate impacts on forests is man`s agressive mentality against nature. In this situation forestry stays helplessly vis à vis his own technology, which in fact is the part of man`s general destruction of nature.

When comparing classical technologies with modern ones we must state: classical technology and its tools are substantial part of our culture and its ethics. Powerful modern technologies are not an organic part of our culture. Therefore the ethical code is required in technique which could help us not to misuse the powerful technologies and to reduce the increasing impacts on the environment. In fact

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it is a matter of responsibility and of our willingness to make this step or not.

Forests are very endangered. It is high time for undertaking the action; any way - in different directions. There are many things which forestry can do to diminish the danger; but the solution cannot be found in continuation of present technologies and their trend - not even in forestry. There is no doubt that various branches of industry and agriculture have to change their technologies for reducing all kind of wastes which impact forests and similar ecosystems.

When fighting against decline of forests, forestry has to develop its own strategy for two reasons:

- to change our own behaviour and especially
- for elaboration of considerations which are influentical in reaching political decisions.

As an example I may explain the situation in Slovenia. After long discussions the priority was given to "clean chimneys" of big power stations.

THERE IS AN EXTREME NEED TO CHANGE FUNDAMENTALLY THE OPINIONS ABOUT WHAT IS A FOREST.

First of all forest must not be the mining object any more. Up to the present it was considered as a place from where different sorts of energy have been collected: litter, fuel, timber etc. which have been thought of as "energy" of other artificial systems. Newly there is an additional exploatation of the forest made by industrial wastes (SO_2 etc.). The forests completely lose their identity and productivity. In this way the forest area has already reached its lowest point which must not be lowered any more. Obviously our forests are far away from their natural identity. They are heavily crippled and therefore not able to withstand different influences. By the way, there is no forest in a condition to resist the existing pressure of dirty technologies.

For better understanding and changing our philosophy, the holistic concept of our behaviour is needed which has to replace the still existing reductionism. In other words forestry research is at the very beginning when tracing these completely new ways.

FOR COMBATING THE IMPACTS OF DIRTY TECHNOLOGIES ON FORESTS, FOREST SHOULD BE OBSERVED AS AN INSTRUMENT INDICATING THE HEALTH CONDITIONS OF THE MAN.

The reason for this proposal can be explained in the following way: forest is a very sensitive system reacting to different influences. Its rather "eternal" presence is endangered. The forest is disappearing in alarming way, telling us what will happen with man.Therefore it should be observed and elaborated as a health indicating instrument. Medicine is not sufficiently informed what is going on in forests. They expect to be given some information from foresters and are interested in preventive medicine. Forestry needs an efficient collaborator who is permanently in touch with the most vulnerable part of man's identity - the psychology of his health.

Some results dealing with the SO_2 impacts on different tree species have been already shown by interesting collaboration between foresters and biologists in researching. There are some severe citogenetic changes caused by SO_2 at some tree species like Abies and Picea. Similar investigations are also needed in human biology.

We have to learn to observe the affected forests. They should be equiped appropriately. Forestry should learn to communicate with various branches like medicine etc. The communication between foretsry, publics and politicians should be developed via medicine. People will realize the severity of dirty environment only when life will be endangered. Forester has to make partnership with the forest against unacceptable dirty technologies.

FORESTRY RESEARCH AND FORESTRY IN GENERAL ARE GENERALLY ORGANIZED FOR NORMALY DEVELOPED FORESTS. BUT FORESTS ARE BECOMING ILL. FORESTRY IS OBLIGED TO REORGANIZE ITS ECONOMY ACCORDING TO NEW SITUATION IN THE FORESTS.

As far as I know no steps have been undertaken to reorganize forestry or to change our habits. Forest has to be recognized as a patient and forestry has to be reconstructed in a sense of a hospital.

FORESTRY AND SILVICULTURAL GOALS HAVE TO BE CHANGED. NEW GOALS, NEW ORGANIZATION AND NEW MEASURES SHOULD BE INTRODUCED ACCORDINGLY.

In a dying forest everything is unexpected. Forester has to adopt his activity to each partial change which occurs in different parts of a forest. He must become satisfied with every green tree or shrub still resisting in the forest stand. Practical experiences in my country since 1965 tell us how successful was this way. When providing an intensive silviculture we managed heavily damaged silver-fir forest on thousands of hectares. In forest enterprises where this was not the case the result was a cemetery of stands and a ruin of forests. Forestry and silviculture have to be organized to help the forest when bridging the unexpected fluctuations.

AN INTERNATIONAL MONITORING OF FOREST DECLINE SHOULD BE ESTABLISHED AND INTERNATIONAL EXPERIENCES SHOULD BE ENCHANCED.

Without close contact between foresters in Europe no success can be expected. As an example I may explain the experiences concerning extention of silver-fir decline which was observed in northern part of Yugoslavia. In early sixties dying of some silver-fir trees was noticed in some parts of Slovenia. First inventory of silver-fir decay was made by my institute. At that time 10% of silver-fir was damaged. The dying was severe on three different places. In some areas no damage was observed. At the same time in the neighbouring Croatia no typical dying of this tree species was found. Today in Slovenia 95% of trees are damaged. In Croatia our best silver-fir stands are rapidly dying and in Bosnia, south wards, next to Croatia, the dying of Abies alba has already begun. In the meantime some additional pollutant industries were built only in the north. The extention of dying forest area is in permanent growth according to the local pollutants, to the pollution coming from the neighbouring countries and according to the interaction of both sources of air pollution.

Strong winds from northern Italy which is more and more industrialized bring poisonous substances to the slopes of the Dinaric Alps and deposit them in these forests. In fact the poisonous cloud like mushroom is growing. It has its own rules of growth which do not respect the boundaries. We can expect that unaffected countries become affected. Air pollution and decaying of forests have become our common problem which can be solved only by round table discussion of all inhabitant of this continent.

SIDE PRODUCTS OF FOREST DECAY (DYING SOILS ETC.) BECOME MAIN PRODUCTS OF DESTRUCTIVE PROCESS.

In elaborating a new strategy forestry should list all possible side effects caused by forest decline which will occur when forests disappear. When using pesticides we are facing a completely new phenomenon: soils lose their substantional function of life. The same is going to happen with forest soils. Not much phantasy is needed to imagine all negative final effects when because of leaching of soils expensive technical investments will be needed to replace the substantional functions of forest soils when covered by tree stands. Many even high educated people are not aware of how the end of forests looks loke. I was personally told the following: one of the Nobelprize-winners explained: if Arabs can stand without forests, why this would not be possible for European people. Not a science fiction scenary but a ghost scenary of the European post-era of forests would be a good help for avoiding similar funny ideas mentioned before.

PSYCHOLOGICALLY INAPPROPRIATE INFORMATION CAN HARM GOOD IDEAS.

People get tired because of too many information. Results can be opposite to our expectations. There are already some reclamations from some countries where people have become deaf. To be successful, forestry needs more education in psychology.

DECAYING OF FORESTS IS BECOMING THE MATTER OF INTERDISCIPLINARITY. BUT FORESTERS ARE OBLIGED TO GO OUT OF THEIR CASTLE, GIVING THIS INTERDISCIPLINARITY THE HIGHEST PRIORITY.

Coming back to the considerations at the beginning: forestry needs much larger and many folded profil. This is hardly to accept. It is the beginning of a new forestry and at the same time the beginning of forests recovery.

8.3 FUTURE POLICIES AND AVOIDING FOREST DAMAGE*

L. Schotte
Laensstyrelsen
S-79100 Falun, SWEDEN

On this matter of future policies I would like to take a humble and open attitude. In a way one can speak irresponsibly as it is very unlikely that one will be present when evaluation time comes along. On the other hand, future policies are really important and that definitely matters. Present knowledge is the platform from which basic planning starts and strategies are to be formulated. So the problem has to be taken very seriously.

Let me begin by stressing the importance of IIASA as an organisation and as an organizer of meetings such as this one. IIASA serves as a catalyst of international cooperation on the scientific level, and for a project like the Forest Study of the Biosphere Project, also as a link to commercial life, forestry and the forest industry. I believe we need that wide approach.

Let me then try to name a few future policies, which I consider being of significance for the future.

1. The nature of biological science is no doubt such that links and mechanisms of the kinds involved here can scarcely be clarified with 100% certainty. Research and countermeasures in the shape of emission control and forest management must therefore proceed in parallel. International co-operation must take place and responsibility must be accepted on an international basis, with active involvement on the part of forestry and the forest-products sector. On such huge issues as these, our watchword should be to think globally and act locally.

2. We need to establish an overall picture encompassing the entire chain of events from chemistry and ecology to economics and market effects. We have to analyse the economic consequences of emissions - in the case of forestry and the forest-products sector - of each country affected, how air polutants affect timber supplies and markets for forest products. There will be different effects, of course, in the short and long term. Only a year or two has in fact passed since researchers and international bodies fully realized the significance of this aspect of the effects of air pollution on vegetation.

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3. Funds for basic research about effects of natural stress factors on vitality of trees and stands must be increased. I think we should know more about the nitrogen effects, nitrogen leakage from soil and more about the ozone mechanisms.

   The better understanding and the ability to manage the consequences of forest decline must deal with complete ecosystems with biological, technical, social, economic and psychological points of view.
4. Ongoing monitoring of damage to forests by air pollutants must of course continue. Data should be compared annually. Results must be updated; this is a necessity. However, there is a strong need to get an international harmonization of the monitoring. Relevant comparisons due to different or changed monitoring or sampling are to some extent impossible. Funds for basic research must be raised for developing improved large-scale monitoring methods.

   IIASA can play an important role here, too, as catalyst and facilitator of development of such improved methods of remote sensing and internationally accepted protocols for ground and remote-sensing data collection for decline estimation.

5. It is important to encourage and make use of the two information centra located in Bratislava and Hamburg. Their unique possibility to take the lead in the process of data communication should be well taken care of. We need early warning systems from ecological as well as from economic standpoints.

