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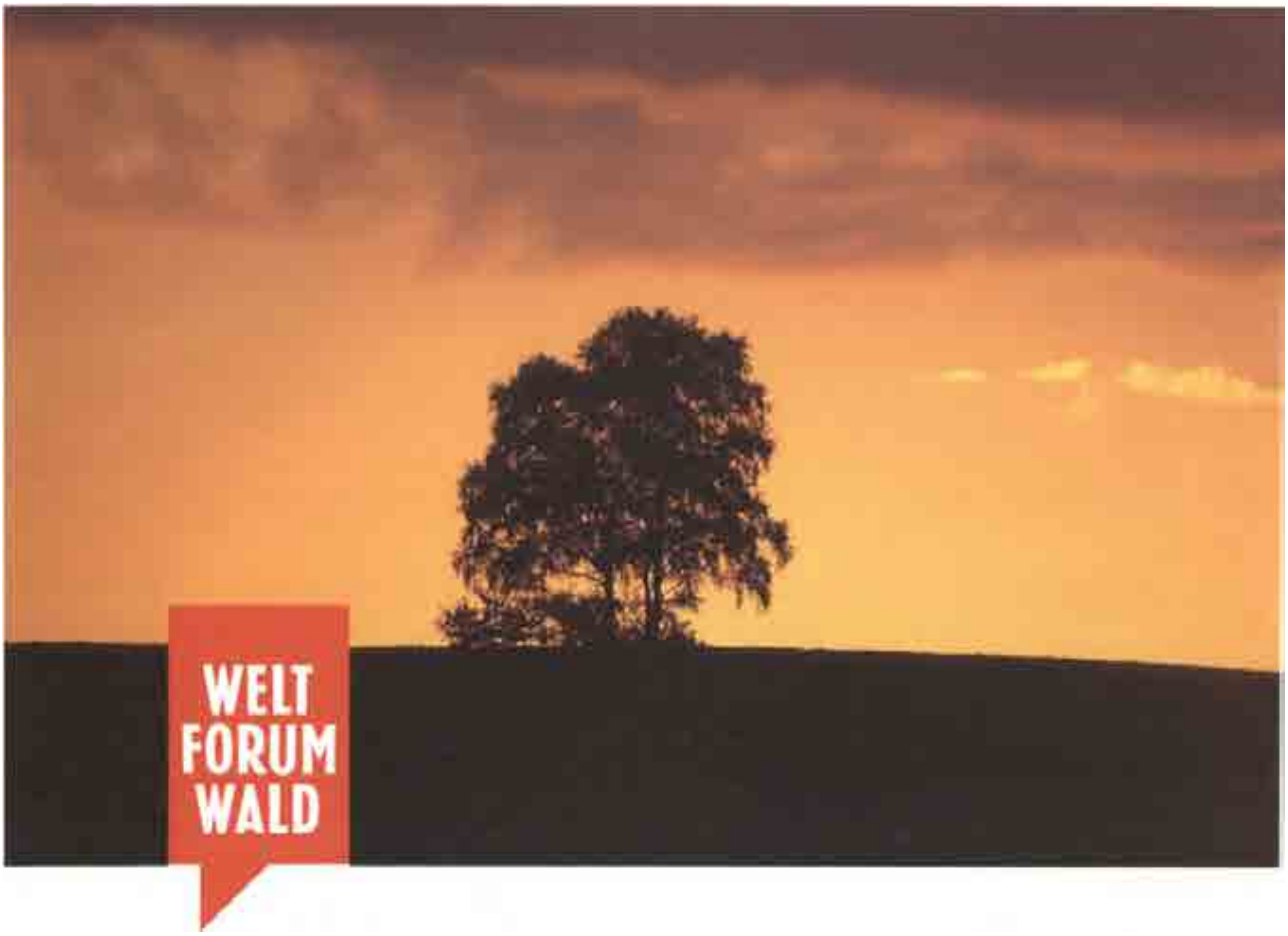

Forests in Focus

Proceedings Forum

Forests and Atmosphere – Water – Soil

2 – 5 July 1999

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Registriertes Projekt
der Weltausstellung

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Responsible for the contents of each contribution is the respective author.

Editorial Remark:
The forum was open to various kinds of contributions by participants. Contributions were made in form of statements, abstracts of papers, scientific papers and posters. This publication includes all these various kinds of contributions without attempt to create a unified format.
Some texts were slightly modified by the editors, mainly in order to overcome language problems, and the text was not revised again by the author. It was not meant to change the contents, but if the modification resulted in a different meaning, it is solely the responsibility of the editors.

Editors: Dr. Jutta Poker, Inge Stein

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Forstwirtschaft
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Schutzgemeinschaft
Deutscher Wald

NNA-Reports

Volume 12, Special Issue 4, 1999

Contents

Workshop Forests as Protectors

Additional Contributions and Poster Presentations

Forests in Focus

within the framework of "WELTFORUM WALD", official project of the World Exposition 2000

A series of fora focusing on global forests issues aims at achieving consensus among relevant interest parties on tools and concepts to sustainably develop the world's forests. The project "Forests in Focus" adds operative recommendations for solving environmental problems concerning forests to current political negotiations and scientific meetings in the field of forestry. The fora act as an agent between politics, economics, science and public and provide condensed up-to-date knowledge as well as agreed upon proposals for action adequate to target groups. Thus, "Forests in Focus" supports the local implementation of guidelines on forest management and enforces the forest related parts of the Agenda 21 process.

Background

The World Exposition 'EXPO 2000 Hannover' presents the concept of sustainable development as agreed upon in the Agenda 21 at the UNCED 1992 in Rio de Janeiro. EXPO 2000 includes various worldwide decentralised projects. One of these, 'WELTFORUM WALD' (World Forum on Forests) has been initiated by authorities of the district Soltau-Fallingbostel, Northern Germany, the Association for the Protection of Forests and Woodlands (SDW), the Forestry Commission of Lower Saxony and the Alfred Toepfer Academy for Nature Conservation (NNA).

The project includes various activities and exemplary projects demonstrating sustainable management and use of forests to local people and international visitors (reafforestation of degraded heathland, redevelopment of former military areas, environmentally sound wooden buildings, thermal use of wood, use of non-timber products, management of a nature reserve and tourism, etc.).

Within this frame, 'Forests in Focus' forms the professional backbone. The fora address institutions and social parties concerned with forests, particularly those which

- are directly connected to forests,
- play an active role in forest management
- are affected by forest management.

The fora intend to encourage the relevant social parties to participate efficiently in decision making on forest issues, thus promoting the worldwide implementation of the recommendations of the Agenda 21.

Auspices

'Forests in Focus' is performed under the auspices of the Federal Minister for Food, Agriculture, and Forestry, Mr. Karl-Heinz Funke.

Time Schedule

Between 1998 and 2000, five fora take place. With respect to the multiple functions of forests, the fora focus from different perspectives on the worldwide sustainable co-existence of mankind and forest:

Forests and Energy (To what extent can forests contribute to the world's future energy supply?) January, 1998

Biodiversity –Treasures in the World's Forests (Prospects of conservation, use and sustainable development of biodiversity in forests) July, 1998

Forests – Source of Raw Material (Potentials of forest products' use and marketing) May, 1999

Forests and Atmosphere-Water-Soil (Regulation of energy and matter cycles with respect to climate change, water cycles and soil degradation) July, 1999

Forests and Society (Interrelation of cultures and environment, public awareness, public participation; integration of recommendations of the former fora) November, 1999

The final events will be the presentations of the results and recommendations of all fora at the EXPO 2000 in Hannover in Summer 2000 and at the congress **Sustainability in Time and Space** – in cooperation with PRO SILVA (Implementation of forest management guidelines in divergent forest types) June, 2000.

Forests and Atmosphere-Water-Soil Forum Recommendations

Chairman: John Innes

Background to the Forum

The forum "Forests and Atmosphere-Water-Soil" was the fourth of five fora organised by the regional EXPO-project 'WeltForum Wald' of the district Soltau-Fallingbostel in Lower Saxony in preparation for EXPO 2000 in Hanover.

The Forum was attended by 80 participants from 19 countries. The participants were drawn from a variety of different backgrounds, providing the opportunity for many new interactions. This was one of the first occasions in which a significant number of specialists on carbon sequestration interacted with specialists from the fields of air pollution and water resources. As much time was provided for discussion and debate, there were many opportunities for cross-fertilisation between the different fields.

During the forum, international distinguished speakers from universities, research organisations and industry gave presentations on topics relevant to the forum. The Forum was split into three workshops, dealing with:

a) forests under mixed inputs of pollutants and nutrients;
b) forests as protectors – water supply, prevention of natural disasters such

as floods, soil degradation, landslides; and
c) forests after the Kyoto Protocol – their potential role as sources and sinks of trace gases, especially carbon dioxide.

Each of these workshops produced a report, and the specific conclusions of each will not be repeated here. Instead, this report provides a form of executive summary, in which the most important points emerging from the Forum are high-lighted. The report was discussed in plenary, and represents a record of the views of the participants at the Forum.

The changing nature of forestry

As we approach the new millennium, it is important to recognise that forestry has entered a period of rapid change. Following the United Nations Conference on Environment and Development in 1992, sustainable development has become a key issue, and the forestry profession has responded with a number of initiatives aimed at sustainable forest management. As part of this process, there has been the increasing recognition that forests provide many different economic, environmental and social benefits, although it is clearly impossible for all forests to fulfil all roles.

A number of different initiatives dealing with forests are in progress. At the intergovernmental level, groups such as the Intergovernmental Forum on Forests are examining critical issues in forestry, and are currently looking at the possibility of a global forest convention. Regional groups, such as the International Tropical Timber Association and the Montreal Process for Boreal and Temperate Forests are examining forest management issues in particular forest types or regions. Industrial forestry is becoming increasing global, and consolidation of this relatively fragmented industry is already occurring. At the national level, there have been initiatives to implement integrated forest policies (e.g. National Forest Programmes). At the same time, there is a growing recognition of the needs to consider the wishes of all stakeholders and to transfer as much decision-making as possible to the local level.

Many of these changes were reflected in presentations made during the course of the Forum, and they also have a bearing on its conclusions and recommendations.

Forests and environment

Forests, as an integral part of the environment, both affect and are affected by it. Many feedback cycles exist, both positive and negative. While much progress has been made in the understanding of these inter-relationships, there are still many gaps in our knowledge. This restricts our ability to predict how climate change, changing pollution concentrations and future forest policies and management regimes will impact forests and the environment. Modelling provides scenarios, but it is important to stress that models are not predictions - they provide an indication of what might happen under certain sets of limiting conditions. Models also help the understanding of processes within complex systems.

Atmosphere

■ Of the gaseous pollutants, sulphur dioxide remains a problem in many parts of the world that have not yet begun emission reductions. It is particularly important in Asia, where emissions are currently increasing, especially in China and India. Emissions of nitrogen oxides remain a problem in most parts of the world. Nitrogen oxides are an important cause of nitrogen deposition and are also important as a precursor for ozone. Ozone has caused major problems for forests in some parts of the world (e.g. California), and is being increasingly recognised as a problem in some parts of Europe. For its control, there is a growing recognition that the critical levels approach has limited applicability and that future regulation should be developed using an effects-based approach. It is recommended that further reductions of air pollution be based on the effects-oriented critical loads and critical levels approaches.

■ In many parts of the world, the relationship between air pollution and tree health remains unclear. However, in such cases, air pollution represents a potential threat to tree health and, as such, steps should be taken to reduce emissions of the most damaging pollutants. It is recommended that the precautionary approach be adopted to pollutant reduction rather than waiting for demonstration of cause and effect mechanisms.

■ Over the past 20 years in Europe and North America, much has been learnt about the impacts of air pollutants on forests. This knowledge has been used to develop emission reduction programmes nationally and internationally. There is great potential for the application of this knowledge to areas where air pollution remains a problem (e.g. sites in the Russian Federation such as Noril'sk and the Kola Peninsula), and areas where air pollution is likely to be a problem in the future (countries currently undergoing rapid population growth and/or development, such as Brazil, China, India, Nepal and South Africa). It is recommended that ways be found to encourage scientists from Europe and North America to work on pollution problems in other parts of the world.

■ There is a general consensus that emissions of carbon dioxide and other greenhouse gases are at least in part the cause of the global sea surface temperature increase that has occurred during the 20th century. A substantial part of these emissions can be attributed to land-use changes, particularly deforestation. Landuse changes in themselves can also have a direct impact on climate, certainly at the regional level (e.g. Amazonia) and possibly at the global level.

■ The Kyoto Protocol opens a number of possibilities for the inclusion of forests and forestry in the carbon dioxide debate. Incentives for good carbon management in the forestry sector are currently absent from the Kyoto Protocol but are to be discussed in the near future. Simple and verifiable methods are required to ensure that forestry projects are in line with the provisions of sustainable forest management. It is recommended that full support be given to the further inclusion of verifiable forestry activities consistent with sustainable development in future developments associated with the Kyoto Protocol.

■ Alone, sequestration of carbon in forests and forest soils will not make full use of all the opportunities that forests and forestry provide to assist the mitigation of climate change. The use of wood as a substitute for fossil fuels and other materials has the potential to have a significant impact on emission levels and atmospheric concentrations of CO_2. It is recommended that the forestry and forest product industries continue to develop markets for wood, with emphasis on promoting the use of wood as a material and the substitution of wood for fossil fuels.

■ The mechanisms currently being discussed within the Kyoto Protocol provide the possibility of transferring some of the environmental benefits of forestry to the financial realm. For example, the protection of forests will have in future a financial value.

■ Many uncertainties still exist over the role of forestry in the Kyoto Protocol. Some terms are inadequately defined (e.g. forest, afforestation, reforestation and deforestation), and there is a need to develop rules and modalities. It is recommended that these uncertainties be clarified as quickly as possible, and that guidelines and modalities for the inclusion of forestry in instruments such as the Clean Development Mechanism be established.

Water

■ Scale is a major issue in the discussion of water and forest interrelationships. Confusion over scales has affected communication between the forest hydrology community and forest engineers regarding issues such as the relationship between forest cover and discharge. It is recommended that scale be given much more attention when examining forest – water issues.

■ Each watershed is a unique biome and generalisations about deforestation impacts on runoff, peak flows and erosion are not universally applicable. A better understanding of forest hydrology interactions is needed to predict the expected response of a forest ecosystem on the scales that are relevant for specific forest management decisions. In addition, some processes in forest hydrology are inadequately understood, resulting in uncertainty over some management practices. It is recommended that greater attention be given to long-term, catchment-scale investigations of forest hydrology.

■ It is important to recognise that carbon and water cycles, especially in tropical rain forests, are inextricably linked. It is recommended that research be undertaken to clarify these interactions and feedbacks.

■ Many achievements have been made in the field of water conservation, especially in countries such as India. However, growing demands for water in many parts of the world means that complacency would be inappropriate. It is recommended that the maintenance of potable water supplies be a key consideration for sustainable forest management. Further, the broad role of forests should be considered in local water management planning.

■ The effects of deforestation extend beyond national boundaries through their influence on regional atmospheric circulation patterns (e.g. monsoon circulations) leading to temporal and spatial shifts in rainfall patterns. The study and arbitration of these effects requires international co-ordination. It is recommended that international climate programmes such as the World Climate Research Programme (WCRP) and the International Geosphere Biosphere Programme (IGBP) co-ordinate their efforts in this area.

Soil

■ Despite major reductions in sulphur emissions, critical loads for forest soils are still exceeded in many parts of Europe, resulting in continuing acidification. Consequently, remedial measures in the form of liming or wood ash applications are still required on some sensitive soils.