6. I would like to underline the importance of a functioning process of knowledge transfer between representatives from science, industry, forestry and politics. Messages are not always understood and made use of in a proper way. Demands and questions are not always phrased precisely enough. Important results should be communicated until receipt is confirmed. The process must be intensive, open and correct. We have something to learn here. To my mind this is a future policy also in general understanding. International agreements - such as emission control programs - have to be locally accepted. In a situation where the local strategies are not effective or significant, even the best international intentions are not likely to function.

7. Basic risk-management thinking should be adopted also to environmental matters. Forestry and industry must deal with forest decline as a potential risk or threat and not just something that might interfere some time on the markets, something only for environmentalists, politicians and scientists.

   I think we have to be more pragmatic. I have already stated that research and action must run parallel. Let us set both targets simultaneously: precise and deep knowledge for scientific understanding and explanation on one side, and a pragmatic utilization of available knowledge and current techniques on the other, as early-warning systems for industry to plan according to and for the policy decision-makers, the politicians, to react upon after a critical evaluation. Let us aim at both targets.

   Also on this pollution matter, it must be accepted in society that action needs to be taken without knowing in advance every detail of the eventual truth.

8. More attention has to be paid to the role of managing or not managing the forests as well as proper management of pollution-damaged forest tracts. Healthy and thriving forests can cope better with stress factors. Through cleaning and thinning operations, unnecessary competition is avoided. Selection of the right kind of seedlings improves resistance.

   The forest-damage threat calls for intensified silviculture, better forest hygiene and good soil care, as well as a ground management adapted to local prerequisites.

9. The discussions, observations and policy decisions taken about forest damages should always be linked to the matter of energy supply, raw material, costs and methods used. The energy balance is in fact a part of the total picture. All political behaviour does not seem to be aware of such a linkage or willing to accept it.

10. I think scenarios of different kinds - such as economic ones, harvest ones, or ones to establish, in terms of mean values, what threshold level of injurious effects in different regions would in fact disrupt world trade - should be strongly recommended and encouraged, being asked for by potential users in commercial life. The results, though, must be interpreted in a critical, realistic and professional way!

11. The importance of the current work of the UN Economic Commission for Europe (UN-ECE) should be underlined. That goes for activities concerning emission control, developing an industrial protocol for monitoring, as well as for following the trade in forest products (mainly lumber) with the notion that a freely operating marketplace might result in serious supply and price disturbances in some time. The continuation work of the special market committee of the UN-ECE is to be seriously considered.

12. I think with such a background it is important to find methods to increase the consumer's use of wood for different purposes, and to regain market shares lost to alternative raw materials. That would contribute to a more balanced market situation. Open relations and contacts between the Forest Study of the Biosphere Project and representatives of international forest industry and trade should be recommended.

13. Irrespective of the importance of all these policies and aspects for the future, and irrespective of what rate different kinds of pollutants take in the combined negative effect of stress factors on forests, the main target is emission reduction and the subsequent long-term conversion of damaged forests by advanced planting. Efforts just have to be intensified to reduce emissions by investing in further emission control programs.

    It is excellent that we have the international agreements on the reduction of emissions, and more are to be expected. But, I have to say honestly that I am personally very concerned about the rate of improvements of the environment.

    Indications from the dose-response investigations in the Nordic countries tell us about too slow a process in the reduction of depositions, and about the unacceptably long period of soil restoration.

To my personal view the present situation has to be changed all over Europe and, presumably, North America as well. Something more than today just has to be done!

Again we have to look upon the situation pragmatically. Countries have different financial possibilities to take action at fast enough a rate. Priorities taken are for various reasons not the same. Nevertheless, the threat is there.

With a personal view again, I suggest that an international responsibility of some kind, sort of a new Marshall-aid, a financial plan on a large scale to make intensive emission reduction investments possible at proper places, might have to be established! That is basic risk-management thinking on a high national level! Some countries might consider such a contribution sort of an ensurance to protect threatened resources of their own.

14. It is true that at present, in general only slight effects have been noticed in the marketplaces for roundwood and lumber due to pollutant damages. Some regional effects are, however, quite serious. And with time an overall considerable risk cannot be ruled out.

I am convinced another important future policy will be to make the commercial representatives of the forest industry, mainly sawmills, more aware of the threat in terms of volumes and prices for raw material and converted products. We have extracted from Nilsson's paper that volumes corresponding to up to 7 normal annual harvests in Central Europe are damaged! That should be information enough to make the statement that the rate of consciousness today is much too low!

Our decline problem should be taken into account in the future planning of forest enterprises. Very few have done that so far. Too often a comment like "it's just the weather" corresponds to the attitude of today! Even marginal chemical influence, with mainly other stress factors weakening a stand, may have dramatic negative effects. And, in my country there is the fear of the lingering, non-visible effect on the trees, eventually leading to a possible reduction in growth rate as a consequence! In addition, how does one interpret the dramatic negative development for deciduous species in last years?

Beyond doubt, we have warning signals enough to be commercially very careful!

Consciousness of the problem should be our watchword!

15. To conclude - whether we are talking about emission reductions, ecology or economics in relation to this complex issue of forest decline, the road to success truly involves international cooperation at a variety of levels. The key-word to achieve results is confidence among individuals and nations!

9. CONCLUSIONS

9.1 OVERVIEW OF DISCUSSIONS*

P. Duinker
Biosphere Project, Environment Program
International Institute for Applied
Systems Analysis
A-2361 Laxenburg, AUSTRIA

1. INTRODUCTION

To fulfill the aims of the Workshop (see introductory paper by Kairiukstis), three set of activities took place: (a) presentation of invited papers; (b) discussions following the presentations; and (c) preparation of a set of resolutions to be adopted by the participants in plenary session. In this paper, I summarize the highlights of the workshop discussions. While rapporteurs were on duty to note significant points raised in all presentations and discussions, there was no intention to report verbatim the discussion which followed each presentation and each session. Thus, the discussions are summarized here according to some main topics concerning forest decline covered at the Workshop.

2. EXTENT OF FOREST DECLINE

The areal extent of declining forests, on local, regional, national, and international scales, and the volume of wood in declining stands was the subject of many papers and much discussion. There was considerable disenchantment over current difficulties in translating (a) single-tree observations into stand- and forest-level decline estimates, and (b) areal estimates of decline into estimates of volume in declining trees or stands. Participants were cautioned that studies such as that by Nilsson on the continental extent of decline in Europe can only produce rough, order-of-magnitude estimates.

Reports of local and regional extents of forest decline were not consistent from one area to the next. For example, Dzialuk reported that the decline situation in Poland was somewhat improved over 1986 compared to earlier years. On the other hand, Amano reported that the area of declining forest around Tokyo is growing. However, Konohira stated that there was no serious pollution-induced forest decline in Japan or New Zealand. Persson suggested that forest decline in tropical areas is not serious beyond specific local cases such as Mexico City. According to Weiss, it is not possible to estimate the areal extent of declining forests in the United States. Additionally, it was stated that timberlines in some mountainous areas of Poland were gradually lowering in altitude, and in the Nordic countries there was evidence that declines increased in severity with increases in latitude.

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3. CHARACTERISTICS OF THE DECLINE PHENOMENON

Many questions were raised about the biophysical nature of the decline phenomenon. At the level of the individual tree, it was noted that the accelerated loss of older foliage of coniferous trees was not serious, but that accelerated loss of new foliage is a sure sign of stress. Thus, assessments of decline based upon foliage losses need to be very carefully carried out. There was repeated discussion over whether air pollution contributes to decline primarily by slowing tree growth or by actually killing trees. This distinction is important because the appropriate silvicultural responses and the effects on current and future wood supply are very different; the growth-decrement effect on harvest will in the short-term be opposite to the mortality effect. Thus, these two kinds of effects should be examined both separately and together in assessments of the effects of continued pollution-induced decline on the forest sector.

Some researchers have observed that stands do not always rebound immediately after removal of stress. For example, Muller noted that drought-stressed stands in France did not experience resumption of "normal' increment and foliage condition until some 5-7 years later. In decline situations, growth losses usually occur well in advance of the more readily apparent symptoms like foliage loss. There is, therefore, a suspicion of a latency period prior to the appearance of decline symptoms. Forest decline was judged to be a form of habitat decline. Air pollution makes stands much more susceptible to other forms of stress on trees, including natural stresses. All instances of forest vegetation damaged by air pollutants can be considered unique, suggesting that great care needs to be exercised in making generalizations about forest decline.

4. CAUSES OF FOREST DECLINE

For many cases of forest decline, debates over their primary causes continue. Such potential causes include competition, climatic factors (mainly temperature extremes, drought, and wind), biotic factors (mainly insects pests and disease), silvicultural interventions, and air pollutants. The main pollutants implicated in forest declines are SO_2, NO_x, and O_3. Pollution stress on trees may be much more serious as a result of events of high pollution rather than long-term average pollution levels. Unfortunately, most longer-term pollution monitoring programs cannot provide data for such episodes of peak pollutant emissions. The effects of any combination of air pollutants on specific forests are strongly modified by the particular ecological conditions within the forests. Some tree characteristics (e.g., wood quality) are affected by pollution in the same way as they are affected by natural stresses. Therefore, pollution control will not eliminate completely any undesirable changes in these characteristics.

There was much discussion about the role of climate alone and in combination with other factors as a cause of forest decline. While climate is strongly implicated in many forest declines, there are examples (e.g., yellow-birch and sugar-maple declines in Canada) that cannot be explained by climate alone. Indeed, climate is often viewed as a stress factor that increases the vulnerability of stands to other natural or anthropogenic stresses. Climatic stress on forests often seriously confounds our ability to distinguish pollution-induced growth decrements.

Several hypotheses were tabled concerning the sequencing and role of particular factors in inducing decline is specific stands, e.g., pollutant stress followed by fungal attack, or planting of ill-adapted species followed by pollutant stress and subsequent insect attack. Clearly, one must examine a broad range of natural (e.g., climate, insects, disease) and anthropogenic (e.g., air pollutants, silviculture) factors, including various mechanisms of synergism, when attempting to profile the multiple causes that could be interacting to produce a forest-decline situation.

5. SUPPLY CONSIDERATIONS AND ECONOMIC EFFECTS

The monetary value of wood increment lost due to air pollution can be enormous in nations like Poland where the problem is acknowledged to be severe and where increased disease and mortality have led to forced increases in harvesting. On the other hand, it was suggested that current declines in nations like the United States will have no measurable effect on the forest economy. Indeed, it was said by several participants that there have been no market disturbances yet in the European forest-products scene, even on a national scale for most countries. However, sub-national market disturbances have been registered. For countries expecting near-term market problems in the absence of changed policies, the response options include at least (a) increasing exports, and (b) delaying harvest in healthy stands.

However, for stands where excess mortality is occuring and where restoration of site is expected to be necessary, there is agreement that silvicultural costs will be higher than normal (a figure of at least 15-20% increase was mentioned). This can be particularly damaging if surplus supplies of timber in the international marketplace lead to depressed prices, as some analysts expect.

6. SILVICULTURE AND FORESTRY DEVELOPMENTS

Some participants cautioned that the silvicultural conditions of many stands in Europe are contributing to decline caused partly by air pollution. Specifically, a great many stands have ages and densities much in excess of reasonable silvicultural objectives. As well, regeneration with specied ill-adapted to local site conditions occured. In general, careful stand management practices are required to mitigate increment losses due to air pollution. Such practices include, for example: (a) matching species with appropriate habitats; (b) promoting understory growth; (c) favouring natural regeneration over planting; (d) promoting genetic diversity; and (e) designing harvesting regimes with silviculture in mind (e.g., shorter rotations and more frequent thinnings).

In some severe cases of forest decline (e.g., Poland), much sanitation harvesting is currently taking place. To compensate for expected decreases in annual cut in Poland, there is an initiative to increase the nation's forested area, concentrating on reforesting vacant lands and lands in need of restoration.

A need was identified to plan tree breeding and regeneration several generations into the future, taking into account the likely changes in the environment, particularly the atmosphere.

7. DEALING WITH POLLUTERS

Participants were reminded not to lose focus on the need to reduce pollution emissions. While finding the culprit polluter in instances where long-range transport of acid precursors is implicated as the primary cause of forest decline is impossible, national government control over air pollution facilitates forcing all major polluters to reduce emissions. Some speakers suggested that emission reductions for SO_2 and NO_x should exceed 50% for the sake of forests in Europe.

8. MONITORING FOREST DECLINE

Considerable attention continues to be paid to various approaches for monitoring the extent and rate of change of forest decline. There is criticism because of systematic bias resulting from immediate selective removal of dying trees from many stands in Europe. Two means offered for solving this problem are (a) reporting of such selective sanitation harvests in national annual forest-condition surveys, and (b) the use of permanent sample plots.

There was much discussion over what variables to monitor. It was suggested that foliage loss and yellowing, even if properly assessed, are of differing importance among species in indicating tree condition. Crown thinning and amount of dying timber were said to be poor reflections of changes in wood increment. Much more appropriate are data on foliar biomass, increment as indicated by tree rings, and wood quality. Indeed, it was pointed out that the only measures of value to the forest-products industry are those that relate directly to volume or mass of merchantable wood.

While it is possible for ecological assessment purposes to monitor the response of tree-reproduction processes to air pollution, the differing sensitivities of various species to acids and other stressors must be explicitly taken into account.

The Workshop heard that international protocols for monitoring forest decline (such as the Draft Manual on Methodologies and Criteria for Harmonized Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests - see paper by Panzer and Materna) should be periodically updated and revised, taking care to ensure that new methods are calibrated to the old. The largest problem with current protocols is considered to be the inability to diagnose what is causing tree injury.

9. RESEARCH

Many statements were made about what subjects needed more research attention, and the kinds of research approaches that should be applied. It was suggested that forest-decline research follow the protocol of pathology, which involves: (a) characterizing the disease; (b) characterizing the causes; (c) re-establishing the disease to check the characterizations; and (d) develop and apply measures for prevention and cure. Assessments of the effects of climate change and air pollution on forests must take account of whatever management actions have taken place and will take place in those forests. When such studies examine possible trends in future wood increment, it is crucial to pay strict attention to past fluctuations in wood increment. When such assessments look at economic repercussions, it is wise to examine the total economic activity and wealth in the area in question.

From the discussions emerged the following research suggestions:

1. identification of the causes of specific forest declines by experimental means;

2. cost-benefit analyses in investigations of what actions to take in response to decline in forests;

3. on the subject of wood quality, more research on (a) formation of wood in stressed trees, both old and young, (b) development of discoloration and irregularities in heartwood, and (c) storage characteristics of logs from diseased trees;

4. research to determine what ecological processes are contributing to and threatening forest productivity;

5. study of the interactions between climate and air pollution in forest declines, and

6. development of genetically superior planting stock based on responsiveness to pollution and natural forms of stress.

Because of the developing role of simulation modelling in forest-decline research, it received considerable attention in discussions. It was said that statistical correlations for the cause-effect relations between air pollution and forest decline from individual studies are often deceptive and dangerous. Much more suitable for such investigations is the construction of mathematical simulation models based on scientific reasoning and experimental evidence. Such models find their strengths in generating internally consistent projections, and in their cognitive characteristics. However, they too can be deceptive tools, particularly if their representation of causal mechanisms can be interpreted broadly and if the links between policy interventions and causal mechanisms are not explicit. Indeed, even physiological simulation models need much more explicit representation of the stresses which are imputed to be impinging on trees.

The links between atmospheric simulation models and forest simulation models are not presently well developed, principally because of problems with cause-effect representation and unmatched spatial scales. In performing regional assessments of the consequences of forest decline, one must take into account the scale problems of moving from tree-level physiological models through stand and forest models to regional models. On all levels, simulation models must account for important dynamics of system behaviour.

Finally on this topic of research, because so many cases of forest decline in Europe, North America and elsewhere have common characteristics, it was recommended that more opportunities for direct interchanges among researchers be developed.

10. SCENARIOS AND SCENARIO BUILDING

Many participants strongly encouraged increased efforts to understand the nature of the forest sector's future through the construction and analysis of scenarios. Scenario construction should take advantage of the results of simulation modelling, with strong efforts to supplement currently available models where these are not sufficiently comprehensive. Participants were also advised to take advantage of basic work already done in scenario building, such as the scenarios in ETTS IV (see paper by Prins). There were many other recommendations for scenario building, researchers being advised to include considerations of:

1. changes in patterns of investment in the forest sector;
2. possibilities of increased tree growth as well as the conventional notion of decreased growth resulting from air pollution;
3. energy conservation in addition to pollution controls on conventional (fossil-fuel) energy technology;
4. short- (10 years), medium- (10-30 years) and long- (30-100 years) term events and trends;
5. local, regional, national, and continental scales of aggregation;
6. changing management of healthy stands as their harvest is delayed while declining stands are being harvested; and
7. the different possible reactions of the various stakeholders to forest decline.

11. CONCLUDING STATEMENTS ON THE OVERALL PROBLEM OF FOREST DECLINE

Several participants made strong statements about the overall problem of forest decline, and about what should be society's reaction to the problem. Some of these statements are reproduced below in paraphrased form.

1. We should not accept any level of air-pollution damage to forests.
2. The forest sector must be prepared to cope with and adapt to continued air pollution. It must also, along with the rest of society, exercise flexible thinking with respect to the goals set for forests. Forest decline as we know it today will likely shake up foresters and forest industry in a desirable way.
3. The condition of forests reflects the conditions of society.
4. Permitting forests to decline due to air pollution is environmentally dangerous and ethically unacceptable.
5. The forest sector needs to be ready to adapt to a future quite different from the recent past.

6. The forest sector must continue to push for reductions of pollutant emissions, and not retreat into sole reliance on forestry adaptations to continued air pollution.

7. Certainty in science is not prerequisite to advising policy-makers on suitable actions in response to forest-decline problems. Policies are elaborated and implemented in domains where there invariably is little if any certainty.

9.2 PROPOSALS FOR TEXT OF RESOLUTIONS*

Several participants, drawn from among the session chairpersons and speakers, were asked by the Workshop organizers to prepare submissions on specific topics for consideration to be included in the final resolutions. These proposals are presented below as submitted by their authors. Readers are reminded that due to the pressures of time, authors of the resolution proposals have not had opportunity for extensive reflection on the precise wordings used.

1. KNOWLEDGE OF FOREST DECLINE

Text proposed by R. Sedjo

It is generally agreed that forest decline is significant in Europe, and occuring on a more modest scale in North America and perhaps elsewhere. Furthermore, it is generally agreed that forest decline is often associated with air pollutants including sulfur and nitrogen compounds, ozone, and heavy metals.

More resources should be directed to research of pollution-related forest decline - its extent, distribution, and the nature of the pollution-related causes. Common, inter-regional measures of the extent of forest decline should be developed. Governments should begin to establish mechanisms for reducing the emissions of pollutants thought likely to be contributors to forest decline.

2. FUTURE FOREST RESOURCES

Text proposed by C. Prins

The Workshop noted that ECE/FAO had recently published "European Timber Trends and Prospects to the Year 2000 and Beyond" (ETTS IV), which contains among other things a full set of forecasts, prepared by national correspondents, for forest area, growing stock, increment and removals to the year 2020. The document also contains a discussion in qualitative terms of the possible developments for air-pollution damage and consequences for the rest of the sector. The forecasts indicate continuing expansion of forest area, increment, growing stock and removals, but with major differences among countries. The Workshop was also informed of the outlook for the forest resources in Japan and the USSR on the basis of national studies.

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The Workshop urged national forest research institutes to construct specific forest-damage scenarios when preparing their forecasts for the forest resources in their countries.

The Workshop welcomed the fact that national and international research institutes were constructing models of the effects of air pollution on the forest and forest-products sector, and urged those responsible for preparing forest-damage scenarios for Europe to take as a starting point the ETTS IV scenarios, which were internally consistent, complete, and nationally approved. This would significantly improve the international comparability of results.