■ In northern Europe and elsewhere, nitrogen deposition has affected the integrity of forest soils. Soil acidification is continuing, and adverse impacts have been identified on the diversity of the ground flora and on soil water. Models suggest that ecosystem destabilisation may ensue. It is recommended that efforts to reduce nitrogen emissions be intensified, particularly from the agricultural sector, and that policies that promote the use of nitrogen in sensitive areas should be discouraged.

■ Insufficient attention has been paid to the maintenance and conservation of forest soils. Forestry practices need to take greater care of soils, particularly during road-building operations and in relation to soil compaction. Much erosion and locally increased stream flows are associated with poor road and drainage design and construction. It is recommended that greater attention be given to forest engineering practices, particularly road design on slopes, when developing criteria and indicators for sustainable forest management.

■ Within forestry, insufficient attention has been given to forest soils as a carbon store. All forest soils contain significant amounts of carbon, with soil carbon contents often being greater than the carbon held in above-ground biomass. It is recommended that forestry practices take greater notice of this, especially in relation to carbon sequestration and carbon emission mitigation projects.

■ The maintenance of soil fertility is critical, and future plans for the utilisation of forest resources must take this into account. Soil fertility is a particularly important issue in relation to fast-growing plantations used for biofuels. In such cases, the return of wood ash to the plantation sites may help to maintain fertility. It is recommended that the monitoring of forest nutrition be a standard aspect of sustainable forest management.

Conclusions

1. The need for integrated management of forest resources

Perhaps the most over-riding conclusion of this conference is the need for the integrated management of forest resources. This is likely to take the form of increased inter-sectoral decision making on land use. Forests cannot be seen in isolation as a carbon sink or as a means to prevent soil erosion. Instead, there is a need for the recognition and valuation of all economic, environmental and social benefits of forests. Major management changes such as afforestation need to be considered from many different viewpoints, such that all the potential ramifications can be identified and taken into account. Consequently, there is a need to obtain a balance between the different benefits offered by forests. Forest needs must be placed into the broader context of societal needs, and any actions taken to benefit forests should be made in the knowledge that the benefits might not be so clear for other sections of society.

2. The need for partnerships and co-operation

Many issues within the realm of "Forests and Atmosphere-Water-Climate" are extremely complex, requiring the work of inter-disciplinary and international teams. The International Geosphere Biosphere Programme has demonstrated the efficacy of such an approach. At the same time, there is a need for capacity enhancement and strengthening (including providing the opportunities for scientists to develop their full potential) in developing countries so that scientists from these countries can take part in international research projects as project leaders and full project partners. Cooperation between scientists is promoted by a number of organisations: within forestry, the most important is the International Union of Forestry Research Organisations (IUFRO) with its 700 member organisations and 15,000 associated scientists.

Other focal points for such cooperation include the Centre for International Forestry Research (CIFOR) and the International Centre for Research in Agroforestry (ICRAF). For many problems, solutions can only be developed at the international level, stressing the importance of instruments such as the Convention on Long-Range Transboundary Air Pollution, the Inter-governmental Panel on Climate Change and the Framework Convention on Climate Change.

As well as partnerships within the scientific community, there is a need for strengthening the cooperation between scientific community and other groups, including non-governmental organisations, the forest and forest products industries and local communities makers. Such cooperation will be of benefit to all parties.

3. The need for education

The subject areas covered by the Forum "Forests and Atmosphere-Water-Climate" were very large. There is a need for forest scientists to have a more holistic perspective of the issues in this field. At the same time, there is a need for foresters and forest managers to have a greater awareness of the implications of their activities. For example, most people in the forestry sector are still unaware of the contents and implications of the Kyoto Protocol. The need for greater education extends to the general public. For example, optimistic forecasts of the acceptance of higher-cost electricity from renewable sources in Germany have not yet been matched by reality.

4. The need for coherent government policy and actions

To be effective, coherent environmental policies are needed at the national and supra-national levels, and these need to be fostered through multi-layered governance in order to come to concrete actions.

Development programmes should take into account environmental needs. There should be more incentives for environmentally friendly measures, such as the development of renewable energy. Carbon sequestration schemes need to recognise that there is a fundamental asymmetry between the aims of the sponsors (primarily carbon sequestration) and the aims of the recipients (primarily sustainable development). Articles 3.3, 3.4, 6 and 12 of the Kyoto Protocol have the possibility to significantly change landuse and forest management practices in many parts of the world, but this has still to be widely recognised. Forest management programmes should be consistent with Integrated Conservation and Development Plans (ICDPs), where such plans exist.

5. The need for greater stakeholder involvement

In many issues, particularly emission reductions and carbon sequestration projects, there is a need for greater stakeholder involvement. Partnerships are required between for example energy producers and their customers to ensure that the best possible solutions to particular problems are implemented. Local communities require further empowerment as their support and participation in the management of their resources is essential if resource management initiatives are to be successful. Demonstration projects have an important role in fostering the local acceptance of many environmentally-friendly management practices.

6. The need for accurate statistics

For many aspects of modern forestry, ranging from the sustainable management of forests to the derivation of national carbon budgets, reliable statistics are essential. Currently, the Food and Agricultural Organisation (FAO) of the UN is responsible for collecting such statistics through its Forest Resource Assessment (the UN Economic Commission for Europe has the responsibility for the temperate and boreal zones). More support needs to be given to this programme, and every effort should be made by national governments to provide the best available information to the FAO and UNECE. Duplication of data collection and verification should be avoided. Synergies between different certification mechanisms need to be encouraged.

7. The need for sustainable forest management

Recent developments in the field of criteria and indicators for sustainable forest management (e.g. the Helsinki Process for the Protection of European Forests, the Montreal Process for Boreal and Temperate Forests excluding Europe, the Lapaterique Process for Central American Forests, the Tarapoto Process for Amazonian Forests and others) have drawn attention to the need for a holistic view when developing plans for the sustainable management of forests. These processes generally recognise the multiple benefits of forests, and it is now the responsibility of forest managers and other stakeholders to ensure that these benefits are realised through implementation.

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Workshop: Forests under mixed inputs of pollutants and nutrients

Chairman: Lennart Rasmussen

Emissions

Acid deposition and atmospheric inputs of nutrients, especially nitrogen, are important environmental issues in relation to forest growth and forest health conditions in Europe and North America. However, problems with forest health are now emerging in new geographical areas, including parts of eastern and southern Asia, southern Africa, and South America. In these areas, emissions of sulphur and nitrogen oxides are increasing rapidly as industrialization proceeds and the use of fossil fuels increases. However, atmospheric deposition of alkaline dust and base cations should be included when assessing the effects of the deposition in these areas and future possible counter measures. Emissions of ammonia in areas with intensive animal husbandry are also a cause of concern regarding the acidification of forest soils and nutrient imbalances in forest ecosystems. Although gaseous ammonia is alkaline and may neutralize airborne acids, when deposited to terrestrial ecosystems, it may be converted to nitrate and become acidifying in its effect on soils and groundwater. Furthermore, emissions of nitrogen oxides are of crucial importance for the formation of photochemical oxidants – especially ozone – in the lower atmosphere, and high concentrations of photochemical oxidants have an impact on forest trees and forest floor vegetation.

Emission reduction

Despite the substantial decreases in sulphur dioxide emissions of 50 % in Europe and 31 % in North America in the period 1980–1995, sulphur deposition in parts of these regions is still at least 10 times higher than it was during the pre-industrial period. Soil acidification will continue until the acidifying input is reduced to levels below the buffering capacity of the soils. For nitrogen compounds a slightly decreasing trend is visible, amounting to about 10% in the period 1980–1995 in both Europe and North America. Nitrogen emissions are, mainly derived from transportation and the agricultural sector. However, emission reduction techniques are being counteracted by increased activities in these sectors. In areas receiving high deposits of nitrogen, especially in the form of ammonia, substantial leaching of nitrate is observed, indicating that nitrogen in these areas may be as important as sulphur for acidification impacts. The high nitrogen deposition in Europe is believed to have caused a general increase in tree growth in nitrogen-limited European forests during the last 10 years. The relative importance of nitrogen deposition is likely to increase in the future even though political measures will be taken to reduce the problem. The base level of ozone is still increasing and high peak values with damaging effects on forests can still be expected.

Forest conditions

Forest health conditions in relation to the impact of air pollution has been monitored in Europe since 1986. Each year, crown condition is evaluated for a very large number of trees of different European tree species, using as an indicator needle/leaf loss in relation to a healthy tree in the same region. Loss of more than 25% of the needles/leaves on a tree is defined as a damaged tree. There were no general dramatic developments in forest health conditions in recent years. In the period 1992–1997, the proportion of damaged trees increased only slightly from 22 to 25 % as an average for all tree species in Europe. In last year's survey, it is reported that parts of central and eastern Europe have the highest defoliation scores. In particular Scots pine received the higest defoliation scores in the Czech Republic, southern Poland and Belarus. Norway spruce was most damaged in Czech Republic, and beech in Germany, at the border between Poland and the Slovak Republic, and in Romania. A recent improvement of crown condition for Scots pine and beech in eastern Germany, northern Poland and parts of the Czech Republic is attributed to the decrease in air pollution and favourable weather conditions. In France crown condition for oak has deteriorated during the last two years, which may be explained by drought, insect defoliators and fungal attack. In other parts of the world, damage to forests has also been observed, especially in industrial emission regions, whereas the causes of damage in other regions are less clear. Large areas of forests are growing on soils that are, or have developed into, very nutrient poor soils with low pH and base saturation. This is the case in many boreal forests, as well as in many tropical and subtropical areas. These soils show very high sensitivity to acid deposition, especially with regard to nitrogen, and this sensitivity may cause problems to forest health and productivity in the long-term. Although air pollution is an important stress factor in forests, climatic conditions, biotic factors, soil types, tree species, tree age, forest management, local conditions etc. should also be included in the evaluation of the crown condition complex. Further, changes in forest biodiversity due to eutrophication have been reported from regions with high nitrogen inputs, especially in north-western and central Europe.

Critical loads and levels

In 1979 the UN/ECE Geneva Convention on Long-range Transboundary Air Pollution was established and the transboundary nature of air pollution was acknowledged. Since then the UN-ECE has been supplemented by initiatives of the European Union.

The problems treated in numerous protocols have principally been acidification and eutrophication resulting from indirect exposure to pollutants acting through soil-mediated changes (*indirect critical loads*). Further, tropospheric ozone acting directly on vegetation and human lung function (*direct critical levels*) has received attention. However, the relationships between the different air pollutants are quite complex as nitrogen may induce both acidifying and eutrophying effects and, in oxidised form, is one of the precursors of ozone. Therefore, the forthcoming initiatives integrate these different effects in Multi-pollutant–Multi-effect protocols under both the auspices of UN-ECE and the EU. The environmental targets are based on the critical loads and levels for impacts on ecosystems and humans. The interim goal is to reduce the area of ecosystems not protected against acidification by 50 % and to reduce human health relevant exposure to ozone by ⅓ from 1990 to 2010. In this way, the principle behind environmental planning becomes effect-based.

A Critical Load is defined as *'A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'*. From this broad and relatively flexible definition there is a long road to operationalised calculations on a European scale. The Steady-State Mass-Balance calculations based on the base-cation/aluminium ratio of 1 as the setting criterion have been a simplified way of calculating comparable critical loads over Europe. But perhaps this criterion has been too simplified. This basic criterion has been questioned and the human utilitarian paradigm behind the protection of forest production is therefore still under discussion. Nowadays, forest management is not only supposed to be environmentally sustainable – it should also be economically feasible, socially acceptable and technically possible. We call it multipurpose forestry. Management should take into consideration external inputs from the air, the possibility of carbon sequestration, the interest and demands of the daily users (forest guests, tourists) and the conservation of rare and characteristic species. According to the 'Convention on Biological Diversity' (1992) there is a global concern about biological diversity in ecosystems, especially in forests.

For the next generation of air pollution abatement discussions we will need to introduce another, supplementary, indicator of sustainable air pollution input. The quality of nature – defined as the originality, the wilderness, the continuity and authenticity of nature, its processes, genes, species, ecosystems and landscapes – could possibly be operationalised and used to monitor the effects of air pollution. The critical loads of today are based on rather weak sustainability principles. Broader ethical considerations are gaining space in environmental planning, and perhaps stronger sustainability principles should be behind the critical loads of tomorrow. The value of nature in itself – the species, the ecosystems, the natural processes should be protected as well, requiring new biological indicators of critical loads exceedances. Experiences from the use of the critical load concept in Europe should be adapted to Asian conditions and used to prevent similar air pollution effects to those observed in Europe.

Nitrogen cycling and effects in forests

The nitrogen cycle is characterised by a huge reservoir of inert nitrogen and smaller amounts of active nitrogen in different chemical forms, including both oxidised and reduced nitrogen compounds. Chemical and biological processes result in its transformation from one form into another. Without the interference of humans, the nitrogen cycle is in equilibrium and there is no serious accumulation of forms of nitrogen leading to disturbance. Nitrogen is an essential nutrient for all forms of life in aquatic and terrestrial ecosystems, including humans. However, nitrogen is also a growth-limiting nutrient in most of these systems. Because of this limitation, a rich biodiversity with very rare species has developed throughout the centuries.

Human activities aim at the enhancement of biological systems with respect to higher yields, involving both the productivity per unit and the geographic extent of biological activities. Human activities also include the use of oil, natural gas and biomass, resulting in release of CO_2 and nitrogen. These processes are characterised by chemical conversions, meaning that there will be an output of unintentional products or wastes. In general, the ecosystems in which human activities are embedded, are capable of absorbing these wastes without serious damage to other processes in the ecosystem. This capacity for the internal removal of unintentional products is tied to critical limits and boundaries. In areas with high densities of human activities, environmental problems arise relating to excess of nitrogen.

Nitrogen is an essential nutrient for all plants, humans, animals, and micro-organisms. Because of this, nitrogen emissions are not harmful to the environment until a certain level has been reached, and for most temperate forest ecosystems nitrogen is a growth-limiting factor. For each system, there is an optimum nitrogen level related to the optimum production of the system. Figure 1 shows a temporal form of the optimum nitrogen curve for forests. It indicates that up to a certain optimum level, production increases whereas above that level production decreases.

Increased amounts of all oxidised forms of nitrogen play a role in atmospheric pollution, deposition and soil and water pollution. Reduced forms of nitrogen, such as ammonia, ammonium and amines also play an important role. Nitrous oxide is a greenhouse gas and contributes to global warming.

Much is known about nitrogen cycling in forests and the resulting effects at increased exposure and loads to ecosystems. The coupling of acidification and eutrophication in forest ecosystem leads to enhanced risk of effects. Acidification leads to a decrease in the availability of base cations through leaching of these nutrients from the soil, whereas increased nitrogen loads lead to a further imbalance in the nutrient status of forests and natural ecosystems. In both acidification and eutrophication, oxidised and reduced airborne nitrogen compounds are involved.