The Workshop, which itself concentrated on the possible undesirable consequences of air-pollution damage to forests, stressed the overriding importance of preventing, and where possible curing, the damage. It also stressed again the importance of basic forestry principles, notably the need to maintain the forest area, to regenerate after felling, to maintain forest health, to maintain or increase site fertility and to optimize stand productivity with reference to management goals. Therefore, the Workshop encouraged research institutes to continue with the utmost urgency their efforts to understand the causes and mechanisms of the damage, and urged governments and members of the public to take all necessary actions to reduce the damage, primarily by reducing emissions of pollutants.

The Workshop noted that ecological developments in one region (e.g., forest decline in central Europe) could have economic consequences over a much wider area through trade, prices, etc. It stressed the importance of monitoring such downstream effects but noted that the FAO/ECE Timber Committee team of specialists on the subject had reported that no significant disturbance to markets had yet occurred because it had been possible to compensate any sanitation fellings by reducing normal planned fellings elsewhere.

3. AIR POLLUTANTS

<u>Text proposed by E. Adema</u>

Huge amounts of SO_2, NO_2, NH_3, heavy metals, hydrocarbons and similar substances cause tremendous effects on regional ecosystems.

It must be realized that there are two ways to argue about relations between environmental conditions and effects:

1. Speaking from the <u>experimental point of view</u>, a great deal of hard information and evidence has been made available about the adverse effects of atmospheric pollutants on soil, surface water, materials, vegetation, and so on. In this respect, scientists are largely in agreement.

2. On the other hand, speaking from the <u>effects point of view</u>, it is often very hard to locate the cause(s). In many cases synergism among multiple causes takes place. In looking for the cause(s) of the observed effects, scientists do not always agree with each other.

However, there is enough evidence to support policy-makers in taking measures against air pollutants, but it will be very difficult to predict the effectiveness of the measures. Nevertheless, policy-makers should take no chances with respect to the deterioration of entire regional ecosystems.

4. POLLUTANTS AND FOREST GROWTH

Text proposed by J. Pollanschutz

The annual increment of trees is one of the most important indicators of vitality. Therefore, assessment of annual increment, especially the relative width of stem rings and their components, should be done in connection with other investigations within a damage monitoring program. As an example, dominant trees in the neighbourhood of permanent sample plots of national monitoring systems should be cut and subjected to stem analysis.

Under specific conditions, increment studies can give information to help assess the causes of forest decline and quantify the damage.

Text proposed by S. Linzon

It has been documented near industrial point sources of air pollutants (e.g., SO_2, HF, and heavy metals) that the growth of forest trees can be reduced. In regions remote from point sources, growth of forest trees has been observed to be reduced up to 20-25 years prior to the onset of visible symptoms in certain locations. The exact cause of the effects on forest growth in regional areas has not been determined, but scientists and foresters agree that air pollution, in conjunction with other factors such as insects, disease and adverse weather, are primarily responsible. Air-pollution abatement measures taken by industries have resulted in marked improvements in forest growth in the vicinity of these industries.

Emissions of sulphur and nitrogen oxides should be reduced substantially (e.g., by 30-50%) to prevent or minimize the impact of these pollutants on forest growth.

5. CAUSES AND EFFECTS

Text proposed by J. Materna

There are various mechanisms of air-pollution influence on forests. The direct impact of gaseous pollutants and the indirect effect of changed soil and other ecological conditions have influenced the vitality and stability of forests. On about 8% of European forests, visible symptoms of damage have developed. At present, only a small area of forests has been totally destroyed, but on a regional scale the stability and the resistance of forests against the impact of other stress factors is decreased.

The consequences are important not only for the forest sector but for the entire society. Wood production is decreasing in affected areas. The genetic base of economically and ecologically important forest tree species is threatened. The fir has disappeared from a great part of its natural distribution, as have some ecotypes of Norway Spruce. Extremely threatened are mountain forests.

In the landscape the ability of forests to protect the soil is weakened. The role of forests in water cycling is also impaired, leading to increased runoff and also the danger of high water tables. High rates of deposition of acid substances from air pollution, changes in soil chemistry, and enhanced runoff can be of negative influence on water quality.

6. MONITORING FOREST DECLINE

Text proposed by F. Last

Many countries are now making repeated estimates of the extent of forest decline. The Workshop urges that these estimates be based on the protocol developed within the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, which includes observations of foliar losses, discoloration and chemical composition, as well as a selection of site factors including soil attributes.

To improve the value of these observations, it is essential to gain more knowledge of (a) the relation between leaf function and composition, and forest productivity, and (b) the composition of the different mixtures of atmospherically dispersed pollutants occuring in different locations. Further, it is desirable to supplement the series of labour-intensive ground observations called for in the above-mentioned protocol with a series of more extensive (synoptic) assessments gained by remote sensing.

In addition to emphasizing the value of the above-mentioned protocol for monitoring forest decline, it is recommended that more resources be devoted to:

1. modelling the occurrence of atmospherically dispersed pollutants in addition to SO_2 and acid rain (sensu stricto);

2. methods (e.g., physiological, dendrochronological, statistical) aimed to improve the prediction of tree growth and forest performance from observations on foliage (including chemical composition) and site factors; and

3. support intensive ground observations by extensive assessments gained from remote sensing.

Text proposed by L. Kairiukstis

Large-scale forest decline can be assessed by remote sensing and modelling of transregional pollutant emissions and depositions. Forest decline monitoring is currently based on crown morphology. This should be supplemented by long-term tree-increment records, filtered using methods of modern dendrochronology, forestry, and tree physiology. Foliar content of pollutants and nutrients, correlated with annual wood growth, can be used to give early indication of pollution pressure on forests.

7. WOOD FORMATION AND WOOD QUALITY

Text proposed by A. Fruhwald

1. The influence of tree disease on wood formation and wood quality is not fully understood yet. Although it seems that wood tissue is almost unaltered in coniferous trees, the knowledge for broad-leaved trees is very poor.

2. The knowledge of wood formation under stress from short-range air pollution cannot describe the impacts on wood quality associated with the present forest decline.

3. Present knowledge shows that mechanical wood properties do not differ significantly between healthy and diseased trees. It is known that wood of dead trees is of lower quality. But it is not known at what stage of disease of the various tree species a severe impact on wood quality occurs and how the wood should be handled and processed to avoid secondary changes. This relates also to the problem of storage of logs from declining forests.

4. It is recommended that research activities on wood formation in trees of all age classes under pollution stress, as well as under natural stresses, be increased.

5. Quality losses that occur in dead trees and stored logs need to be determined. Improved techniques for handling and storage should be developed.

6. Studies are necessary on how wood from declining forests, with possible changes in its properties, can meet the requirements of wood processing and utilization.

8. INTERNATIONAL COOPERATION

Text proposed by H. Steinlin

Forest decline is clearly multinational in many important facets, including transboundary air pollution, global forest-products markets, and far-reaching ecological consequences. The workshop stressed therefore the need for strong international cooperation in monitoring, research, and transfer of research results which can improve understanding and mitigation of the problem, as well as coordinated actions by governments and industries to alleviate the situation. The Workshop urges all responsible concerned publics as well as private concerns to join their forces in a big effort to improve the living conditions of the forests.

9. RESTORATION OF DAMAGED FORESTS

Text proposed by D. Mlinsek

The Main Strategy

1. It is to be expected that similar environmental disturbances will negatively influence forests as well as the health of citizens. Thus it is advisable to initiate comparative research studies about these phenomena.

2. Communication methods should be elaborated for better contacts between policy-makers and people like foresters and environmentalists.

3. An international monitoring system for the present state of forests and for all forest damages should be elaborated (emissions, new contemporary forest damages, natural disasters, etc.).

4. A reorganization of national forest services in order to control current changes and to prevent secondary damages on the local level in needed.

Silvicultural Measures

1. Verification of different silvicultural systems, and their adaptability to anthropogenic environmental changes, are required.

2. Checking and changing of silvicultural goals and subsequent consequences (e.g., choice of tree species, tending, regeneration, rotation period, forest fringe maintenance) should be carried out.

3. Stronger consideration of local site conditions, of stands in total and in detail, and of all other vegetation, is necessary.

4. Biomonitoring should be added as part of the regular duties of local foresters in order to be up-to-date on what is going on in each part of the forests.

5. Implementation of suitable sanitary control and reconstruction measures (e.g., substitutive fertilization, hydrophysiological measures, reproduction of grasses and shrub vegetation) is needed.

10. MODELLING IN FOREST DECLINE RESEARCH

Text proposed by H. Bossel and J. Owsinski

Forest dieback occurs when life processes of trees have been stressed beyond the irreversible breakdown threshold. In order to comprehend fully the course of the process, models must be built reflecting knowledge and hypotheses related to multiple interrelated subprocesses, giving dynamic images of tree, stand and forest dynamics incorporating damage from various stresses.

Such models can be used for cognitive, managerial and policy purposes, indicating site, age and species sensitivity, and responses to particular pollution levels, especially over the long term. Once validated, the models can be used without the necessity of performing experiments on large forest areas.

In addition, models of environmental input to, and industrial use and management of, the forest should be built, along with models of timber trade, influencing forest use. International effort is needed here in data definition and provision, and model development and testing, the latter preferably through a case-study approach with free exchange of the software developed.

11. CONSEQUENCES FOR INDUSTRY

Text proposed by T. Bencze

Forest decline will have an effect on the forest-products industry in both the short and the long run relative to the likely period of serious pollution emissions. The effects might be just the opposite at the beginning and at the end of the pollution period. Consequences could be a possible increase in the raw material supply at a lower price at first, and a possible decrease at a higher price later on. However, one should take into consideration that in Europe the consumption of wood products depends on national economic development tendencies which can scarcely be influenced by the wood industrial sector because of its small share in national economies. For this reason it is important to take measures to avoid serious market disturbances in the interests of the industry and of forests as well.

Text proposed by T. Stemberger

Economic evaluation of forest damage is an important means to make people conscious of the problems of forest decline. Monetization should therefore use a sound basis of biometric data and be restricted to the objective damage in relation to the direct economic effects of forests primarily, and carried out continuously as a dynamic evaluation taking into account the damage done to forests up to a specific point in time and - on a ceteris-paribus basis - the future consequences of the damage caused so far. Scenarios using specific assumptions on future development of damaging factors and the damaging processes should not be used for evaluations. Taking into account their arbitrary nature, calculations based on scenarios should be declared as expert estimates revealing the underlying assumptions.

Text proposed by A. Fruhwald

It is not clear whether wood properties are at normal levels in all cases and what possible technical and economic consequences will arise. Increased removals from the forests in some very heavily affected regions could disturb the timber market in a way that availability and timber prices could have an impact on the competitiveness of the forest-products industry with respect to (a) the same industry in other regions, and (b) other industrial sectors in the same region. It is not clear whether special measures have to be taken to adapt processing technology and storage techniques either to slightly changed properties of the wood of diseases trees or possible changes in timber cutting practices.

12. REGIONAL ASPECTS

Text proposed by H. Steinlin

The effects of forest decline are not confined to forest owners and forestry as such, but may well impact on the quality of life and the general economic conditions of a whole region. Regional problems must be solved on a regional basis taking into account the interests of all concerned. A region has to be understood as a section of the biosphere and a complex system with many linkages and interactions between its elements and subsystems. The delimitation of a region depends on the effects to be studied and the common problems to be solved. Very often such a delimitation of a region does not coincide with administrative or political borders.

13. RESEARCH DIRECTIONS

Text proposed by P. Rennie

The workshop has resulted in improved quantification of forest resources. They are seen to be not inexhaustible. Some are diminishing in area, and many are under serious threat, especially from air pollution.

Declines in forest productivity are occurring through a variey of causes. Some are well understood and controllable using well-known cultural techniques. Others are not understood, involve a complex of factors, and require more intense research. Others are clearly due to persistent high levels of air pollution and can only be cured by reduction in emissions.

More attention needs to be paid to mixtures of pollutants which act cumulatively or synergistically. Air quality standards have to be developed in terms of both concentrations of mixtures and deposition levels. This would cover the two main ways air pollutants act - directly on tree tissues and indirectly through the soil. Monitoring networks need to be expanded in respect to both pollutant levels and forest well-being.

Although there are many forest areas where the complex interactions and effects of air pollutants require resolving by a variety of research studies, there are major forest areas where the effects of air pollutants are so well established, clear, and serious, that the urgent priority in these areas is abatement of emissions, not further research.

9.3 RESOLUTIONS*

In the final plenary session of the Workshop, participants were presented with a set of draft resolutions drawn from what the organizers considered to be the most important messages arising from the presented papers, the discussions, and the proposals for texts of the final resolutions. The draft resolutions were discussed and then revised accordingly. They are presented below in the form in which they appeared in the press release issued by the Workshop organizers on 27 March 1987, in Kraków.

POLLUTION

Forest decline is a very serious problem throughout most of Europe, and is occurring in other parts of the world such as Japan, Canada, and the United States. Declines occur from both known causes such as pests, climatic factors, and high ambient concentrations of pollutants, as well as from unknown causes. The Workshop concluded that governments, industry and the public must take the necessary actions to reduce emissions to acceptable levels. This could be stimulated by international cooperation in research and development on environmental protection and energy conservation technologies with emphasis on facilitated and free exchange of information and technology. In addition, society in general, and the forestry community in particular, must continue to search for ways to adapt to the inevitable near-term consequences of continued forest decline caused by air pollution.

MONITORING

Most European countries experiencing forest declines have only recently started to monitor systematically the condition of their forest resources. The Workshop agreed that monitoring must be done on a unified basis following internationally accepted protocols. Unification should include harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. The Workshop urged countries to adopt the internationally accepted protocols in their existing or newly established monitoring programs. The Workshop recognized the importance of additional measurements, including especially remote-sensing techniques and volume-increment studies. These program components need to be integrated into multifactor analyses that attempt to provide early warning of impending changes and improve understanding of basic processes for forecasting purposes.

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*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

RESEARCH

Forest decline is a very complex and uncertain phenomenon. The Workshop identified the need for well-coordinated, interdisciplinary, systems-oriented research programs in several specific areas including physiological and ecological cause-effect relationships, social and economic consequences, and policy responses. Such research needs a balanced combination of empirical studies and modelling efforts including the development of early-warning systems. Since both the causes and the effects of many current forest declines are regional in scale, great advantage would be gained from an international set of regional case studies, involving both East and West with emphasis on Central Europe. Such case studies should include analyses of how various stakeholders might react to a range of forest-decline scenarios. Support for forest-decline research should be shared among governments, industry, forest land-owners and international organizations.

FUTURE FOREST RESOURCES

The Workshop agreed that the best way to explore possible effects of forest decline on future forest resources is to construct consistent and complete scenarios based on a combination of explicit assumptions, forecasting models and expert opinion. Scenario building should be interdisciplinary, including at least climatological, ecological, social, and economic factors, to make results of greater potential value to policy-makers in their consideration of the future potential of forest resources under decline conditions.

TRADE AND MARKETS

No significant regional market disturbances have yet occurred that can be attributed to pollution-induced forest decline. However, given current patterns of forest decline, particularly in Europe, future disturbances to roundwood and forest-product markets, trade patterns, and industry structure due to forest decline cannot be ruled out. Indeed, changes in the timber-supply situation in Europe may lead to disturbing consequences for timber-exporting nations in other continents. The Workshop concluded that exchange of information between timber producers and timber-processing industries, as well as among wood-product importing and exporting nations, should be improved.

INTERNATIONAL COOPERATION

Forest decline is clearly a multinational problem in many respects, including transboundary air pollution, policies for emission reductions, global forest-product markets, research, and resources for mitigating the problem. Therefore, the Workshop stressed the need for strong international cooperation in these areas (such as the Convention on Long-Range Transboundary Air Pollution), as well as coordinated actions by governments and industries to alleviate the problem. The Workshop urged all responsible concerned publics as well as private concerns to join forces in a concerted effort to improve the condition of forests.

CONCLUSION

The forest-decline problem embraces environmental, social and economic implications as well as timber considerations. Therefore, the Workshop concluded that efforts to understand better and manage the consequences of forest decline must deal with complete ecosystems in which man is an integral component from biological, technical, social, economic, and psychological points of view.

The Workshop also agreed that the extent and causes of forest decline are different in different regions of Europe and elsewhere because of differences in factors such as pollutant types and loadings, forest types, climatic conditions, site conditions, and silvicultural regimes. At this time, it is possible only to deliver simple, general recommendations on the steps necessary to avoid continued and new forest decline in the future. Such recommendations must be adapted to actual conditions prevailing in specific local or regional cases of forest decline, but the knowledge required to do this is usually not available. The Workshop concluded that strong efforts must be made as soon as possible to generate this basic information for effective international decision-making.

Finally, the Workshop agreed that clear and consistent national policies related to the forest sector and to pollution, as well as international cooperation in air pollution control measures and exchange of research and monitoring results, are required. It was recognized that IIASA is an appropriate institution to catalyse such cooperation.

APPENDIX I: LIST OF PARTICIPANTS*

WORKSHOP on

"FOREST DECLINE AND REPRODUCTION: Regional & Global Consequences"

March 23–26, 1987
Holiday Inn Hotel, Kraków, Poland

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Dr. K. ARMOLAITIS
Scientific Research Institute
of Forestry
Lithuanian Academy of Sciences
Girionys
234312 Kaunas, Lithuanian SSR
U. S. S. R.

Prof. Eduard H. ADEMA
Dept. of Air Pollution
Agricultural University
P.O. Box 8129
6700 EV Wageningen
THE NETHERLANDS

Mr. Masahiro AMANO
Dept. of Forest Management
Forestry and Forest Products
Research Institute
P.O. Box 16
Tsukuba Norin Kenkyu Danchi-nai
Ibaraki 305
JAPAN

Dr. Allan N.D. AUCLAIR
LRTAP Liaison Office
Atmospheric Environment Service
Environment Canada
4905 Bufferin Street
Downsview, Ontario M3H 5T4
CANADA

Dr. BAZIRE
Chef du Service de l'Inventaire
Forestier National Francais
Direction des Forets
Ministère de l'Agriculture
1 ter, Ave. de Lowendal
F-75007 Paris
FRANCE

Dr. Z. BEDNARZ
Dept. of Forest Botany and
Nature Protection
Agricultural University
Al. 29 Listopada 46
PL-31 425 Kraków
POLAND

Dr. Otmar BEIN
Secretary
International Union of Forestry
Research Organizations (IUFRO)
Tirolergarten - Schönbrunn
A-1131 Vienna
AUSTRIA

Dr. Tibor BENCZE
Dept. of Forestry & Forest Industry
National Planning Office
Rossevelt tér 7-8
H-1370 Budapest V
HUNGARY

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*In: Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

Prof. Clark S. BINKLEY
School of Forestry and
Environmental Studies
Yale University
New Haven, CT 06511
U. S. A.

Prof. Hartmuth BOSSEL
Environmental Systems
Analysis Group
University of Kassel
Mönchebergstr. 21 A
D-3500 Kassel
FEDERAL REPUBLIC OF GERMANY

Dr. Otto Ulrich BRÄKER
Swiss Federal Institute
of Forestry Research
CH-8903 Birmensdorf
SWITZERLAND

Mr. Stanisław BROZEK
Faculty of Forestry
Agricultural University
Al. 29 Listopada 46
PL-31 425 Kraków
POLAND

Dr. Roger M. COX
Research Scientist
Canadian Forestry Service
Maritimes
Government of Canada
P.O. Box 4000
Fredericton, N.B. E3B 5P7
CANADA

Prof. S. DUNIKOWSKI
Forest Research Institute
Wery Koschew u. 3
PL-00973 Warsaw
POLAND

Mr. Ryszard DZIALUK
Director General
State Forests Enterprise
ul. Wspólna 30
PL-00 973 Warsaw
POLAND

Ing. Irena EZECHIASOVA
Institute for Environment
and Natural Resources
Slezská 9
CSSR-120 00 Prague
CZECHOSLOVAKIA

Dr. Eduard FELIKSIK
Dept. of Forest Ecology
Section of Forest Climatology
Agricultural University of Kraków
Koniewa 49/7
PL-30 150 Kraków
POLAND

Dr. Andrew J. FRIEDLAND
University of Pennsylvania
Whiteface Mountain Research
Station
P.O. Box 29
Wilmington, New York 12997
U. S. A.