The increased growth rates of trees in European forests are supported by evidence from long-term field experiments. Simultaneously the mean weight of needles appears to have increased. However, tree growth increases are observed only as long as the system is not saturated. After saturation, growth decreases often occur. The carbon/nitrogen ratio in the organic layer, in conjunction with appropriate deposition information, can be used as an indicator of the risk of nitrate leaching. Nitrogen deposition may cause imbalances to other nutrients such as in phosphorous, potassium, calcium and/or magnesium, and increases the potential of attacks by parasites, diseases and insects. A multiple effect of acidification and increased

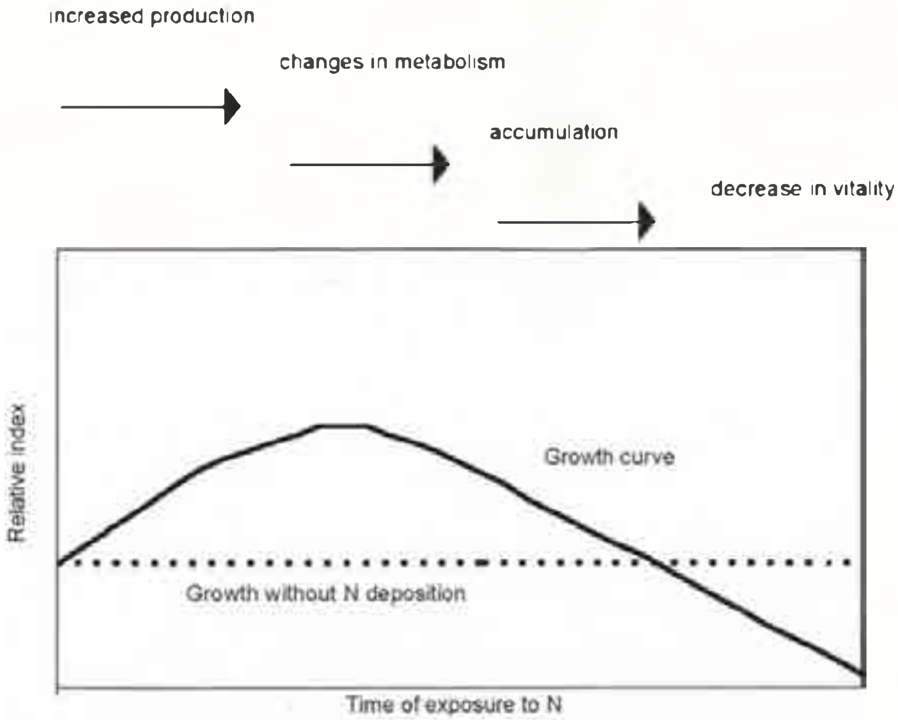

Fig. 1: Hypothetical growth curve.

nitrogen availability increases the negative biological effects. N deposition decreases biodiversity and vegetation composition towards a more nitrogen-demanding community, changes bacterial and mycorrhizal composition and contributes to changes in plant nutrition and composition.

In Western Europe the nitrogen issue has been widely acknowledged. This is less true in other parts of the world, such as the USA and Asia. In some areas, nitrogen pollution is heading towards the situation in Western Europe. Development of policies for nitrogen emission abatement is therefore needed.

The region with the largest human perturbation of the nitrogen cycle is Asia. The nitrogen problems will be greatest in this region unless drastic measures are taken.

An integrated approach in nitrogen pollution abatement is strongly recommended. In this way targets for forest damage, acidification, eutrophication, human health and global warming can be met at the same time.

Forest soil acidification

In Europe, the soils that are the most sensitive to acidification are found in the Scandinavian countries. Even though the atmospheric deposition of acidifying compounds is relatively low in Scandinavia, many forest soils in southern Scandinavia are acidified to low pH levels, and cannot sustain healthy tree growth. Despite the reduction in atmospheric emissions during the last decade, acidity is still accumulating in the soils. The same is true for high deposition areas in central Europe, whereas soil acidification does not seem to be a problem on the more alkaline soils in southern Europe and southeastern Asia. If the input of acidity to the soil from atmospheric deposition or biological processes, such as for example from nitrification, is larger than the buffering capacity of the soil, soil acidification will proceed. Base cations, calcium, magnesium and potassium, will be depleted by leaching and will leave the forest ecosystem. A similar effect can be induced by too intensive logging, which also will remove the base cations from the forest ecosystem and thereby prevent sustainable use of the forest. Even micronutrients like boron and copper are now depleted in many Scandinavian forest soils.

However, most trees can continue to live in an acidic environment for some time. Even oak trees, which are usually considered to prefer better soil conditions, can grow in very acidic soils and still show acceptable growth. Apart from the depletion of base cations in acidic soils, the increased solubility of aluminium in the soil solution creates toxic conditions for root growth and decreases the dissolution of phosphate ions. These are precipitated in the soil or around the fine root bark as aluminium-phosphate, and prevent or delay increased uptake of phosphate by the trees. A negative correlation is reported between the phosphorous concentration in leaves and exchangeable aluminium concentrations in the soil. All these changes might cause stress problems to trees.

Remedial fertilisation with adequate mineral nutrients (except nitrogen) and liming has improved the conditions for tree growth in regions with acidified soils in central Europe and southern Sweden. However, the application of this technique in general is still under discussion.

Global change effects on forests

Forests are vulnerable to climate change, due to the longevity of trees and the expected climate change within their life span. At the same time, forests play an important role in the global carbon budget, as they contain two-thirds of the carbon contained in the terrestrial biosphere, and because they play a dominant role in the regulation of the exchange of carbon and water between the atmosphere and the biosphere. Information on the future carbon sequestration capacity of European forests will be necessary for the commitments associated with the Kyoto protocol on reducing greenhouse gas emissions. The models are supported by a European network of measuring stations, which is delivering the input data. A parallel network is now under development in North America. The models are expected to identify and predict future sustainable forest management strategies that minimise risk of decline or damage, and maximise carbon sequestration in forests in Europe. The preliminary results of the model run shows that European forests may act as a carbon sink sequestering about 10 % of present day carbon dioxide emissions. Measured above the canopy, a typical carbon budget of a managed forest ecosystem in Europe shows an annual carbon sequestration in wood products of 3 tons/ha, but this figure is reduced to

0.5 tons/ha per year when product decomposition outside the forest is taken into account. Future increases in atmospheric carbon dioxide concentrations are expected to increase the annual increment of trees, although there are examples where no such effect has been observed. On the other hand, respiration processes from plants and soil are also expected to increase if the temperature increases. It is therefore very difficult to predict exactly what the future carbon sequestration will be, especially taking into account the uncertainties which may appear as a result of future changes in water and nutrient availability. There is thus a link between the reduction in atmospheric emissions of air pollutants and processes related to climate change problems.

Conclusions

- Atmospheric inputs of air pollutants have negative effects on forests ecosystems, biodiversity, forest soils, surface and groundwater.
- Emission reductions are so far insufficient to prevent soil acidification in soils with low weathering capacity. Prediction models indicated increased disturbances in especially South America and Southeast Asia.
- Ozone is an important stress factor on trees in many areas of Europe and North America, and may also lead to acute damage.
- Nitrogen deposition has become increasingly important and dominates acidifying inputs to forests in many areas.
- Nitrogen and carbon cycles are strongly coupled.
- Nutrient imbalances are important stress factors on trees.
- Counter measures against soil acidification in the form of remedial fertilisation or liming may be needed on strongly acidified and sensitive forest soils.

Recommendations

- Despite the need for more data, the fundamental aspects of input of pollutants and nutrients to forest ecosystems are sufficiently well understood to necessitate additional measures for emission reductions.
- In order to reverse the acidification in already acidified regions, the emissions of sulphur and nitrogen compounds have to be decreased to a level that brings the deposition below the critical loads, i.e. the exceedance should be zero.
- The effects of atmospheric emissions in countries undergoing industrialisation should be counter measured via the experiences obtained in Europe and North America.
- In order to avoid future impacts of photochemical pollutants on forest trees and vegetation, nitrogen oxides and volatile organic compound emissions must be reduced to an extent necessary to reduce ozone levels below critical levels.
- Long term monitoring programmes should be kept running or established to keep track on the effects of emission reductions.
- Sustainable forest management practise should be applied, including maintenance of soil fertility and biodiversity of soil fauna, flora and microorganisms.
- Research on problems related to future global change effects should be intensified in order to be able to counteract the effects of increased carbon dioxide and the potential changes in temperature and water availability.
- Research co-operation between scientists in developing and developed countries should be intensified to help exchange of experiences.
- Large interdisciplinary research programmes should be established to solve the complex problems represented by air pollution and global change impacts on forest ecosystems.
- Education at all levels should be intensified to improve the general knowledge on issues related to atmospheric pollution and global change.

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Workshop: Forests after the Kyoto Protocol – Their potential role as sources and sinks of trace gases, especially carbon dioxide

Chairmen: Klaus Böswald, Bernhard Schlamadinger

The CO_2 concentration in the earth's atmosphere has increased from a pre-industrial level of about 280 ppmv to currently 365 ppmv, with a projected trend of further increase. This is caused mainly by CO_2 emissions from the combustion of fossil fuels such as coal, oil and natural gas. Additional contributions come from land-use changes, particularly deforestation in tropical regions. It is widely believed that the observed increase in global average temperature can be attributed to the enhanced CO_2 concentration.

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was adopted and later ratified by a sufficient number of countries to come into force in 1995. Its main objective is the stabilization of greenhouse gas levels in the atmosphere at a level that prevents dangerous interference with the climate system. As an initial step towards reaching this objective, the Kyoto Protocol was adopted in 1997. It is the first international legal framework that includes binding obligations for countries to reduce greenhouse gas emissions. It calls for a reduction of emissions by 5 % between 1990 and the 2008–2012 commitment period in industrial countries. In the absence of such a limitation, emissions are expected to increase by 15 to 20 %.

Forests and forestry are seen as part of the solution for reducing net CO_2 emissions. This can be achieved through five mechanisms:

- Increasing carbon stocks through improved sustainable forest management, afforestation or reforestation;
- increasing the carbon stored in long-lived wood products;
- forest protection to avoid the loss of carbon stocks through forest degradation or deforestation;
- using wood for energy to displace the use of fossil fuels; and
- using wood as raw material to displace the use of other, often more energy-intensive, materials.

While changing the stock of carbon in forests or wood products (options 1 to 3) are measures with limited capacity because stocks are limited in their size, the substitution of fossil fuels through the use of biomass products and fuels can be done repeatedly and within a closed carbon cycle (see Fig. 1). Carbon sequestration in forests and forest products do, however, offer cost-effective short-term opportunities for addressing climate change. A long-term, continuous strategy involving forests must build on the use of renewable products and fuels from the forest while trying to maintain biotic carbon stocks at high levels.

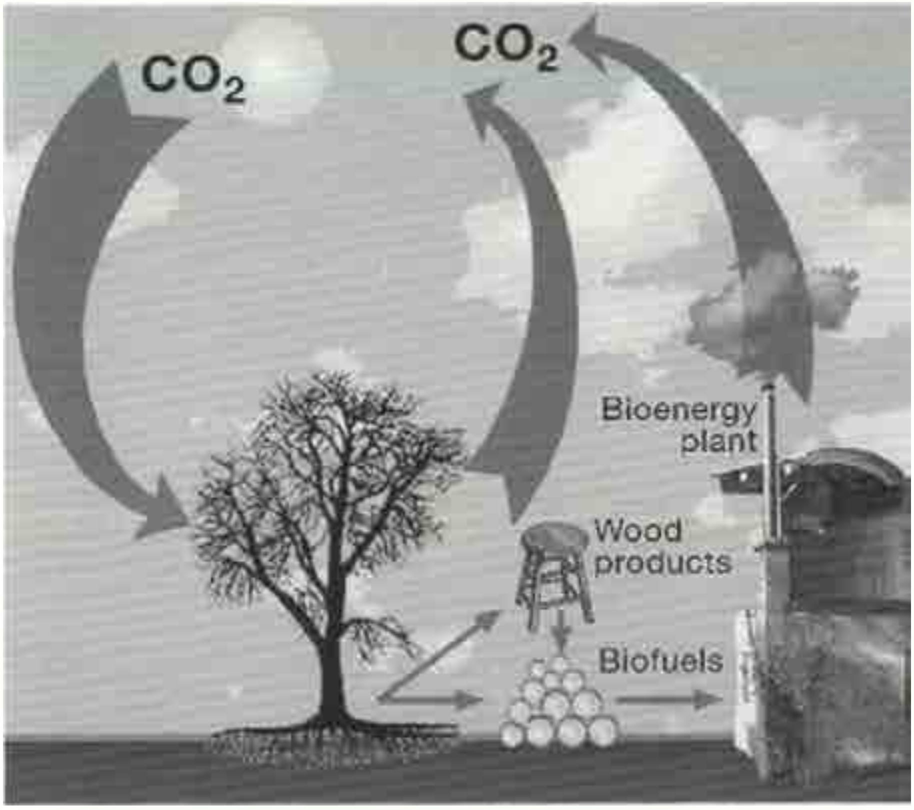

Fig. 1: Biomass use for wood products and biofuels is usually part of a closed carbon cycle, i.e. emissions from combustion and oxidation are offset by CO_2 uptake through photosynthesis.
(IEA Bioenergy, November 1998, www.joanneum.ac.at/iea-bioenergy-task25/pospapa4.pdf)

Forestry options in the Kyoto Protocol are currently limited to "afforestation, reforestation, deforestation since 1990" within industrialized countries (Article 3.3). Definitions for these terms have yet to be agreed upon, and the Intergovernmental Panel on Climate Change (IPCC) has been requested to author a special report on "Land use, land-use change, and forestry" to discuss many of the unresolved issues in the Kyoto Protocol. No doubt the above provision heavily limits the inclusion of forests. It is also clear that the choice of definitions for terms such as "reforestation" and "forest" will influence the amount of credits or debits resulting from Article 3.3, and that there are circumstances under which a country might report net emissions even though its carbon stocks and forest area have increased. Minimizing such unintended effects will be an important task when elaborating the modalities and rules for the carbon accounting under this international environmental treaty.

There is, in Article 3.4 of the Protocol, the possibility to negotiate additions of other forest-based activities. A decision on such additional activities will be made by early 2001. One of the reasons of limiting the inclusion of forests to certain activities in the first place was the disparity of data with respect to sources and sinks of carbon in forests. For example, it was shown in the workshop that results from flux-tower measurements of CO_2-uptake and from national inventories in Europe differ by a factor of about four. Selection of individual activities guarantees that carbon sinks can be measured and verified more precisely, and can be counted against emissions from other sectors of the economy without a significant increase in uncertainty. The limited approach does, however, complicate the carbon accounting.

The Kyoto Protocol also provides that one industrialized country can invest in forestry measures in another such country and thus claim credits for an achieved improvement (Article 6). The "Clean Development Mechanism" (CDM) in Article 12 provides for projects in developing countries to reduce emissions. The prime requirements for such projects under the CDM are 1) that they provide sustainable development and 2) that they are additional to any activities that would occur in absence of the project. Given that the legal text on the CDM mentions "reductions of emissions by sources", but not "enhancement of removals by sinks", there are negotiations pending whether and to what extent forests and forestry can be covered by this mechanism.

One of the contentious issues is the accounting of carbon sequestered in a project but released after project termination, for example due to harvest or natural disturbance. Workshop participants came up with several possible ways of addressing this issue, such as insurance policies which would create a replacement carbon sink, or to reward the climatic benefits of carbon storage by forestry on a tonne-year basis (i.e. as multiples of the value of storing 1 tonne for 1 year). The latter concept would give credit for temporary storage and after a certain time period, for example 55 years, the project would no longer incur a liability if the carbon happened to be released to the atmosphere. This can account for dynamic land-use systems in which the sizes of different carbon pools fluctuate – helping open-ended carbon management to allow for flexible land-use strategies (corresponding to changing needs), rewarding carbon benefits ex post if and when they are generated (and to the appropriate degree). Participants cautioned, however, that this approach might not be compatible with the current wording of the Kyoto Protocol. It might discourage forestry and land-use projects due to a delayed crediting of reduced emissions and enhanced removals, possibly resulting in a lower net present value of biotic mitigation projects.

If forestry and land-use projects are to be included under the CDM, they will need an integrative approach considering a variety of other objectives and functions besides carbon sequestration. Participants agreed that project success depends on more than the calculation and reporting of greenhouse-gas emissions and removals. Examples are (1) consistency with nationally defined sustainable development goals and objectives, (2) availability and building of sufficient institutional and technical capacity, (3) voluntary and equitable participation, (4) transfer of technology, and (5) risk management. Biodiversity, water availability and socio-economic circumstances need to be fully considered and are key components to the success of such projects.