Prof. Arno FRÜHWALD
Department of Wood Technology
University of Hamburg
Leuschnerstrasse 91
D-2050 Hamburg 80
FEDERAL REPUBLIC OF GERMANY

Mr. Ferenc GERELY
Head of Department
Ministry of Food and
Agriculture
Kossuth Lajos tér 11
H-1055 Budapest
HUNGARY

Dr. Krzysztof GŁĘBICKI
Botanical Garden
Polish Academy of Sciences
POB 84 - Prawdziwka, 2
Powsin
PL-02 973 Warsaw 34
POLAND

Dr. I.V. GOLOVICHIN
All-Union Institute of Forestry
and Mechanization – VNIILN
Ulista Institutskaya 15
Pushkino Moscow Region
U. S. S. R.

Dr. A.J. GRAYSON
Research Director
Forestry Commission
Alice Holt Lodge, Wrecclesham
Farnham, Surrey GU10 4LH
UNITED KINGDOM

Prof. Jan GRESZTA
Forest Research Faculty
Dept. of Forest Ecology
Agricultural University of Kraków
Al. 29 Listopada 46
PL-31 425 Kraków
POLAND

Prof.Dr. Krystyna GRODZIŃSKA
Dept. of Ecology & Plant Geography
Institute of Botany
Polish Academy of Sciences
ul. Lubicz 46
PL-31 512 Kraków
POLAND

Prof.Dr. Wladislaw GRODZIŃSKI
Dept. of Ecosystem Studies
Jagiellonian University
ul. Karasia 6
PL-30 060 Kraków
and
Institute of Fresh Water Biology
Polish Academy of Sciences
ul. Slawkowska 17
PL-31 016 Kraków
POLAND

Dr. Satu HUTTUNEN
Department of Botany
University of Oulu
Linnanmaa
SF-90 570 Oulu
FINLAND

Acad. A.S. ISAEV
Institute of Foresty and Wood
USSR Academy of Sciences
Siberian Branch
Academy Town, Krasnojarsk
USSR

Dr. Pekka KAUPPI
Ministry of the Environment
P.O. Box 306
SF-00531 Helsinki
FINLAND

Prof. Emil KLIMO
Forestry Faculty
Agricultural University
Zemedelská 3
CSSR-61300 Brno
CZECHOSLOVAKIA

Dr. Yukuchi KONOHIRA
Faculty of Agriculture
Shinshu University
P.O. Box 1
Ina, Nagano 396
JAPAN

Dr. Raymond KONTIC
Institute of Botany
University of Basel
CH-4000 Basel
SWITZERLAND

Mr. Jan KOZINSKI, M.Sc.For.
Senior Forestry Specialist
Dept. of Forestry & National Parks
Ministry of Agriculture, Forestry and Food Economy
ul. Wspólna 30
PL-00 930 Warsaw
POLAND

Prof.Dr. Heinz KROSKE
Heinrich-Hertz Institute for Atmospheric Research and Geomagnetism
Academy of Sciences of the GDR
Rudower Chaussee 5
DDR-1199 Berlin
GERMAN DEMOCRATIC REPUBLIC

Prof.Dr. Horst KURTH
Bereichsleiter
Sektion Forstliche Ertragskunde
Technische Universität Dresden
Pienner Str. 8
Postschliessfach 10
DDR-8223 Tharandt
GERMAN DEMOCRATIC REPUBLIC

Prof. F.T. LAST
Department of Forestry and
Natural Resources
The University
Kings Building, Mayfield Road
Edinburgh EH9 3JU, Scotland
UNITED KINGDOM

Dr. S.N. LINZON
Manager, Phytotoxicology Section
Air Resources Branch
Ontario Ministry of the Environment
880 Bay Street
Toronto, Ontario M5S 1Z8
CANADA

Acad. Jerzy LITWINISZYN
Chairman, Kraków Branch of the
Polish Academy of Sciences
Director, State Mechanics
Research Institute of Kraków
ul. Reymonta 27
PL-30 059 Warsaw
POLAND

Dr. Lars LONNSTEDT
Dept. of Operational Efficiency
Faculty of Forestry
Swedish University of
Agricultural Sciences
S-750 07 Uppsala
SWEDEN

Dr. Ludmilla MALINOVA
Research Development & Computing
Center of the Committee for
Environmental Protection
Industrialna No. 7
Sofia
BULGARIA

Prof. Marin MARINOV
Forest Research Institute
Bulgarian Academy of Sciences
Guichet 15
BG-1080 Sofia
BULGARIA

Dr. Alexander MARTYNIUK
All-Union Institute of Forestry
and Mechanization - VNIILN
Ulista Institutskaya 15
Pushkino Moscow Region
U. S. S. R.

Dr. J. MATERNA
Research Institute of Forest
Economy and Hunting
Hranady 167
Zbraslav n. Vltava
CZECHOSLOVAKIA

Prof. Dušan MLINŠEK
Professor of Silviculture
Biotehniska fakulteta
Krekov trg 1
YU-61001 Ljubljana
YUGOSLAVIA

Dr. Bogusław A. MOLSKI
Director, Botanical Garden of
the Polish Academy of Sciences
POB 84 - ul. Prawdziwka, 2
Powsin
PL-02 973 Warsaw 34
POLAND

Dr. Maurice MULLER
Ministère de l'Environnement
14, Boulevard du Général Leclerc
F-92524 Neuilly s/Seine Cedex
FRANCE

Dr. Ståhle NAVRUD
Dept. of Forest Economics
Agricultural University of Norway
P.O. Box 44
N-1432 As-NLH
NORWAY

Dr. Peter NITZSCHE
Council for Environmental Research
Heinrich-Hertz Institute for
Atmospheric Research and
Geomagnetism
Academy of Sciences of the GDR
Rudower Chaussee 5
DDR-1199 Berlin
GERMAN DEMOCRATIC REPUBLIC

Dr. Jan OWSIŃSKI
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
PL-01 447 Warsaw
POLAND

Prof. PASTERNAK
Ukranian Scientific Research
Institute of Forestry &
Forestry Protection
Pushkinskaya 86
310024 Kharkov 24, Ukranian SSR
U. S. S. R.

Prof. Z. PATALAS
Forest Research Institute
Wery Koschew u. 3
PL-00973 Warsaw
POLAND

Dr. Reidar PERSSON
SAREC
Birger Jarlsgatan 61
S-105 25 Stockholm
SWEDEN

Dr. Jean-Luc PEYRON
Ecole Nationale du Génie Rural,
des Eaux et des Forêts (ENGREF)
14, rue Girardet
F-54042 Nancy Cedex
FRANCE

Prof. Josef POLLANSCHÜTZ
Deputy Director
Forstliche Bundesversuchsanstalt
Tirolergarten - Schönbrunn
A-1131 Vienna
AUSTRIA

Mr. C.F.L. PRINS
Timber Section
ECE/FAO Agriculture and Timber
Division
Palais des Nations
CH-1211 Geneva 10
SWITZERLAND

Prof. J. PRUCHNICKI
Institute of Meteorology
and Water Resources
Podlesna 61
PL-00 967 Warsaw
POLAND

Prof. Ju.G. PUSACHENKO
Institute of Evolutional Mor-
phology and Animal Ecology
Lenina 33
Moscow
USSR

Dr. Georgi RAFFAILOV
Department of Silviculture
Higher Institute of Forestry and
Forest Technology
Bul. Kliment Ochridski 10
BG-1156 Sofia
BULGARIA

Dr. Peter RENNIE
Canadian Forestry Service
Agriculture Canada
351 St. Joseph's Blvd.
Ottawa, Ontario K1A 1G5
CANADA

Prof. Roman RIEGER
Dept. of Dendrometry
Agricultural University of Kraków
Al. 29 Listopada 46
PL-31 425 Kraków
POLAND

Prof. K. RYKOWSKI
Forest Research Institute
Wery Kostrzewy 3
PL-00973 Warsaw
POLAND

Prof. Lennart SCHOTTE
General Director
Laensstyrelsen
S-79100 Falun
SWEDEN

Dr. Roger A. SEDJO
Resources for the Future
1616 P. St. N.W.
Washington, DC 20036
U. S. A.

Dr. J. SIENKIEWICZ
Forest Research Institute
Wery Kostrzewy 3
PL-00973 Warsaw
POLAND

Prof. M. SIEWNIAK
Agricultural University of Warsaw
ul. Rakowiecka 26/30
PL-02 528 Warsaw
POLAND

Prof. A. SOKOLOWSKI
Forest Research Institute
Wery Kostrzewy 3
PL-00973 Warsaw
POLAND

Prof. Rezső SOLYMOS
Ministry of Food and
Agriculture
Kossuth Lajos tér 11
H-1055 Budapest
HUNGARY

Dr. Ed. de STEIGUER
USDA - Forest Service
Forestry Services Lab.
South Eastern Station
P.O. Box 12254
Research Triangle Park
North Carolina, 27709
U. S. A.