While the workshop participants recognized that the Kyoto Protocol can have an important impact on global forests and forestry, they also stressed that there are various other processes that influence forestry decisions, such as world trends in consumption of wood products, market prices for agricultural and wood products impacting the relative attractiveness of forestry and agricultural land uses, trade agreements such as GATT or NAFTA, the possible EU expansion, etc. Forests are also subject to impacts of climatic changes, and to local pollution and natural events such as fire and disease. Carbon sequestration benefits will have to be seen as additional to other values and functions that forests already provide to society (e.g. soil protection), in order for carbon mitigation projects to be successful throughout their lifetime. Many of these projects are anticipated to last several decades.

The economic dimension of project-based options and emissions trading under the Kyoto Protocol is expected to be between 2 and 40 billion US$ annually. Most investments to date have been committed either shortly after the adoption of the UNFCCC, or after the adoption of the Kyoto Protocol in 1997. Carbon credits are a means of translating environmental services into financial revenues, but for a carbon market to develop, sufficient supply and demand of projects needs to arise. This is only likely to happen once there is clarification on which activities can be counted for carbon credits under the Kyoto Protocol, and how these credits will be assessed and assigned. Carbon credits need to result from a well thought through accreditation and certification procedure in order to create a credible market. The revenues are likely to be substantial and could promote a transition to sustainability and/or more sustainable forestry practices.

A comparison of forestry projects in different parts of the world (The Netherlands, Czech Republic, Ecuador, Malaysia and Argentina) reveals that projects in Europe are more cost-intensive due to greater labour costs and lower tree growth rates. It is essential that a full cost calculation of a project includes not only the direct cost of e.g. establishing and maintaining a new forest, but also the transaction and opportunity costs, and the costs incurred by the local community.

Most of the issues to date have been analyzed scientifically. Workshop participants emphasized the need for gaining valuable insights from ongoing projects. Therefore, the participants encouraged entities implementing projects not only to reveal their success but also to identify failures and mistakes. It was suggested that an evaluation of CDM projects could take place after 3–5 years and should go beyond a mere listing of technical details to provide a broader picture of the projects impact.

The Clean Development Mechanism, where it refers to projects for reduction of emissions from fossil fuels, will be of limited scope in African countries because emissions are still at a very low level. It is anticipated that investments in this region might be lower than in other regions unless land-use and forestry projects are admissible. It must also be acknowledged that the two purposes of the CDM, creating carbon credits and enabling sustainable development, require a careful balancing of the interests of the investor and of the country where the project is carried out. One needs to factor in the reality that the local population's interest is not mainly in carbon credits, but how they can potentially benefit from improvements with respect to economic opportunities, biodiversity, or water availability. For example, people in many communities depend on the use of wood for energy and basic material requirements. Establishment or improvement of village woodlots can be an attractive option that accommodates some of the needs that many developing countries face. Other attractive forestry options in Africa, and this holds true not only for tropical forests but also woodlands, include reduced impact logging, forest protection, fire management, and reforestation in commercial plantations and on degraded lands. In any of these cases it is important to build on existing initiatives, so that transaction costs as well as socio-economic and political risks can be minimized.

A presentation of large-scale impoverishment of Amazon forests showed that there are various socio-economic factors, including low incomes and inefficient logging practices, in combination with a change of the hydrological cycles, can lead to the repeated occurrence of forest fires which open up the forest for further development, finally leading to complete deforestation. In this respect the workshop participants viewed as important the recent change in the Brazilian position towards the inclusion of forestry in the CDM.

Although the discussions in the workshop sessions were mostly focussed on issues related to the Kyoto Protocol, it was also recognized that biotic sink and emission reduction projects can be based on voluntary initiatives. For example, consumers pay a slightly higher price for electricity produced from renewable sources or produced with an offset of CO_2 emissions through forestry projects. This shows, that biotic offset or mitigation projects can be successful even without international agreements such as the Kyoto Protocol.

In summary, the workshop made it clear that forests and forestry are important parts of a solution towards the mitigation of climate change. Key tasks in the near future are to protect existing forests from degradation and deforestation, to integrate sustainable forest management into project implementation and to enhance the use of wood for products and fuels where this can be done with high efficiency. Therefore, it is recommended that

1. full support be given to the further inclusion of verifiable forestry activities under the Kyoto Protocol that are consistent with sustainable development, provided that their inclusion does not undermine equally necessary emission reduction measures in the energy sectors;
2. the forestry and forest product industries continue to develop markets for wood with emphasis on promoting the use of wood as a renewable material and fuel, thus reducing the discharge of carbon from fossil fuels;
3. uncertainties over the role of forestry in the Kyoto Protocol be clarified; that rules, modalities and guidelines for project-based forestry activities be established; and that experience be gained from their application in concrete projects.

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Workshop: Forests as Protectors

Chairman: Rick Lawford

Introduction

The "Forest as Protectors" workshop dealt with forest interactions with the atmosphere, water and soils. Forests are viewed as protectors of the quality and quantity of water resources, maintainers of soil integrity, preventors of natural hazards, contributors to a stable climate, and sustainers of air quality and biodiversity. Forest interactions with their environments occur over a large range of space and time scales. Many misunderstandings in communication exist between researchers, the forestry community and the political body about the protecting functions of the forests. These misunderstandings occur because of failure to account for the difference in scales in the debate (local to global) and the conflict between short and long term interests/objectives of various stakeholders.

Foresters and hydrologists generally have very different perceptions of the impacts of forests on water resources. It is often part of foresters' "received wisdom" that forests increase rainfall, regulate flows, reduce erosion and flood hazards, sterilize water supplies and improve water quality. Hydrological research shows a much more complex picture that can be in conflict with these views. It is important that current hydrological knowledge is taken into account by foresters and land use planners to prevent the further occurrence of situations where forestry projects do not meet their expectations in terms of hydrologic benefits.

On the global scale the biosphere plays an important role as a regulator of global temperatures. For example, biospheric mass concentrations are correlated with historic global temperature changes for reasons that are not fully understood. According to model studies, deforestation in large tropical river basins can have major regional impacts. In the Sahel, land cover changes involving the removal of woody materials over large areas during the last 40 years appear to be related to significant changes in albedo that, in turn, have affected regional atmospheric circulation and rainfall patterns and an observed decrease in the discharge from the Niger River.

Similar changes are anticipated in the Amazon where deforestation has been proceeding very rapidly. The highly patterned forest cover resulting from Amazonian deforestation has implications for mesoscale circulations and the formation of convective cells and localized precipitation maxima. In many regions, changes in regional temperature and precipitation patterns associated with deforestation are as large as those projected by global models with a doubling of carbon dioxide. The inclusion of LSMs (Land Surface Models) that properly account for land surface processes including changes in carbon loadings are needed for more accurate assessments.

Forests are perceived as playing a critical role in maintaining soil and water quality, regional evapotranspiration, ground water levels and decreasing the vulnerability to erosion. Well structured experiments being undertaken in the United States and elsewhere are testing many of these widely held generalizations. In particular, the effects of clearcutting and forestry road construction have been documented. In general, the weight of scientific data from around the world supports an interpretation of modest to moderate forest linkages with key hydrologic processes. Hydrologists understand these effects but they need to ensure that this information gets disseminated.

Trees play an important role in stabilizing hillslopes where the friction angles of the landscape could lead to geomorphic slippage. For more gentle slopes, hydrologic factors appear to drive the landslip phenomenon. Through recent developments such as models, Geographical Information Systems (GIS) and high resolution satellite data landscape management decisions can be based on strong scientific inputs. Specific results from microscale studies in forest plantations and tropical environments demonstrate the importance of local forest processes such as local evapotranspiration, and the role of leaf type in splash erosion. These studies highlight that, to a large extent, each watershed is a unique biome and generalized statements about forest-hydrology responses are not always reliable.

Climate issues

On a global scale, the biosphere can be perceived as having a maximum mass capacity. Introduction of this concept: a) explains temperature variations in the Holocene and Eem epochs, b) provides another perspective on current temperature trends, and c) suggests that the changes in global temperature and biomass could happen quite abruptly due to non-linearities in the system. Studies based on introducing this non-linearity into a one-dimensional climate model suggest there may exist a critical forcing (CO_2-concentration) where global climate makes an abrupt transition to a higher temperature.

The removal of forests from the Sahel has had large effects on surface albedo which in turn has altered the atmospheric circulation regimes of the region. Furthermore, land surface degradation may be responsible for decadal regional climate anomalies in the Sahel. Changes in convective heating and latent heat flux are the dominant factors producing changes in the atmospheric circulation. Subsidence and a weakened monsoon flow account for the simulated rainfall reductions. Other consequences include: a) shifts in the rainfall patterns, b) less northward penetration by the ITCZ, and c) increased surface temperatures, and d) decreased precipitation and runoff in SW Africa.

The location of forests in different climate regimes determines the climatic consequences of deforestation. For example, in China (Mongolia) the climate does not appear to have the same sensitivity to land use change as in the Sahel due to the major influence of sea surface temperatures on China's atmospheric circulation.

Tropical Rainforests are complex multi-dimensional systems and integrated approaches for studying their functioning need to be explored, both through research and articulating their conserving and protecting functions. Synergies of integrated approaches in addressing these issues can lead to "win-win" situations for governments, the public, the private sector and the science community. An example of such synergy is the linkage between carbon and water cycles: deforestation will change the regional climate which in turn will impact on the soil capacity of carbon sequestration. Protecting these rainforests therefore has both direct and indirect (through climate feedback) impact on the (global) carbon balance.

The rapid deforestation in the Amazon has potential to influence large scale temperature and precipitation patterns and, in turn, runoff and sediment loading. Deforestation can affect local rainfall patterns through changes in latent heating and changes in aerodynamic resistance.

In addition to climate effects the loss of tropical rainforests also eliminates their protecting functions. Their effectiveness in conserving fresh water and storing carbon (approx. 1–4 tonnes/ha/yr of C) is decreasing. No longer will these forests remove pollutants from the atmosphere, but through deforestation practices employed in the Amazon that forest actually contributes to the particulate loading of the atmosphere. Furthermore, the removal of this forest destroys one of the main depositories of the world bio-diversity resources.

One study addressing these issues is the Large Scale Biosphere Atmosphere (LBA) experiment in Amazonia (1997–2005). It is the first example of an integrated large scale study into the functioning of tropical rainforest systems and the effects of landuse changes in the tropics (deforestation) at regional and global scales. LBA will provide data, models, scientific understanding and techniques, and strategies to support the sustainable management/development of the Amazonia forest by safeguarding and protecting functions for both regional and global environmental systems.

Hydrology issues

The influence of forest practices on water resources depends on the long-term use of forests themselves and short-term management interventions. In tropical rainforests, deforestation is often the first step in converting forests to agricultural land. This was also true for the Mississippi River Basin when forests were removed and grassland ploughed during the previous century to provide land for agriculture. The consequences these land use changes frequently involved changing temperature, precipitation and runoff patterns, altered ground water regimes and increased erosion. Modeling studies for the Mississippi River Basin have suggested that these changes have been significant.

However, in the Pacific Northwest of the US, forests are viewed as biospheric reserves and logged forests are replaced by forests. This leads to the implementation of environmentally friendly afforestation practices and some longer term monitoring activities. This monitoring has clarified the existence (or non-existence), magnitude and duration of some of the effects generally assumed to be associated with deforestation. When deforestation occurs, annual water yield appear to increase on small to medium size watersheds. In the Pacific Northwest the effects last until vegetation regrows.

In clearcut areas, larger snow accumulation and more rapid spring melt occur, leading to higher peak spring flows. Watershed responses to rain events indicate that for medium size events, peak flows are higher. However, surface vegetation appears to have no significant influence on large flood events. Forestry roads have significant influences on drainage, flood patterns, and erosion rates. The construction of forestry roads tends to increase runoff. The effects are dominated by subsurface flow, and influenced by road location and orientation. The practices of clear cutting (patches) and road construction enhance peak flows of medium floods in an additive way. Forestry roads also contribute to enhanced erosion (especially during construction).

The role of forests as protectors relative to erosion processes is strongly conditioned by its biogeoclimatic context. Based on these findings it is clear that there is a requirement for an expanded emphasis on harvest and road effects across a range of biogeoclimatic settings with particular emphasis on a) tropical sites, b) areas with high erodible bedrock and soils, c) areas of extreme rainfall, and d) areas where expanded development is planned.

The occurence of landslips (mudslides, debris flows) depends on precipitation inputs and the landscape slope. In areas where geomorphic slip is possible, forests can play an important role in stabilizing the slopes. For areas of medium slope the potential landslip is dependent on hydrology. In these areas the evidence that forest plantations protect against landslips is not conclusive.

Models play an important role in assessing hydrologic and geomorphic impacts. Models can be used to predict the location of potential failures on a hillslope, based upon local topographic setting. Although the forest effect is not yet explicitly taken into account in these models, they are being adopted by local authorities in some areas (e.g. Oregon Department of Forestry, California Division of Mines and Geology) to delineate possible scenarios resulting from deforestation. One such model developed in the US has been applied in Italy, where it successfully explains effects of past deforestation on landslips.

At the micro (tree) scale in tropical forests, evapotranspiration is controlled by advection, radiation, physiology, tree size, soil moisture and drop size. Evapotranspiration in forests is generally greater on an annual basis than in shorter crops in both wet and dry environments. For wet temperate forests (e.g. Plynlimon, Wales) two thirds of the total evaporation can result from the evaporation of water intercepted by the canopy (the other third coming from direct transpiration). The relative role of transpiration increases in importance in dry climates. Some tree types produce much higher evapotranspiration rates due to their high water use. In particular, eucalyptus trees can have a very significant impact on water resources. In India, their roots have been shown to deplete soil water to a depth of 9 metres within two and a half years of the date of planting.

In summary, the workshop highlighted the need to consider forest hydrology linkages on all scales before formulating forest management strategies. This need for providing this information can best be met through long term monitoring programs, specific observational initiatives and modeling studies. The need for this information is becoming more critical as population pressures increase the demands for deforestation and alternative land use on one hand and interests in carbon sequestration increase demands for afforestation on the other.

Based on these deliberations the workshop recommended:

1. In modeling the global atmosphere, the role of the biosphere in abrupt climate change should be understood and represented.
2. Deforestation and desertification effects extend beyond national boundaries though their influence on regional and global atmospheric circulation regimes leading to temporal and spatial shifts in rainfall patterns. The study and arbitration of these effects must have an international dimension. Consideration should be given to a joint WCRP/IGBP initiative to address this issue.
3. The influence of climate change on forests and deforestation impacts need to be better understood. The effects of land use changes on temperature and precipitation must also be quantified and their relationship to CO_2-induced climate change be clarified, the interactions and feedbacks between water and carbon cycles need to be quantified and incorporated into models. Furthermore, the degree to which current warming trends are related to deforestation and land use change rather than greenhouse effects should be determined.
4. Models are useful in predicting vulnerability, trends and possible effects of land use management on forests, their soils and local water resources. This is particularly evident in the atmospheric and hydrologic fields. Improved modeling tools are needed to permit the analysis of alternative landscape designs and development schemes that influence streamflow, groundwater, and natural hazards. However, models to support decision making also need to include information on the uncertainties, limitations and the degree to which they can be generalized.
5. Based on recent studies it is clear that some of the generalized perspectives on the values of forests for water resources are site-specific and do not always account for regional biogeographic differences. In cases where after-cut areas are being managed to maintain soil structure, options for afforestation should also be considered in an ecosystem context.
6. The broad role of forests in local water management should be considered in all managed forests. Long-term monitoring and related research are needed to provide the scientific basis for such strategies.
7. A global data base including the data sets and analyses from instrumented small watershed studies should be developed. Existing watershed networks (i.e. Long-Term Ecological Research sites, Benchmark sites) should be used as the foundation for this database. It could be set up along lines of WMO protocols for meteorological stations. The UNESO/WMO Hydrology for Environment, Policy and Life Programme (HELP) is a possible opportunity for this initiative.
8. Given access to soil water, eucalyptus trees are generally found to have both high water use and high growth rates, and on a plot basis, high water use efficiencies. The challenge for the future is to design sustainable forestry systems for eucalyptus which minimize some of the adverse hydrological impacts and which are compatible with social and economic needs.

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Congress Programme

Friday, 2 July 1999

Schreiner, Johann	Opening Address
Innes, John	Introduction into the forum
Rasmussen, Lennart	Introduction into WS Forests under mixed inputs of pollutants and nutrients
Böswald, Klaus	Introduction into WS Forests after the Kyoto Protocol
Lawford, Rick	Introduction into WS Forests as Protectors

Workshop Forests under Mixed Inputs of Pollutants and Nutrients

Thörnelöf, Eva	The Global Exposure of Forests to Air Pollutants
Tybirk, Knud	Critical Loads and Levels, incl. Sulphur, Nitrogen and Ozone

Workshop Forests after the Kyoto Protocol

Schlamadinger, Bernhard	Forests under the Kyoto Protocol - State of the Art, Issues and Possible solutions
Nabuurs, Gert-Jan	Accuracy of Long-term Forest Resource Projections of the European Forests

Workshop Forests as Protectors

Lawford, Rick	Overview of forests and hydroclimatology and issues analysis framework
Grant, Gordon E.	Deforestation and erosion/flood vulnerability
Calder, Ian R.	Forests and water resources
Grant, Gordon	Effects of logging on floods in the US Pacific Northwest (by Prof. Dennis Lettenmaier)

Saturday, 3 July 1999

Strich, Sigrid	Welcoming Address
Berndt, Hartmut	Welcoming Address

Key-notes

Kabat, Pavel	Landuse and Effects on Climate
Wassmann, Reiner	Forests as Sources and Sinks for Greenhouse Gases
Beese, Friedrich O.	Forests as Filters and Buffers of Pollutants
Baur, Robert	Development of the CO_2-Problem from the Point of View of a Regional Energy Supplier
Calder, Ian R.	Water Resource and Forestry Issues
John Joseph, S.	Forest and Water Supply
Sah, Shambu Prasad	Present Status of Air Pollutants Deposition and their Impacts on Vegetation in South East Asia
Lindner, Marcus	Scenario on Regional Impacts of Climate Change on the Forests in the Federal State of Brandenburg
Schröder, Günter	Groundwater Protection Strategies of a Water Supplier

Sunday, 4 July 1999

Workshop Forests under Mixed Inputs of Pollutants and Nutrients

Erisman, Jan Willem	Nitrogen Deposition, Turnover and Effects in Forests
Nihlgaard, Bengt	Effects of Soil Acidification, Aluminium Toxicity and Base Cation Depletion on Forests
Schaaf, Wolfgang	Effects of Alkaline Dust versus Acid Deposition in Scots Pine Ecosystems of Eastern Germany
Mohren, Frits	Global Change Effects on Forest Ecosystems
Erhard, Markus	Growth of Pine Forests-Ecosystems (*Pinus sylvestris* L.) under Changing Climate and Pollution Stress
Rode, Michael	Natural Forest Development – Pattern of Forest Management?

Workshop Forests after the Kyoto Protocol

Böswald, Klaus	Emission Reduction via Forest Protection – A Case Study from Argentina
Jones, G.	The Kyoto-Protocol and the Forestry Sector: Creating an efficient Certification and Verification Framework
Moura-Costa, Pedro	Economic Dimension of Project-based Forestry Options under the Kyoto Protocol
Emmer, Igino	Monitoring and Research: Quantifying Carbon Offsets in FACE Reforestations
Karjalainen, Timo	Afforestation, Reforestation and Deforestation: A Review for EU Countries and Nordic Countries
Cochrane, Marc	Large Scale Impoverishment of Amazonian Forests by Logging and Fire
Frost, Peter G. H.	Forests in Africa: Options for Sustainable Development and Climate Change Mitigation

Workshop Forests as Protectors

Xue, Yongkang	Deforestation and Climate Effects
Gassmann, Fritz	Potential of Forests to Control Regional and Global Climate by Evapotranspiration
Kabat, Pavel	Protecting the Amazon Forest in the Context of the LBA Experiment
Lawford, Rick	Deforestation and Migratory Pathways (by Dr. Gay Bradshaw)
Casadei, Mauro	Hillslope Hydrology, Landuse and Shallow Landslides Initiation
Lawford, Rick	Response of High Rainfall – High Runoff in tropical catchments in Northeast Queensland Using Environmental Deuterium as a Tracer: A Monsoon Storm Case Study (by Dr. Mike Bonell, UNESCO, and Dr. Christopher Barnes, CSIRO, Australia)

Monday, 5 July 1999

Additional Contributions. Chairman: Jens Brüggemann

Münzenberger, Babette	Some Effects of N on Ectomycorrhizal Diversity of Scots Pine (*Pinus sylvestris* L.) in North-eastern Germany
Beyse, Rudolph	An Interim Balance after 15 years of Survey of New Types of Forest Decline throughout the Federal Republic of Germany

Presentation of Posters

Asche, Norbert	Waldkalkung mit Asche / Der Wald hat Hunger
Blum, Oleg	Ozone Air Pollution in the Ukrainian Carpathian Mountain Forests
Bredemeier, Michael	Results of Research in Forest Ecosystems
Busch, Gerald	Forest Ecosystems and the Increasing Nitrogen Input and Acid Deposition under Changing Atmospheric CO_2 Concentration – A Global Overview
Claassen, André	The Robinia Foundation & its Goals and Strategies
Metzger, Matthias	The Planned Forest-Water-Demonstration Path in Soltau

Opening Address

Johann Schreiner

Ladies and Gentlemen

It's a pleasure to welcome you to this Forum on "Forests and Atmosphere, Soil and Water". Welcome in the name of the Alfred Toepfer Academy for Nature Conservation and the co-organizers

- the German Association for the Protection of Forests, today represented by Mr. Gerd Bosse and Hartmut Berndt
- the Forestry Commission of Lower Saxony, today represented by Mr. Jörg Bode
- the Soltau-Fallingbostel district, represented by Prof. Gottfried Vauk
- and the Waldforum 2000 Association, represented by Mr. Klaus Forstmann and Mr. Michael Wedler.

This is the fourth Conference during the series of fora dealing with the earth's forests on the threshold of the third millennium and in the run-up to the EXPO 2000 in Hanover.

This conference would not have been possible without help and support of numerous Persons:

First of all Mr. Karl-Heinz Funke, Federal Minister for Food, Agriculture and Forestry, who became already patron of the WorldForum on Forests when he was Minister in Lower Saxony. Tomorrow Ms. Sigrid Strich will deliver his message of greetings.

Then I have to thank the members of the International Advisory Board. They act as guarantors for the specialist quality and the internationality of the fora.

It's a special pleasure to welcome the present members of the steering committee, who launched the programme of this conference. Especially our colleagues from Göttingen University, represented by Prof. Friedrich Beese and Dr. Michael Bredemeier.

But what would such a conference be without financial support? Many thanks for funding and sponsoring to the German Federal Foundation for Environment, the Environmental Foundation of Lower Saxony, the EXPO 2000 p.l.c., the Alfred Toepfer Foundation F.V.S., the Association of the Friends and Supporters of the Alfred Toepfer Academy, the municipal services of Hanover and Schneverdingen, the EWE energy supplying company, the IDUNA Nova insurance company, the Harz Water Company and the EFFEM p.l.c.

Last, but not least the speakers, the chairpersons of the plenary sessions and the workshops, decisively contribute to the success of the conference. As representative of these persons many thanks especially to Prof. Dr. John Innes, Faculty of Forestry, University of British Columbia, Vancouver, Canada.

After dealing with "Forests and Energy", "Forests and Biodiversity", "Forests as source of raw materials" today and the next 3 days are under the sign of the interrelationships between the forests and their environment, the atmosphere, the soil and the water.

Today we know that on the one hand climatic factors are influencing the composition of the tree species and the growth of trees in forests; and on the other hand forests are major factors in the Micro- meso- and even the macroclimate.

By combustion of fossil energy sources and the global destruction of forests the carbon dioxide concentration in the atmosphere is increasing. Carbon sequestration is necessary. What's the potential for carbon sequestration in the existing forests and to what extent can it be increased by afforestation, maybe compared to other carbon sinks such as peatlands. Is there a relevant effect of different forest management types?

The relevance of the carbon dioxide concentration for the greenhouse effect is clear. But this forum should bring us nearer to answering the question if the causal chain "increase of CO_2" means "increase of greenhouse effect" and this means "global warming" is existing.

We consider a world-wide increase of the emissions of sulphur dioxide, nitrogen oxides, hydrocarbons and chlorofluorocarbons. We know, that there are negative effects on forest ecosystems. But this forum should bring us nearer to answering the question about the quantitative effects.

It seems that reduction of the emissions of the hazardous gases mentioned before in Germany has reduced the increase of the "Waldsterben". We have to answer the question if this is right and what we can learn from this for the situation in some developing countries where air pollution is still increasing.

There are not only very close interrelationships between forests and atmosphere. The qualities of soil and water are influenced by forests. Worldwide water is the fastest decreasing natural resource both in quantity and quality. We have to analyse the effects of forests as reservoirs of water, combined with the effects of evaporation by trees. But we have also to calculate the effects of extracting water for drinking water on forests. We have to answer the question about the influence of forests on the global distribution of rainfall.

We have to show the filter and buffer effects of forests on groundwater quality and have to answer the question about the carrying capacity concerning airborne pollutants.

We basically know about the regulation effects of forests in the catchment areas of rivers on the discharge regime. But we have to know more about the quantitative effects. We have to learn about the effects of deforestation in Middle Europe in the past two thousand years. These effects were not only influencing the landscape water balance. We know, that effects on soils were dramatically. Soil erosion in upstream catchment areas caused by deforestation was the reason for the thick alluvial loam layers in the inundation areas downstream.

Forests enhance the formation of new soil and protect it from erosion by water and wind. This forum should concentrate on the main problems of protecting soils by sustainable forestry. It should provide answers from international case studies which can be implemented by new forms of land use planning.

Ladies and gentlemen, there are a lot of questions which have to be answered the next 4 days; not only answered by scientists but also by practical persons of the land using disciplines, especially forestry water suppliers and high emission industries, by government and state representatives and authorities, by the representatives of environmental organisations and experts from media.

In dialogue between all parties concerned the forum should elaborate recommendations or conclusions on sustaining the functions of forests as regulators in energy fluxes and matter cycles.

We have to integrate the existing knowledge together with the various utilization aspects and we have to prepare the results for the wide public. Your presence, ladies and gentlemen, shows, that we are on the right way. The evaluation of the results, the response of the public will show later, if we succeeded in building bridges between the different parties concerned for the benefit of future generations.

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Welcoming Address

Sigrid Strich

Ladies and Gentlemen,

I wish to convey to you the best regards of the Federal Minister for Food, Agriculture and Forestry, Mr Karl-Heinz Funke, who has assumed the patronage over the entire series of events. I am pleased that you have accepted the invitation to the Forum "Forests and Atmosphere – Water – Soil" in such a large number.

We started yesterday and in the days to come we will continue intensive discussions on the role our forests play for the environment and for element cycles at the local as well as the global scale. I do not wish to enter into the details of scientific discussion, but to make some fundamental observations, referring to a text written by the Swiss author and cabaret artist Franz Hohler. What he says in his "Ballad of the end of the world" can roughly be summarised like this:

The end of the world will start with the extinction of an inconspicuous small beetle somewhere on a remote island in the Pacific. The population will be happy about the disappearance of the beetle as this was a rather annoying beetle living in the dirt and giving man itching allergies.

Yet, the extinction of this species will trigger directly or indirectly the extinction of other animal species. Fishing yields will decline and crop failures occur in agriculture because the biological control agents will be missing all of a sudden. First prices will be rising, then a food crisis will follow.

In a crazy association of chains of cause to effect, positive feed-backs and entirely unexpected interactions, in an ever faster spinning spiral of disastrous events, the author attributes global climate change, natural disasters, streams of refugees and armed conflicts up to the apocalyptic finale to the extinction of the small beetle.

The story makes two points:

- first: why the small beetle disappeared has not been cleared up scientifically yet.
- secondly: perhaps the end of the world has already started – with the extinction of an inconspicuous animal or plant species somewhere on the globe.

Ladies and Gentlemen, this story very graphically points out the following truths:

We live in a networked world. With everything we do or don't do, we share the responsibility for developments unfolding in far-off places. On the other hand, developments in distant parts of the world can exert effects here, just think of the destruction of tropical forests and its effect on atmospheric CO_2 and climate change.

What matters more than ever in our networked world, therefore, is to think in a wider context and to bring the sustainability principle to fruition. In doing so, the precautionary principle makes it necessary to take action against harmful developments even before the scientific relations have been explored down to the last detail.

The Federal Government is convinced that we have to incorporate the concept of sustainability, which arose over 200 years ago in European forestry, more strongly than ever into all fields of human thinking and action.

Under the motto "think globally – act locally" we must start with this in our own country.

Within his competence, the Federal Minister of Food, Agriculture and Forestry is actively involved in developing a sustainability strategy of the German Government.

Yet, we also have to share in the responsibility for a sustainable development beyond our borders. The 1992 Earth Summit in Rio was an encouraging start.

It led, inter alia, to the Convention on Biological Diversity, to the Framework Convention on Climate Change and to the Convention to Combat Desertification, which were ratified by Germany. Germany set itself particularly ambitious objectives in the climate sector.

All of these Conventions contain references to the conservation and sustainable management of forests.

In Rio, the community of nations also adopted the forest principles, which are not legally binding, however. Furthermore, with Agenda 21 the states having gathered in Rio drew up a set of obligations for implementing sustainable development, with a separate chapter being devoted to forests.

According to the Federal Government, we should not be content with this. The valuable concepts of forest conservation world-wide should be developed further. They should, if possible, result in a comprehensive agreement on the conservation and sustainable use of all forests, which is binding under international law. Together with our partners in the European Union, the Federal Government champions this aim.

Ladies and Gentlemen, may I also request your support for this endeavour.

Thank you for your attention. I wish us a successful meeting with many fruitful and enriching discussions.

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Welcoming Address

Hartmut Berndt

About six years ago the first ideas were developed for the contents of the World EXPO 2000 in Hanover. It was inspired by the outcome of the United Nations Conference on Environment and Development in Rio de Janeiro, 1992.

Sustainability was awakened in the global consciousness. Concrete measures for the solutions to the serious global environmental, economic and social problems were proposed.

EXPO 2000 promises to offer a platform for the discussion of new perspectives for the coming millennium.

The organisers feel that forests are an essential topic to be included at the EXPO 2000.

There are three important reasons for this:

- first: the principle of sustainability is derived from forest management systems which prove that sustainable management of ecosystems is possible; forests therefore have a great exemplary value for other sectors. Forests can be used as a source for a wide range of renewable raw Materials and products, which play an important role in sustainable systems
- second: in a world-wide view forests and woodlands are one of the resources that are most severely threatened by unsustainable practices. Direct destruction reduces forest area dramatically, and the high input of pollutants and emissions have threatened and damaged our forests.
- third: there is an obvious interrelation between forests and other natural resources, for example: drinking water, clean air and fertile soil. Serious problems like climate change, the increasing number of floods and storm disasters are partly caused by the destruction or loss of woodlands.

This forum is one of a series of discussions about the importance of forests for sustainability. We started with the forum titled "Forests and Energy" in January 1998, in July last year participants from 35 nations met here to talk about "Biodiversity Treasures in the World's forests", in May this year our subject was "Forests as Source of Raw Materials" and in November we are planning to continue with the forum "Forests and Society".