Prof.Dr. H. STEINLIN
Institut für Landespflege
Albert-Ludwigs-Universität
Bertoldstrasse 17
D-7800 Freiburg
FEDERAL REPUBLIC OF GERMANY

Dipl.Ing. Thomas STEMBERGER
Präsidentenkonferenz der Land-
wirtschaftskammern Österreichs
Löwelstrasse 12
A-1014 Wien
AUSTRIA

Mr. Roger B. STREET
Superintendent Bioclimate
Atmospheric Environment Service
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4
CANADA

Dr. Wladislaw STRYKOWSKI
Wood Technology Institute
Winiarska 1
PL-60 564 Poznań
POLAND

Prof. Andrzej SZUJECKI
Dept. of Forest Protection
& Ecology
Agricultural University of
Warsaw
ul. Rakowiecka 26/30
PL-02 528 Warsaw
POLAND

Prof. H.O. THOMASIUS
Bereichsleiter
Sektion Forstwirtschaft Tharandt
Bereich Waldbau u. Forstschutz
Technische Universität Dresden
Pienner Strasse 8
Postschliessfach 10
DDR-8223 Tharandt
GERMAN DEMOCRATIC REPUBLIC

Mr. Ryszard WACŁAW
Director
Department of Forestry and
National Parks
Ministry of Agriculture,
Forestry and Food Economy
ul. Wspólna 30
PL-00 930 Warsaw
POLAND

Dr. Jacek WALCZEWSKI
Division of Remote Sensing of
the Atmosphere
Institute of Meteorology and
Water Management
ul. Borowego 14
PL-30 215 Kraków
POLAND

Dr. January WEINER
Dept. of Animal Ecology
Institute of Environmental Biology
Jagiellonian University
ul. Karasia 6
PL-30 060 Kraków
POLAND

Mr. Melvyn WEISS
Louis C. Wyman Forestry
Sciences Laboratory
P.O. Box 640
Durham, New Hampshire 03824
U. S. A.

Dr. Suzanne WIENER
Plant Physiology Dept.
University of Vienna
Althanstrasse 14
A-1090 Wien
AUSTRIA

Dr. J. WILTOWSKI
Administrative Director
Kraków Branch of the Polish
Academy of Sciences
ul. Slawskowska 17
PL-31 016 Kraków
POLAND

Dr. Tiziano WOYNAR
Director
Regional Agency of Forestry
of Lombardy
Palazzo Verrochio
I-20090 Segrate - Milano 2
ITALY

Mr. Andrzej WYLEZINSKI
Faculty of Agriculture and
Forest Engineering
Agricultural Academy of Warsaw
Nowoursynowska 166
Warsaw
POLAND

Dr. Marco ZANETTI
Swiss Federal Office of Forestry
Laupenstrasse 20
CH-3001 Bern
SWITZERLAND

Dr. T. ZAWILA-NIEDZIECKI
Remote Sensing Center
Institute Geodesy & Cartography
Jasna 2/4
PL-00 950 Warsaw
POLAND

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REPRESENTATIVES OF THE POLISH ACADEMY OF SCIENCES (Warsaw)

Dr. Piotr HOLNICKI
Dr. Andrzej JAKUBOWSKI
Dr. Andrzej KAŁUSZKO
Dr. Tomasz ROMANOWICZ
Prof. Andrzej STRASZAK
Mrs. Maria NACHTMAN
Mrs. Teresa LANGNER
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
PL-01 447 Warsaw
POLAND

* * * * * * * *

IIASA PARTICIPANTS

Dr. Joseph ALCAMO
Acid Rain Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Prof. Mikhail ANTONOVSKI
Biosphere Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Dr. Peter DUINKER
Biosphere Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Acad. Leonardas KAIRIUKSTIS
Deputy Leader, Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Dr. Annikki MAKELA
Acid Rain Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Prof. Robert E. MUNN
Leader, Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Prof. Sten NILSSON
Biosphere Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Dr. Harry VALENTINE
Acid Rain Project
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

Ms. Olivia VOLKER
Administrative Assistant
Environment Program
IIASA - A-2361 Laxenburg
AUSTRIA

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APPENDIX II: AGENDA*

International Institute for Applied Systems Analysis - IIASA
Laxenburg, Austria

Systems Research Institute - SRI
Polish Academy of Sciences
Warsaw, Poland

and

International Union of Forestry Research Organizations - IUFRO - Forest sector analysis - P4.11

WORKSHOP

on

"FOREST DECLINE AND REPRODUCTION: Regional & Global Consequences"

Holiday Inn Hotel, Kraków

March 23–27, 1987

FINAL AGENDA

SUNDAY 22nd MARCH, 1987

15:00 - 18:00 REGISTRATION of PARTICIPANTS — **Holiday Inn Hotel**

18:30 - 20:00 **Meeting of Organizing Committee, Session Chairmen & Rapporteurs - Conference Secretariat**

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*In: Proceedings of the Workshop on **Forest Decline and Reproduction: Regional and Global Consequences**, Kraków, Poland (23-27 March, 1987), L. Kairiukstis, S. Nilsson and A. Straszak (Eds.), 1987, IIASA, A-2361 Laxenburg, Austria.

MONDAY 23rd MARCH, 1987

08:30 - 09:00 REGISTRATION

09:00 - 10:20 OPENING SESSION

09:00 - 09:20 WELCOME FROM THE INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS (IIASA) and INTRODUCTION TO THE WORKSHOP

Acad. L. KAIRIUKSTIS *(Deputy Leader, Environment Program, IIASA)*

09:20 - 09:35 WELCOME FROM THE KRAKOW BRANCH OF THE POLISH ACADEMY OF SCIENCES

Acad. J. LITWINISZYN *(Chairman, Krakow Branch of the Polish Academy of Sciences)*

09:35 - 09:50 WELCOME FROM THE MINISTRY OF AGRICULTURE FORESTRY AND FOOD ECONOMY

Mr. R. WACŁAW *(Director, Department of Forestry and National Parks, Warsaw)*

09:50 - 10:05 WELCOME FROM KRAKOW CITY

Mr. Marek PASZUCHA (Vice Mayor, City of Kraków)

10:05 - 10:20 WELCOME FROM THE INTERNATIONAL UNION OF FORESTRY REESEARCH ORGANIZATIONS (IUFRO)

Prof. L. LÖNNSTEDT *(Forest Sector Analysis - P4.11, IUFRO, and Swedish University of Agricultural Sciences, Uppsala, Sweden)*

10:20 - 11:10 SELF-INTRODUCTION OF PARTICIPANTS *(about 30 seconds each)*

[Giving name, affiliation, and scientific interests]

11:10 - 11:30 B R E A K

Monday 23rd March, 1987 (Continued)

SESSION I: FOREST RESOURCES AND FOREST DECLINE

11:30 - 13:10 **CHAIRMAN:** **L. KAIRIUKSTIS (IIASA/USSR)**

Rapporteurs: **P. Duinker (IIASA/Canada) & J. Owsiński (Poland)**

11:30 - 11:55 **S. Nilsson (IIASA/Sweden):** *The State-of-the-Art of Forest Decline in Europe*

11:55 - 12:20 **R. Dzialuk (Poland):** *Sanitation and Health Conditions of Mountain Forests in Poland*

12:20 - 12:45 **R. Sedjo (USA):** *Forest Decline in the U.S. and Possible Implications for Future Harvests*

12:45 - 13:10 **M. Amano (Japan):** *Japanese Wood Supply in the Future and the Effects of Air Pollutants*

13:10 - 15:00 **L U N C H**

SESSION I (Continued)

15:00 - 18:00 **CHAIRMAN:** **W. GRODZINSKI (Poland)**

Rapporteurs: **P. Duinker (IIASA/Canada) & J. Owsiński (Poland)**

15:00 - 15:25 **H. Kurth (GDR):** *Future Wood Supply in Eastern Europe*

15:25 - 15:50 **P. Bazire (France):** *Results of the Survey of the Health Condition of the French Forest in 1986*

15:50 - 16:15 **Y. Konohira (Japan):** *Forest Resources of Two Island Countries on the Pacific Rim – Comparison of Japan and New Zealand*

16:15 - 16:35 **B R E A K**

16:35 - 17:05 **C. Prins (ECE/FAO Timber Comm., Geneva):** *The Outlook for the European Forest Resource, and Possible Effects of Air Pollution Damage*

17:05 - 17:30 **D. Mlinšek (IUFRO/Yugoslavia):** *Changed Silviculture Regimes Due to Damage*

17:30 - 18:00 **DISCUSSION**

19:30 **RECEPTION - Holiday Inn Hotel (hosted by IIASA)**

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TUESDAY 24th MARCH, 1987

SESSION I (Continued)

08:30 - 13:00 **CHAIRMAN:** **D. MLINSEK (IUFRO/Yugoslavia)**

Rapporteur: **P. Duinker (IIASA/Canada)**

08:30 - 08:55 **R. Persson (Sweden):** *Forest Resources of the World and their Future*

SESSION II: AIR POLLUTANTS AND POSSIBLE CAUSES AND EFFECTS

08:55 - 09:20 **Z. Patalas & K. Rykowski (Poland):** *Conservation of Forests Under Conditions of Growing Threats to the Environment*

09:20 - 09:45 **A. Grayson (UK):** *Assessing Effects of Air Pollution on Growth*

09:45 - 10:10 **J. Pollanschütz (Austria):** *Effects of Air Pollutants on Forest Growth*

10:10 - 10:35 **E. Adema (Netherlands):** *Quantification of Air Pollutants in Europe and its Importance to Vegetation*

10:35 - 10:55 **B R E A K**

10:55 - 11:20 **R. Cox (Canada):** *The Effects of Wet Deposition of Acidity and Copper on the Reproductive Biology of Populus Tremuloides*

11:20 - 11:45 **J. Materna (IUFRO/CSSR):** *Cooperative Program of Assessment and Evaluation of Air Pollution Influence on the Forest*

11:45 - 12:10 **J. Alcamo (IIASA/USA):** *Future Sulfur Deposition Scenarios for Forested Areas of Europe*

12:10 - 12:35 **M. Muller (France):** *Atmospheric Pollution and Forest Decline in France: The State of Progress of Research*

12:35 - 13:00 **DISCUSSION**

13:00 - 14:30 **L U N C H**

Tuesday 24th March, 1987 (Continued)

Session II (Continued)

14:30 - 17:30 CHAIRMAN: **P. RENNIE (Canada)**

Rapporteur: **P. Duinker (IIASA/Canada)**

14:30 - 14:55 **C. Binkley* & B. Larson (USA):** *Simulated Effects of Climate Warming on Northern Hardwood Forest Productivity*

14:55 - 15:20 **A. Mäkelä (IIASA/Finland):** *Impacts of Sulfur on Forests – Regional Assessment of Risk*

15:20 - 15:45 **A. Frühwald (FRG):** *Wood Formation Under Pollution Stress and Consequences for Wood Quality*

15:45 - 16:10 **B. Molski (Poland):** *Fir and Pine Floem and Wood Growth Retardation due to Air Pollution*

16:10 - 16:25 B R E A K

16:25 - 16:50 **R. Solymos (Hungary):** *Impacts of Air Pollution on Hungarian Forests*

16:50 - 17:15 **P. Rennie (Canada):** *The Significance of Air Pollution to Forest Decline in Canada*

17:15 - 18:00 DISCUSSION

18:00 EVENING FREE

18:30 - 19:30 Informal Meeting on "Impacts of Changes in Climate and Atmospheric Chemistry on Northern Forest Ecosystems and Their Boundaries: Research Directions"

Chairman: P. Duinker (IIASA/Canada)

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*This author presented the paper.