In all these fora we followed a new principle: it was our aim not to focus on specific scientific aspects of forestry problems and subjects alone, but to discuss these problems in a social, economic and ecological context. It is part of our philosophy to invite people from very different backgrounds, who do not often have the opportunity to meet.

We have welcomed not only forest scientists but also representatives of industry, environmental organisations, of water and energy suppliers, politicians etc.

It may be more difficult to find a consensus on future actions within such a heterogeneous group, but we think that it gets more important to include a wide diversity of opinions and interests.

With globalisation, economic interests increasingly dominate political actions. But it is essential to have a realistic balance between economic, environmental and social aspects. We need to communicate effectively the consequences of unsustainable management practices. We need to work with other groups in our society to find new acceptable solution.

The organisers hope that this forum contributes to this aim. It is our goal to provide the best possible environment for fruitful discussions for you. Let us know how we can better provide for your needs.

Finally, we are very happy that so many participants followed our invitation into the Luneburg heath. The Luneburg heath may be a warning example which shows what happens when we do not use forests in a sustainable way. Total destruction was the result. Many pictures and descriptions illustrate the large scale devastation of this area. The situation seemed to be hopeless, but by extraordinary reforestation efforts the landscape came back to life. This gives us hope that solutions can be found through creative efforts.

We wish, that some of this hope will be reflected in the results of this forum.

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Key-notes

Forests as Sources and Sinks of Greenhouse Gases: An Overview

Rainer Wassmann and Hans Papen

Introduction

Forest systems cover more than 4.1×10^9 ha of the earth's land area and play a prominent role in global biogeochemical cycles (*Allen* and *Barnes*, 1985; *Ludeke* et al., 1990; *Myers*, 1995). In particular, their contribution to the greenhouse effect has gained growing attention over the last years (*Jones* and *O'Neill*, 1993, *Fujisaka* et al., 1998). In Amazonia, the sheer size of deforestation that has raised concern on the impact for the carbon burden of the atmosphere (*Malingreau* and *Tucker*, 1988; *Fearnside*, 1990). Forest fires in Southeast Asia were exacerbated by drought and atmospheric conditions brought on by the El Niño weather phenomenon of 1994 and 1997 (*Goldammer*, 1998).

However, the significance of forests for the greenhouse gas effect goes beyond the immediate release of carbon dioxide (CO_2) from fires. Outside the tropics, the net-effect of forests may in fact be positive with regard to greenhouse gas emissions. While temperate and boreal forests were historically a very large source of atmospheric carbon, they are presently estimated to be a carbon sink (*Kauppi* et al., 1992). Fertilization through air-borne nitrate and ammonium stimulate plant growth that may further be spurred by enhanced CO_2 levels in the atmosphere. It has often been postulated that forest growth corresponds to the 'missing sink', i.e. an unknown sink needed to balance the global carbon cycle (*Houghton* et al., 1996).

Forests of different climatic regions act as sources of nitrous oxide (N_2O) and nitric oxide (NO) and as sinks of CH_4. These trace gases are produced or consumed by the soil microflora. Conceptually, the greenhouse gas balance of forests can be divided into three components (Fig. 1), i.e. (i) fluxes of N_2O/ NO/ CH_4, (ii) CO_2 emissions through deforestation, and (iii) CO_2 deposition in form of carbon sequestration. The interactive effects of all these factors on the world's forest regions differ among geographic regions and forest types.

N_2O/ NO/ CH_4 fluxes

N_2O contributes app. 6 % of the anthropogenic greenhouse gas emissions (*IPCC*, 1996). Due to the long residence time of N_2O (132 years) and the continuous increase in concentrations (0.25 % per year) it seems likely to assume an increasing significance of this greenhouse gas in the future. Soils are an important source of N_2O; the microbial processes of nitrification and denitrification occurring in soils contribute ca. 60–70 % of global sources (*Rennenberg* et. al., 1996).

However, the accuracy of the estimates of N_2O emissions from forests is still constrained by (i) low number of forest sites studied, (ii) high sampling frequency and long duration required for compiling annual budgets of N_2O fluxes, and (iii) scarcity of comparative studies conducted at different forest ecosystems. Furthermore, the understanding of the underlying processes involved in the N_2O budget, i.e. nitrification and denitrification, is still insufficient.

The trace gas NO is oxidized in the troposphere to nitrogen dioxide (NO_2) that is – in turn – converted back to NO (*Hansen* and *Lindbergh*, 1991). These gases that are collectively termed as NO_x play important roles in the chemistry of the stratosphere (i.e. depletion of the ozone layer) and the troposphere (formation of photosmog). Wet and dry deposition of NO_x imply diverse ecological consequences such as acidification of soils and freshwaters as well as the increasing over-supply of macro-nutrients in natural ecosystems.

The global sources of NO are insufficiently quantified; microbial emissions from soils may roughly account for 15 to 50 % of the total source strength (*McKenney* and *Drury* 1997). The pronounced uncertainty is attributed to various factors such as the limited data base on field studies over sufficient observation times. The net-release of NO

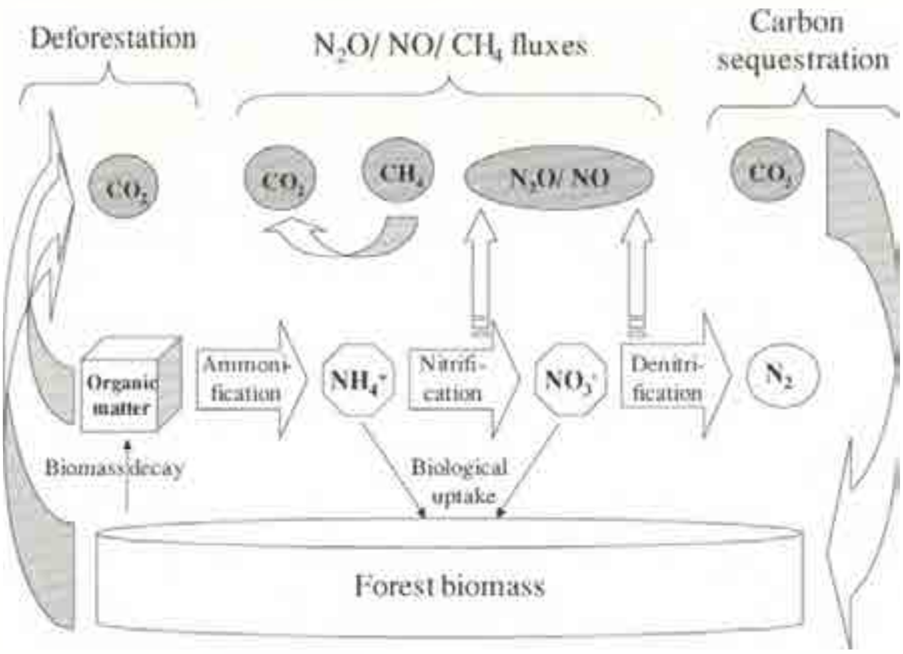

Fig. 1: Schematic view of the processes involved in emission and deposition of greenhouse gases in forest systems.

from forests is further compounded by the uptake through the forest canopy, requiring a correction the flux rates from soil by a 'canopy-reduction'-factor of NO emission (*Hansen* and *Lindberg*, 1991).

In contrast to wetlands, forest soils act in most cases as a sink for CH_4. (*Crill*, 1991, *Butterbach-Bahl* et al., 1998). Flux rates depend on the ability of soil microorganism to consume CH4 at atmospheric concentrations. This sink is globally estimated at 30 ± 15 Tg per year corresponding to annual increment in the atmospheric methane burden (*IPCC*, 1996).

Various factors affect the microbial processes involved in the budget of N_2O, NO and CH_4 (*Bouwman*, 1990). Different forests show inherent differences in emissions and depositions of these gases related to composition of tree species. Deciduous forests emit more N_2O than coniferous forests whereas the reverse was found for NO (*Butterbach-Bahl* et al., 1997).

Increasing N inputs drastically change microbial activities involved in nitrification, denitrification, and methane oxidation in pristine forest systems. Vast areas of temperate forests have already shifted from nitrogen limitation to saturation. This surplus of nitrogen that cannot be fixed in the system by vegetation or microbial immobilization may be released to the atmosphere in form of NO. At the same time, high inputs of nitrate and ammonia reduce CH_4 consumption in forest soils (*Butterbach-Bahl* et al., 1998). Soil acidification as well as its combat through lime application showed strong effects on microbial activity as well as N_2O/ NO and CH_4 fluxes. Liming of a spruce forest resulted in a reduction of NO emission, but significantly enhanced N_2O emission rates (*Butterbach-Bahl* et al., 1997).

CO_2 sequestration

In most developed countries, the rate of forest clearing for crop cultivation and pasture slowed in the late 19th century and has virtually ceased in the first half of the 20th century (*Houghton*, 1998). Improved forest management practices and the regeneration of previously cleared forest areas have resulted in an annual net uptake (i.e., sequestration) of carbon. In addition to forest regeneration and management, forest harvesting and timber use have also affected carbon pools (*Ehrlich*, 1996). Because most of the timber that is harvested forests in the developed countries is used in wood products, significant quantities of this harvested carbon are transferred to long-term storage pools rather than being released to the atmosphere.

During the 1980s, forests in the Northern Hemisphere sequestered about 140 million metric tons of CO_2 per year corresponding to 7 percent of global CO_2 emissions from anthropogenic sources (*Houghton* et al., 1995). With more CO_2 in the air, plants typically increase their photosynthetic carbon uptake, resulting in greater biomass production. Coniferous and deciduous trees increased their biomass by 130 % and 50 %, respectively, in response to a doubling of the air's CO_2 content (Saxe et al, 1998). In the next step, higher CO_2 levels result in higher carbon allocation to the soil (*Gorison*, 1996). The incremental growth in response to higher CO_2 levels will decline within 5 yrs given a constant nutrient supply (*Comins* and *McMurtrie*, 1993). Because most forest systems are nitrogen limited, the incremental growth of forest is closely linked to actual nitrogen inputs, namely atmospheric depositions.

Higher atmospheric concentrations of ammonia and nitrate (stemming from fossil fuel consumption and agricultural sources) lead to enhanced deposition of nitrogen compounds that directly translates into higher plant biomass. Increased above-ground production may result in a proportional buildup of the soil carbon pool as shown for coniferous forest (*Nilsson*, 1995). However, the interaction among vegetation and soil in response to enriched nitrogen and CO_2 availability is complex and deserves specific considerations for different forest systems (*McGuire* et al., 1995).

The amount of carbon that could be stored in terrestrial vegetation due to added nitrogen range from 100 to 1,300 Tg C per year, but the actual amount of carbon sequestered through this process is highly disputed (*Nadelhoffer* et al., 1999). Atmospheric deposition of nitrogen compounds is not evenly distributed over the globe. Temperate and boreal forests located in Central Europe and Eastern Asia receive high doses of airborne nitrogen, locally exceeding 5 g $Nm^{-2}yr^{-1}$ (*Lammel* et al., 1998). Other forest areas, especially those with a very high growth potential throughout the annual cycle, are virtually unaffected by anthropogenic nitrogen inputs.

CO_2 emission through deforestation

Rain forests are being destroyed at an alarming rate that poses a major threat on global biodiversity and the carbon budget. At current deforestation rates, the world forest resources would extinguish within 100 years (*Skole* et al., 1998). However, deforestation is not a uniform process in different locations – deforestation happens by different methods, at different rates, and in different time scales. The bulk of deforestation in the tropics is associated with agricultural land use for grazing of cattle and planting of crops. "Slash and Burn" practices encompass logging of relatively small areas followed by burning. In traditional shifting cultivation, the land was used for two to four years before farmers moved on to clear a new patch of forest. The short cropping period followed by a long fallow (for up to 60 years) restored carbon and nutrients to the system. Increasing population pressure jointly with better access of remote forest areas has adversely affected the long-term equilibrium in the carbon budget of these systems alternating between forest and agriculture use. Commercial logging of rain forest – though often limited in space – may markedly accelerate deforestation rates by making remote places accessible for further use. Large-scale conversion of rain forests is commonly found in Southeast Asia for palm trees and in South America for pasture (*Kummer* and *Turner*, 1994, *Fearnside*, 1993).

The estimates on the area affected by deforestation rates differ largely. The FAO assesses the global area affected by deforestation in the tropics 15.4 × 10^6 ha yr^{-1} during the 1980s (*FAO* 1993). However, rates of deforestation vary from region to region and show pronounced changes over time. In the Brazilian Amazon, the deforestation rate was around 1.8 × 106 ha yr^{-1} from 1978–1986, but fell to 1.4 × 106 ha yr^{-1} from 1986–1993 (*Skole* and *Tucker*, 1993). Massive fires in Southeast Asia devastating ca. 4.5 10^6 ha of forests during the El Niño year of 1997 were thoroughly published in international media.

As a consequence of different area assessments, the estimates of carbon emission associated with deforestation are also uncertain. Historically, the loss of forests (in boreal, temperate and tropical regions) has accumulated to app. 122 × 109 metric tons of carbon into the atmosphere from 1850 to 1990 corresponding to app. 20 years of fossil fuel consumption at current rates (*Skole* et al., 1998). Presently, the carbon release through deforestation is estimated to be 1.6 billion metric tons of carbon per year (Skole et al., 1998) corresponding to app. 25 % of fossil fuel consumption. According to a recent study, however, the emission estimates derived from satellite imagery may underestimate the forest damage in Amazonia due to smaller fires that are concealed by the forest canopy (*Nepstad* et al., 1999).

Several field studies have focused on the immediate effects of deforestation, while the recuperation patterns of carbon stocks and carbon fluxes within a ensuing land-use systems or secondary forest is less known. Fires and logging in Amazonia do not only release about 0.3 billion tons of carbon into the atmosphere, but also impoverish the soil in large section of the Amazon basin (*Nepstad* et al., 1999). The net-release of carbon through deforestation largely depends on the type, intensity, and duration of land use after clearance. After "Slash and Burn", only a small fraction of the nutrients enter the soil and become available for the post-clearance vegetation. The bare soil is more vulnerable to erosion and leaching, reducing the nutrient pool as well as the formation of biomass even further. When soil fertility becomes too low for viable farming, the area is abandoned and rain forest grows back within a time span of 50 years or less. In Amazonia, the secondary forest had only 17 % of the above ground biomass, whereas the below ground C pool cycle was nearly identical with those of the unaltered primary forest (*de Camargo* et al., 1999).

Under commercial logging of a rain forest, only a few trees are cut down for timber. However, the use of heavy machinery tears up the ground and knocks down or damages many other trees. In a study in Indonesia, cutting down only 3 % of the trees, a logging operation damaged 49 % of all the trees in the forest (*Johns*, 1985). Yet even with all that damage, the rain forest will grow back relatively quickly if left alone after selective logging. Tropical forests represent an enormous reservoir of carbon storing 460–575 × 10^9 metric tons of carbon worldwide (*McKane* et al., 1995), giving global significance to changes management practice and area extent.

Conclusion

Forests are complex ecosystems with several compartments acting as reservoir, source and sink of greenhouse gases. Forest soils emit nitrous oxide (N_2O) and nitrogen monoxide (NO) to the atmosphere, but also consume substantial amounts of methane (CH_4). The net exchange of carbon dioxide between forest and the atmosphere is the sum of the net changes in the total amount of carbon stored in trees, understory and floor vegetation as well as soil organic matter. While the carbon balance of mature forest should be zero, natural succession as well as anthropogenic activities may result in substantial emission or deposition of carbon dioxide.

The UN Framework Convention on Climate Change (UNFCCC) aims at 'the stabilization of greenhouse gases in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system'. The Kyoto Protocol, signed in 1997, outlined a possible trading of sequestered carbon units between those countries committed to mitigate their greenhouse gas emissions and those that can supply the land resources for carbon sequestration. Although the implementation of 'Clean Development Mechanisms' is still unclear, this type of agreement between developed and developing countries may in future facilitate more reforestation projects.

Mitigation options in forests include (i) a halt to deforestation; (ii) an expansion in the land area of forests; (iii) an increase in the stocks of carbon in existing forests; (iv) more efficient harvest and greater use of wood in long-lasting products; and (v) the substitution of wood fuels for fossil fuels (*Houghton* et al., 1996). However – even if implemented globally – these measures will not reverse the trend of global warming as long they are not accompanied by simultaneous efforts in the other sectors of the society in particular those sectors with high energy use.

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Future development of the CO_2-problem from the point of view of a regional energy supplier

Robert Baur

Abstract

Since the beginning of industrial revolution the CO_2 concentration in the atmosphere increased by 25 %. The hothouse effect is by 50 % caused by CO_2. This CO_2 comes mainly from the combustion of fossil energies and increases because of earth population growth and industrial energy demand.

Renewable energy sources can not contribute an essential share for relief in the near future. Therefore the use of energy sources with low emission of CO_2 is necessary. This is hindered by current eco taxes, which do not create an incentive to switch to natural gas and electricity from renewable sources. Besides that, falling prices as a result of the liberalization of the energy market do not lead to more saving of energy.

Utilities play a major role in promotion of the use of renewable energies and the economical use of energy or the development of new technologies, but a distinct reduction of CO_2 emissions can only be achieved on a global level and under conditions which are fair and bearable for the consumers.

What is EWE?

The map of Northern Germany shows the area served by EWE. EWE is based in Oldenburg and is one of the largest regional energy providers in Germany.

With 4 million people, about 5 % of all German citizens belong to our customers. EWE is a service provider for energy, the environment and telecommunication sector for the Ems-Weser-Elbe area, Brandenburg and Rügen, shown on the map as coloured areas.

We supply the region between Ems, Weser and Elbe with electricity and in many places also with natural gas. In the eastern part of the State of Brandenburg, on the island of Rügen and in parts of northern Vorpommern, we are also creating a gas supply network.

History of the CO_2 problem

One international conference on climate protection follows the other, one statement of principles is announced after the other. Important subjects such as energy consumption, CO_2 emission and protection of the atmosphere are almost stuck in conflicting interests.

Since the beginning of the industrial revolution, an increase of the CO_2 concentration in the atmosphere by 25 % has been measured. According to the Max-Planck-Institute for Meteorology, for instance, this increase, together with other factors, is – with a probability of 95 % – responsible for the increase of earth's global mean temperature of 0.7 degrees in the past one hundred years, even if this is still in the scope of the natural climate fluctuation.

What has caused this increase?

The hothouse effect is to 50 per cent caused by the increasing CO_2-content of the atmosphere. And this is predominantly a consequence of the combustion of fossil energy sources.

The speed of the increase in the consumption of fuels is frightening: the generation currently living on the earth consumes as much fuel as approximately 20,000 generations living before it. The increasingly more rapid growth of the earth population boosts additionally the expanding demand of industry.

In 1992, all people in the world emitted world-wide slightly more than 22 billion tons CO_2. Uniformly distributed across the German Federal Republic, this would result in a layer of about 30 meters thickness. The approximately one billion tons CO_2 from German sources would result in a breast-high layer of almost one and a half meter.

What future development do we anticipate?

We follow the state of the scientific discussion, as far as it can be considered as reliable. And that is: "up it goes", faster and faster.

Let me concentrate for a few moments on electricity production as a major source of CO_2-emissions.

The CO_2-free "fuel", that renders currently the largest contribution to the relief of the atmosphere, is nuclear energy. Currently about one third of the total generation of electric current in Germany comes from nuclear plants.

With the second CO_2-free source, the renewable energies wind, sun and water about five per cent of the total current generation were generated. The water generated power accounts for the largest part, wind and solar energy account for 20 per cent.

By 2005, the economic potential of the renewable energies will continue to increase to seven per cent of the current generation. The photo-voltaic share in the total current supply will

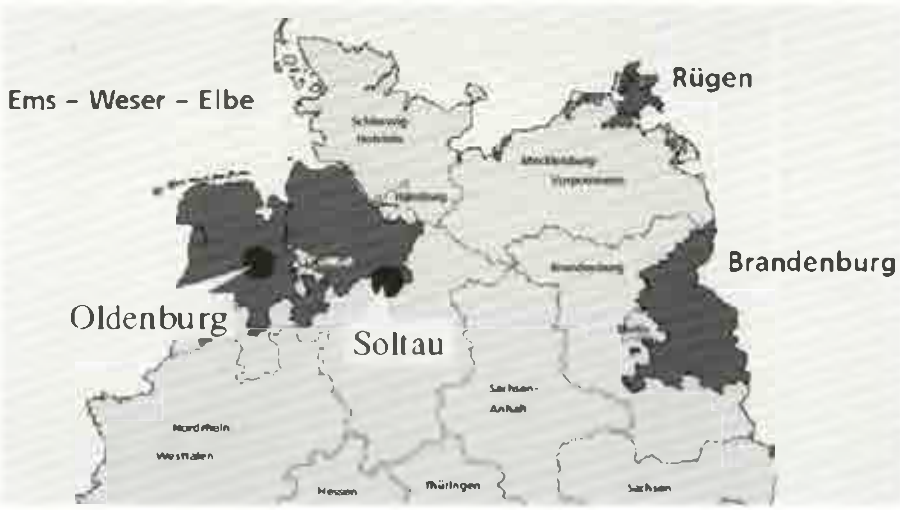

Fig. 1: Map of Northern Germany/Area served by EWE.

increase from presently 0.004 % to 0.03 %.

The largest growth rate in Germany is predicted for current generated from wind: According to the Ministry of Research, the economic potential is to be assessed two to thirty times the current potential of nearly 3,000 MW installed capacity in the Federal Republic of Germany.

In the case of thermal solar energy use, the outlook is neither more promising: The total sun collector area rose from 170,000 m² in 1983 to more than 2,300,000 m² in 1998. It is expected that the thermal use of solar energy will provide 0.12 % of the total heat generation by 2005.

The release of CO_2 will, as a consequence, continue to increase exponentially, the renewable types of energy can, in the foreseeable future, contribute no essential share for relief.

What does that mean for the industry?

Besides the use of renewable types of energy, there is above all the reduction of the energy consumption and the use of economical energy consumption technology in the foreground.

It is a matter of the energy suppliers to distribute as little as possible energy encumbered with CO_2. That does not mean, however, to promote renewable types of energy at any price.

Under what conditions can we act?

The most effective way is to resort for the CO_2 reduction both in the generation of electric current and in the heat supply to energy sources which quickly reduce the CO_2 proportion.

A brown coal power plant emits 1.04 kg CO_2 to generate one kWh of electric current. In the case of hard coal, this is still 0.82 kg.

A modern gas and steam power plant which is fuelled with natural gas emits only 0.38 kg. The sector of photovoltaic technology does not achieve much better results: In Germany, the construction and the production emits 0.2 kg CO_2.

Here, however, the question must be raised whether this CO_2 reduction program must be punished by the government: The levying of eco taxes in early 1999 on natural gas in the same way as on other fossil energy sources does not create an incentive for consumers to switch to natural gas, not to speak of using current from renewable types of energies because this current is again burdened with an additional tax.

The liberalization of the energy markets in Germany about one year ago, which we have carried out in good old German custom very thoroughly, is extremely blossoming: The price level is reducing enormously. But this leads by no means to the saving of energy at falling prices. The contrary might be more probable.

What is more, we are supposed to cut off the largest CO_2 avoiding installations, the nuclear power plants, on the basis of political resolutions, but we have to take on the basis of the liberalization atomic power from France and from Russia and Ukraine into our networks, because many customers want to have cheap current from the atomic power plants.

All this does not fit together and does not result in a reasonable concept. It rather shows the political helplessness in front of the many problems that have remained unsolved for many generations. The emphasis must now be placed on looking for solutions which are reasonable in political and economic respect and to transform them with a sense of proportion.

What does EWE do?

EWE generates current from renewable sources of energy and trades with it

The *photo-voltaic technology* is used to an increasing extent in the EWE supply area, however the costs of this type of current at one to two DM/kWh are still very high. The installed electric power is continuously increasing and achieved in 1998 already more than 220 kW. EWE operates five photo-voltaic plants with a total of 16 kW peak capacity which generate in the course of the year around 10,000 kWh current.

Wind generated energy is the most important source of renewable energies in our region. The sight of wind generation plants has become an everyday picture because here in the vicinity of the sea coast there are favourable wind conditions. The stronger and more uniform the wind blows, the higher the current output. The sites of installations are particularly frequent along the coast. But also in the hinterland, suitable sites can be found under favourable conditions, though they are by far not so frequent.

Beginning from the middle of the eighties, the installed capacity increased. In 1998, the EWE wind parks with their installed performance of 15 MW generated a total of 43,000 MWh current.

For the future, a continued heavy increase in wind power plants is to be expected.

By the end of 1998, a total of 520 MW electric output was installed at the wind power plants in the whole supply area. These plants generated about 1,024,100 MWh current, for which about 17 Pf/kWh is paid. In this way, EWE pays about 170 Mio. DM to the owners of the "wind mills".

What is more, the price for wind generated current is considerably higher, approximately twice as much than that for current from power plants. On account of this, EWE suffered in 1998 disadvantages amounting to 94 Mio. DM. Similar is the situation also for other energy suppliers in the coastal regions of Northern Germany. Here a uniform distribution of this burden to all customers in the Federal Republic of Germany can help. The best solution, however, would be the complete cancellation of the remuneration for feeding current into the net, which is fixed by the Government, and which should be replaced by another solution adapted to the market. For instance by the obligation of the consumer that he has to cover a certain percentage of his demand for electric power from renewable types of energy and setting him free in his choice of source. There is a great number of offers for this in the market. It is also possible to check such a proportion.

We promote energy savings and the economical use of energy

All customers find suitable consultation offers at EWE.

In addition, EWE offers to examine the power consumption and to check for opportunities to save energy.

For this purpose, EWE lends measuring instruments free of charge by means of which household appliances consuming excessive quantities of power can easily be identified at home.

EWE offers an Energy Savings Loan to help all customers to realize energy savings measures.

Since 1990, in around 43,000 loans more than 160 Mio. DM were paid, at an especially favourable rate of interest of 4 per cent.

In the SynergieHaus Project, EWE addresses all housebuilders who are thinking of tomorrow when building today: EWE promoted the building projects when the heat requirements are at least 30 per cent below the current demand when a controlled ventilation plant is installed. So far, 430,000 DM were paid in the scope of the program for 50 dwelling units.

Natural gas and heat from EWE relieve the environment

We achieve, with the gas supply by EWE, together with the German gas industry, an essential contribution to the protection of climate and environment. In 1998, we sold 39 billion kilowatt hours. To achieve this, we invested during the same year more than 150 million DM. In this way, the environment is relieved from 3.2 Mio. ton CO_2.

In road traffic we also see a great opportunity for an effective relief for the environment and operate, for this purpose, in Oldenburg and in Vogelsdorf in the east of Berlin in co-operation with Aral a natural gas station. In our fleet of company vehicles, we operate more than 30 vehicles powered by natural gas.

Also the number of cogeneration heating systems at EWE is increasing. We operate 26 cogeneration systems with a total of 7,900 kWel and 67,174 kWth including the peak load boilers. For this purpose, we invested more than 30 Mio DM.

EWE is testing new technologies – for instance fuel cells

In tomorrow's energy supply, households can generate their power demand for electric current, heat and hot water in fuel cells themselves.

These fuel cells could supplement the network based energy supply on a wide basis. Through a coupling of current and heat generation, it is possible to achieve a still more efficient, more economical energy consumption which is also kind to the environment: Electric power is generated where waste heat can usefully be applied for heating purposes.

This was a short look on EWEs activities to reduce energy demand and CO_2-emissions to the atmosphere.

Will that be enough?

The answer is: NO. The emission of CO_2 into the atmosphere will continue to increase world-wide. For this reason, all approaches for a reduction must be applied world-wide. Each individual consumer – also each individual company, also each energy provider – can make only a limited contribution. The engagement of EWE – as important as it is – cannot solve the CO_2 problem alone.

As important as these contributions are – a distinct reduction can be achieved only at a global level and under conditions which are fair and bearable for the ultimate consumer, in the best of cases even under attractive conditions.

Here all participating parties are challenged: Governments, scientists, the industry, energy providers and the consumers of energy. And that actually means ALL, as we are here meeting today.

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Water Resources and Forestry Issues

Ian R. Calder

Abstract

Foresters and hydrologists generally have very different perceptions of the role of forests in relation to water resources. It is often part of foresters' received wisdom that forests necessarily increase rainfall, increase runoff, regulate flows, reduce erosion, reduce floods, "sterilize" water supplies and improve water quality. Yet hydrological research shows a much more complex picture which often is in conflict with these views. The supporting and conflicting evidence is reviewed here and gaps in our knowledge of the underlying processes which determine the hydrological responses are identified.

This paper is based on an article which was commissioned by the CGIAR's Systemwide Initiative for Water Management (SWIM paper 3) and the book "The Blue Revolution".

Forests and water – differing perceptions

Foresters and hydrologists generally have very different perceptions of the role of forests in relation to water resources. It is often part of foresters' received wisdom that forests necessarily increase rainfall, increase runoff, regulate flows, reduce erosion, reduce floods, "sterilize" water supplies and improve water quality. Yet hydrological research shows a much more complex picture which often is in conflict with these views. Hydrological research shows that many of the "forest effects" and the "forest management effects" can be detrimental to water resource interests.

Integrated land use and water management must take into account, and recognise, both the benefits of the forests together with some of their potential water resource disbenefits. This means, in simple terms, and particularly in situations where water resources are scarce that the value of the forest (for timber, amenity, conservation and other products) must be considered in relation to the value of the extra water it consumes.

The perception that forests are always necessarily "good" for the environment and water resources has, however, become so deeply ingrained in our collective psyches that it is usually accepted unthinkingly. Foresters have long been suspected of deliberately propagating these perceptions and myths.

H. C. Pereira (1989) states in relation to forests and rainfall:

The worldwide evidence that high hills and mountains usually have more rainfall and more natural forests than do the adjacent lowlands has, historically led to confusion of cause and effect. Although the physical explanations have been known for more than 50 years, the idea that forests cause or attract rainfall has persisted. The myth was created more than a century ago by foresters in defence of their trees... The myth was written into the textbooks and became an article of faith for early generations of foresters.

The overwhelming hydrological evidence supports Pereira's view that forests are not generators of rainfall yet this "myth", like many others in forest hydrology may contain a modicum of truth that prevents it from being totally "laid to rest".

When scrutinised much of the folklore and many of the "mother statements" relating to forestry and the environment are seen to be either exaggerated or untenable. For others we still require research to understand the full picture. Seven mother statements in relation to forests, productivity and hydrology are considered:

1. Forests increase rainfall
2. Forests increase runoff
3. Forests regulate flows
4. Forests reduce erosion
5. Forests reduce floods
6. Forests "sterilize" water supplies – improve water quality

Clearly it is important to know what veracity can be attached to these statements for the proper management of water resources and land use. Many forestry projects in developing countries are supported because of assumed environmental/ hydrological benefits, whilst in many cases the hydrological benefits at best may be marginal and at worst, negative. The evidence, for and against each of these mother statements, is taken in turn and appraised; the need for further research is also assessed.

Forests increase rainfall?