WEDNESDAY 25th MARCH, 1987

SESSION III: FIELD TRIP TO A FOREST UNDER STRESS OF AIR POLLUTION

INTRODUCTORY PAPERS

08:30 - 10:30 **CHAIRMAN:** **F.T. LAST (UK)**

Rapporteur: **Dr. Romanowicz (Poland)**

08:30 - 09:10 **W. Grodziński (Poland)**: *Disturbances of Forest Function under the Stress of Air Pollution*

09:10 - 09:35 **J. Walczewski (Poland)**: *Remote Sensing of Air Pollution and Forest Damage*

09:35 - 10:00 **K. Grodzińska (Poland)**: *Biomonitoring of Forest Ecosystem Disturbance*

10:00 - 10:25 **J. Weiner (Poland)**: *Energy, Nutrient and Pollutant Dynamics in Lowland Forest Ecosystems*

10:30 - 18:00 FIELD TRIP TO THE NIEPOLOMICE FOREST

This historical forest is situated in the Vistula River valley, at 20–35 km East of Kraków, representing a rather large area (11000 ha) of pine and deciduous stands. During the last three decades, the forest has been exposed to chronic airborne pollution at moderate levels, mainly sulphur dioxide, heavy metals and fluoride.

During the trip, we shall view parts of the forest and special attention will be given to the bio-indication of industrial damage and the disturbances of the main forest functions (primary production, decomposition rate) will be discussed. Weather permitting, a field experiment on the impact of heavy metal dusts will be carried out.

Lunch will be taken in the Niepolomice. It is recommended that participants should wear comfortable walking shoes and warm clothing.

18:00 **(approximately) – Return to Holiday Inn Hotel**

18:00 **EVENING FREE**

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THURSDAY 26th MARCH, 1987

SESSION IV: NATIONAL EXPERIENCES AND RESEARCH OF FOREST DECLINE

08:00 - 10:00 **CHAIRMAN:** **L. SCHOTTE (Sweden)**

Rapporteur: **P. Kauppi (Finland)**

08:00 - 08:25 **S.N. Linzon (Canada):** *Studies on Tree Damage in Canada*

08:25 - 08:50 **A. Friedland (USA):** *Red Spruce in the Northeastern United States: Symptoms, Extent and Nature of the Decline*

08:50 - 09:15 **M. Weiss (USA):** *Forest Decline in Major Forest Types in the Eastern United States*

09:15 - 09:40 **H. Thomasius (GDR):** *Experience on Forest Regeneration in the German Democratic Republic*

09:40 - 10:00 **DISCUSSION**

10:00 - 10:20 **B R E A K**

10:20 - 13:00 **CHAIRMAN:** **A.S. ISAEV (USSR)**

Rapporteur: **P. Kauppi (Finland)**

10:20 - 10:45 **A. Martyniuk*, V. Kasimov & N. Moiseev (USSR):** *Impact of Anthropogenic Pollution on Forest Ecosystems in the USSR and its Evaluation*

10:45 - 11:10 **M. Vaichys & K. Armolaitis* (USSR):** *The Impact of Atmospheric Pollution on Forest Ecosystems in the Lithuanian SSR*

11:10 - 11:35 **E. Klimo (IUFRO/CSSR):** *Some Results of the IUFRO-MAB Symposium on Pollution and Stability of Conifer Ecosystems and Experience in Field Studies in Czechoslovakia*

11:35 - 12:00 **M. Dakov & G. Raffailov* (Bulgaria):** *Present State and Possible Future History of Forest Damage Attributed to Air Pollution in Bulgaria*

12:00 - 12:25 **A. Auclair (Canada):** *Distribution of Forest Decline in Eastern Canada*

12:25 - 13:00 **DISCUSSION**

13:00 - 14:00 **L U N C H**

Thursday 26th March, 1987 (Continued)

Session IV (Continued)

14:30 - 18:00	**CHAIRMAN:**	**R. SOLYMOS (Hungary)**
	Rapporteur:	**A. Friedland (USA)**
	14:00 - 14:25	**P. Pasternak (USSR):** *Effect of Technogenic Air Pollution on Forest Stands of the Ukraine and Measures of Forest Operations to Increase their Resistance*
	14:25 - 14:50	**M. Marinov (Bulgaria):** *Trends of Multipurpose Management and Utilization of Beech Forests in Bulgaria*
	14:50 - 15:15	**J. Materna (IUFRO/CSSR):** *The Direct Influence of Air Pollution of the Forest Situation and Prognoses in Central Europe*
15:15 - 15:35	**DISCUSSION**	
15:35 - 15:50	**B R E A K**	

SESSION V: MONITORING FOREST DECLINE

15:50 - 18:30	**CHAIRMAN:**	**J. MATERNA (Czechoslovakia)**
	Rapporteur:	**A. Friedland (USA)**
	15:50 - 16:15	**F. Last (UK):** *Early Diagnosis of Forest Decline*
	16:15 - 16:40	**P. Kauppi (Finland):** *Some Concepts and Methods of Assessing Forest Damage*
	16:40 - 17:05	**U. Bräker (Switzerland):** *Tree-Ring Analysis in the Swiss Forest Decline Study of 1984*
	17:05 - 17:30	**R. Kontik (Switzerland):** *Comparative Studies on the Annual Ring Pattern and Growth Conditions*
	17:30 - 17:55	**L. Kairiukstis (IIASA/USSR):** *Dendrochronological Indications of Forest Decline and their Application for Monitoring*
17:55 - 18:30	**DISCUSSION**	
18:45	**Bus leaves for St. Catherine's Church (ul. Augustianska)**	
19:00 - 20:00	**Organ Concert (Jerzy Kukla - organist)**	
20:00	**Bus returns to Holiday Inn Hotel**	
20:30	**Evening Free**	

FRIDAY 27th MARCH, 1987

Session V (Continued)

08:00 - 10:00 CHAIRMAN: **J. MATERNA (CSSR)**

Rapporteur: **P. Duinker (IIASA/Canada)**

08:00 - 08:25 **H. Bossel (FRG):** *Modelling the Dynamic Process of Tree Dieback for Spruce and Beech*

08:25 - 08:50 **J. Owsiński et al. (Poland):** *Forest Dieback Dynamics: A Modeling Study for Polish Conditions*

08:50 - 09:15 **B. Molski, K. Głębicki & W. Dmuchowski (Poland):** *Computer System for Identification of the Pollution Impact on Forests*

09:15 - 09:40 **M. Antonovsky (IIASA/USSR):** *General Problems of Modeling the Age Structure of Forest Dynamics*

09:40 - 10:00 DISCUSSION

10:00 - 10:20 B R E A K

SESSION VI: ECONOMIC INDUSTRIAL AND ECOLOGICAL CONSEQUENCES OF FOREST DECLINE

10:20 - 13:30 CHAIRMAN: **R. SEDJO (USA)**

Rapporteur: **L. Lönnstedt (IUFRO/Sweden)**

10:20 - 10:45 **T. Stemberger (Austria):** *Economic Evaluation of Forest Damage*

10:45 - 11:10 **L. Lönnstedt (IUFRO/Sweden):** *Effects on the Industry from Forest Damage – Some Examples*

11:10 - 11:35 **J-L. Peyron (France):** *Dynamics of Forest Resources – The Burgundy Region Example*

11:35 - 12:00 **H. Steinlin (FRG):** *Regional Effects of Forest Damage Attributed to Air Pollutants*

12:00 - 12:25 **T. Bencze (Hungary):** *Forest Decline and Satisfying the Demand for Forest Products in Europe*

12:25 - 12:50 **S. Navrud (Norway):** *Possible Regional Economic Consequences of Forest Die-Back – Norway as an example*

12:50 - 13:30 DISCUSSION

13:30 - 14:30 L U N C H

Friday 27th March, 1987 (Continued)

SESSION VII: COMMON APPROACHES TO INTERNATIONAL PROTOCOL OF MONITORING FOREST DECLINE

14:30 - 15:30	**CHAIRMAN:**	**H. STEINLIN (FRG)**
	Rapporteur:	**J. Kałusko (Poland)**
	14:30 - 14:55	**S. Huttunen (IUFRO/Finland):** *The Policy of IUFRO Concerning Forest Damage Attributed to Air Pollution*
	14:55 - 15:20	**L. Schotte (Sweden):** *Future Policies and Avoiding Forest Damage*
15.20 - 15:30	**DISCUSSION**	
15:30 - 15:45	**B R E A K**	

SESSION VIII: FINAL DISCUSSION AND ADOPTION OF RESOLUTIONS

15:45 - 17:30	**CHAIRMAN:**	**R.E. MUNN (IIASA/Canada)**
	Rapporteur:	**P. Duinker (IIASA/Canada)**

18:00 **EVENING FREE**

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SATURDAY 28th MARCH, 1987

08:00	**Bus leaves for Field Study Trip**
	FIELD STUDY TRIP TO TATRA NATIONAL PARK
	Tatra Mountain trees as the object of dendroclimatological investigations: View of the landscape of Zakopane, the Alpine Timber Line, upper spruce (*Picea abies*) forest zone, etc.
13:00	**L U N C H (in Zakopane)**
19:00	**Bus returns to Holiday Inn Hotel**
20:00	**CLOSING RECEPTION (hosted by the Polish Academy of Sciences)**

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