Pereira (1989) denounced the linkage between forests and increased rainfall as a myth yet there may be some situations where this positive linkage cannot be totally discounted, where the presence of forests does lead to a small increase in rainfall. Theory indicates that the height of trees will slightly increase the orographic effect which will, in turn, lead to a slight increase in the rainfall. Modelling studies using mesoscale climate models have shown that some of the intercepted water retained by forest canopies and re-evaporated will return as increased rainfall (*Blythe* et al., 1994) but this result although indicating an increase in the gross rainfall above the vegetation would suggest that the overall net rainfall reaching the ground surface would be reduced as a result of the presence of the forest.

Application of Global Circulation Models, GCMs, (*Rowntree, 1988*) indicate that vegetation changes will have a regional impact on climate. Use of these models in Amazonia shows that total removal of the Amazonian rainforest would affect rainfall patterns with reductions in the rainfall, particularly in the drier north-east of the continent by about 0.5 mm per day on average, Figure 1. For the whole of the Amazon basin, rainfall would be reduced by 6 % (*Institute of Hydrology*, 1994).

Similarly GCM modelling studies for the Sahel (*Xue*, 1997) indicate that past removal of the indigenous bush vegetation will have altered the spatial distribution of rainfall in a manner that bears a close correlation with observed changes in the distribution patterns, Figure 2. Yet in southern India studies of historical rainfall records (*Meher-Homji*, 1980), indicate that annual rainfall over

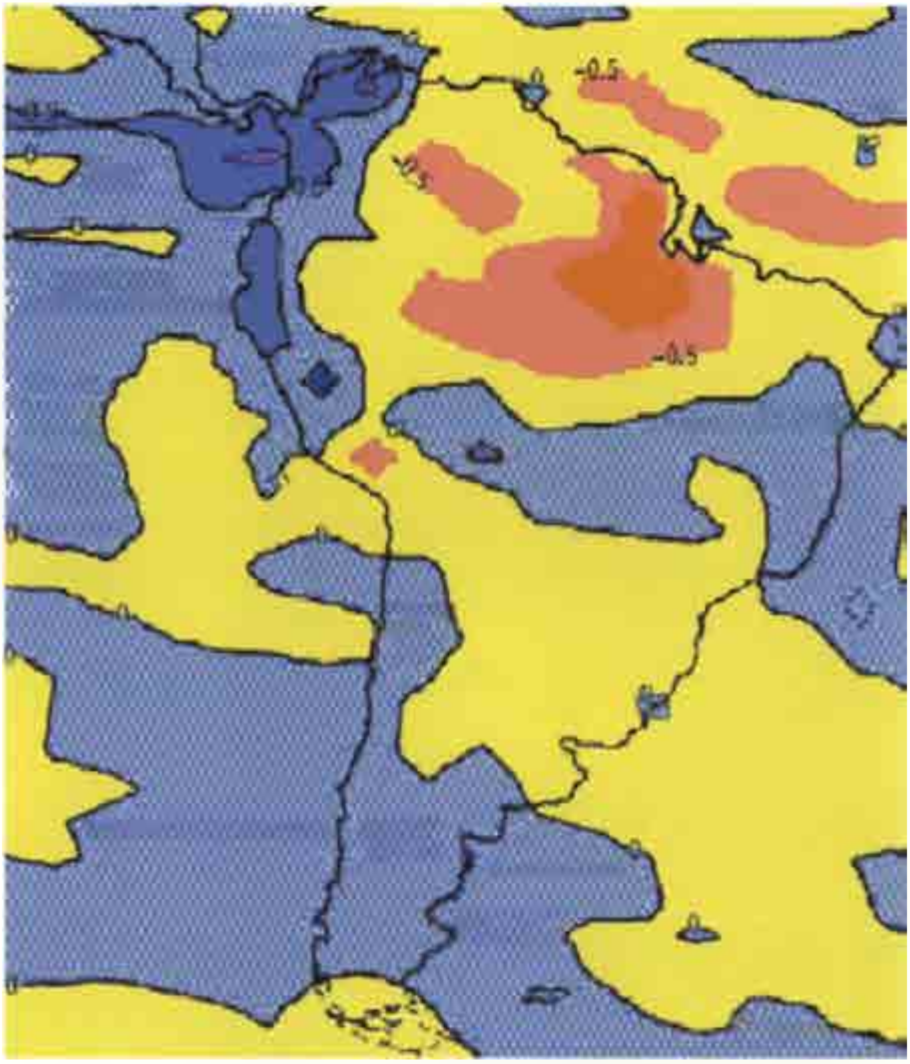

Fig. 1: Predictions made by the Hadley Centre GCM of the spatial variation of the annual change in rainfall (mm d⁻¹) over Amazonia resulting from complete removal of the Amazon forest, from Institute of Hydrology 1994.

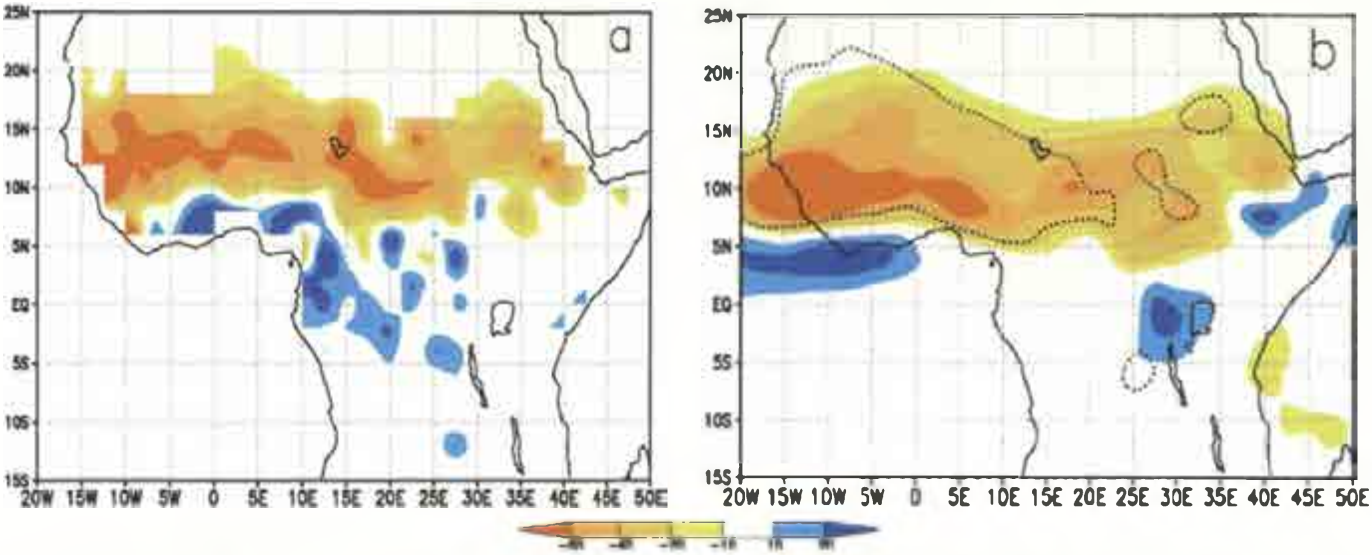

Fig. 2: Spatial variability of the predicted change in rainfall (b), for the months July–September over central Africa as a result of the degradation of the Sahel vegetation occurring over the last 30 years, together with the observed change in the rainfall pattern (a), from Xue, 1997.

the last 100 years has NOT decreased despite the large scale deforestation that has taken place as the dry deciduous forest has been converted to agriculture, although there is some evidence for a decrease in the number of raindays.

The issue is well summed up by *Bands* et al.(1987), quoting from experience in South Africa: "Forests are associated with high rainfall, cool slopes or moist areas. There is some evidence that, on a continental scale, forests may form part of a hydrological feedback loop with evaporation contributing to further rainfall. On the Southern African subcontinent, the moisture content of air masses is dominated by marine sources, and afforestation will have negligible influence on rainfall and macroclimates. The distribution of forests is a consequence of climate and soil conditions – not the reverse."

Conclusion: Although the effects of forests on rainfall are likely to be relatively small they cannot be totally dismissed from a water resources perspective.

Research requirement: Further research is required to determine the magnitude of the effect, particularly at the regional scale.

Forest increase runoff?

A new understanding has been gained in recent years of evaporation from forests in dry and wet conditions based on process studies. These studies, and the vast majority of the world's catchment experiments, indicate decreased runoff from areas under forests as compared with areas under shorter crops. This knowledge has been gained from a host of different studies using a range of different techniques and methodologies. "Natural" lysimeters have been used to measure total evaporation. Transpiration has been determined using soil moisture measurements (*Bell*, 1976), micrometeorological and eddy correlation methods (*Dyer*, 1961), plant physiological studies and tree cutting studies (*Roberts*, 1977,1978), and heat (*Cohen* et al., 1981), radioactive (*Kline* et al., 1970, *Luvall* and *Murphy*, 1982) and stable isotope tracing methods (*Calder*, 1991). Interception has been determined by a number of techniques including interception gauges (*Calder* and *Rosier*, 1976), gamma-ray (*Olszyczka*, 1979, *Calder* and *Wright*, 1986) and microwave attenuation methods (*Bouten* et al.,1991), "wet lysimeters", and rainfall simulators (*Calder* et al., 1996).

These studies indicate that in wet conditions interception losses will be higher from forests than shorter crops primarily because of increased atmospheric transport of water vapour from their aerodynamically rough surfaces.

In dry (drought) conditions the studies show that transpiration from forests is likely to be greater because of the generally increased rooting depth of trees as compared with shorter crops and their consequent greater access to soil water.

The new understanding indicates that in both very wet and very dry climates evaporation from forests is likely to be higher than that from shorter crops and consequently runoff will be decreased from forested areas, contrary to the widely accepted folklore.

The few exceptions, (lending some support to the folklore), are:

1. Cloud forests where cloud-water deposition may exceed interception losses.
2. Very old forests. *Langford* (1976) showed that following a bushfire in very old (200 years) mountain ash, *Eucalyptus regnans*, forest covering 48 % of the Maroondah catchment, one of the water supply catchments for Melbourne in Australia, runoff was reduced by 24 %. The reason for this reduction in flow has been attributed to the increased evaporation from the vigorous regrowth forest that had a much higher leaf area index than the former very old ash forest.
3. Observations and modelling studies of the evaporation from broadleaf forest in southern England growing on chalk soils have been interpreted as showing reduced water use as compared with grassland (*Harding* et al., 1992). Further research is planned to investigate these results, exceptional in world terms, and to determine if these results are applicable to other regions of the UK.

Conclusion: Notwithstanding the exceptions outlined above catchment experiments generally indicate reduced runoff from forested areas as compared with those under shorter vegetation (*Bosch* and *Hewlett*, 1982).

Caveat: Information on the evaporative characteristics of different tree species/soil type combinations are still required if evaporation estimates with an uncertainty of less than 30 % are required. In both temperate and tropical climates evaporative differences between species and soil types are expected to vary by about this amount. For example 30 % differences in the water use of the same species of *Eucalyptus* growing on different soils have been recorded in southern India (*Calder* et al., 1993) whilst similar differences have been recorded between different tree species growing on the same soil type (*Calder* et al., 1997a). In the UK further research is required to determine, at better than 30 % uncertainty, the evaporation from different tree species/ soil type combinations to determine the potential water quantity impacts of the proposed doubling of UK lowland forests (*Calder* et al., 1997b).

Forests regulate flows – increase dry season flows?

Although it is possible, with only a few exceptions, to draw general conclusions with respect to the impacts of forests on annual flow, the same cannot be claimed for the impacts of forests on the seasonal flow regime. Different, site specific, often competing processes may be operating and the direction, let alone the magnitude of the impact, may be difficult to predict for a particular site.

From theoretical considerations it would be expected that:

1. Increased transpiration and increased dry period transpiration will increase soil moisture deficits and reduce dry season flows.
2. Increased infiltration under (natural) forest will lead to higher soil water recharge and increased dry season flows.
3. For cloud forests increased cloud-water deposition may augment dry season flows.

There are also observations (*Robinson* et al., 1997) which indicate that for the uplands of the UK drainage activities associated with plantation forestry increase dry season flows both through the initial dewatering and in the longer term through alterations to the hydraulics of the drainage system. The importance of mechanical cracking associated with field drainage and its effects on drainage flows has been highlighted by *Robinson* et al.(1985) whilst the work of *Reid* and *Parkinson* (1984) indicates that landform and soil type may sometimes be the dominant factors determining soil moisture and drainage flow response.

There are also observations from South Africa that the increased dry period transpiration is reducing low flows. *Bosch* (1979) has demonstrated, from catchment studies at Cathedral Peak in Natal, that pine afforestation of former grassland not only reduces annual streamflow by 440 mm but also reduces the dry season flow by 15mm. *Van Lill* and colleagues (1980), reporting studies at Mokobulaan in the Transvaal showed that afforestation of grassland with *Eucalyptus grandis* reduced annual flows by 300–380 mm, with 200–260 mm of the reduction occurring during the wet summer season. More recently *Scott* and *Smith* (1997), analysing results from five of the South African catchment studies, concluded that percentage reductions in low (dry season) flow as a result of afforestation were actually greater than the reduction in annual flow. *Scott* and *Lesch* (1997) also report that on the Mokobulaan research catchments under *Eucalyptus grandis* the streamflow completely dried up by the ninth year after planting, the eucalypts were clearfelled at age 16 years but perennial streamflow did not return for another five years. They attribute this large lag time as being due to very deep soil moisture deficits generated by the eucalypts which require many years of rainfall before field capacity conditions can be established and recharge of the groundwater aquifer and perennial flows can take place.

Bruijnzeel (1990) discusses the impacts of tropical forests on dry season flows and concludes that the infiltration properties of the forest are critical in how the available water is partitioned between runoff and recharge (leading to increased dry season flows).

Conclusions: Competing processes may result in either increased or reduced dry season flows. Effects on dry season flows are likely to be very site specific. It cannot be assumed that it is generally true that afforestation will increase dry season flows.

Caveat: The complexity of the competing processes affecting dry season flows indicates that detailed, site specific models will be required to predict impacts. In general the role of vegetation in determining the infiltration properties of soils, as it affects the hydrological functioning of catchments through surface runoff generation, recharge and high and low flows and catchment degradation remains poorly understood. Modelling approaches which are able to take into account vegetation and soil physical properties including the conductivity/water content properties of the soil, and possibly the spatial distribution of these properties, will be required to predict these site specific impacts.

Forests reduce erosion?

If foresters are under suspicion for propagating the myth that forests are the cause of high rainfall in upland areas then there may be equal suspicions raised regarding the oft cited universal claims of the benefits of forests in relation to reduced erosion. As with impacts on seasonal flows the impacts on erosion are likely to be site specific, and again, many, and often competing processes, are likely to be operating.

In relation to beneficial impacts conventional theory and observations indicate that:

1. The high infiltration rate in natural, mixed, forests reduces the incidence of surface runoff and reduces erosion transport.
2. The reduced soil water pressure and the binding effect of tree roots enhance slope stability, which tends to reduce erosion.
3. Windthrow of trees and the weight of the tree crop reduces slope stability, which tends to increases erosion.
4. On steep slopes forestry or agroforestry may be the preferred option where conventional soil conservation techniques and bunding may be insufficient to retain mass movement of soil.

Adverse effects, often related to forest management activities, may result from:

1. Bad logging techniques which compact the soil and increase surface flow.
2. Pre-planting drainage activities which may initiate gully formation.
3. Road construction and road traffic which can initiate landslips, gully formation and the mobilization of sediments.
4. Excessive grazing by farm animals which leads to soil compaction, the removal of understorey plants and greater erosion risk.
5. Splash induced erosion from drops falling from the leaves of forest canopies.

Perhaps least recognised of these adverse impacts is the potential for certain forest types to induce splash induced erosion through drop size modification and this topic is discussed below.

Drop size modification

Contrary to popular belief, forest canopies do not necessarily "protect" the soil from raindrop impacts. Although not generally recognised, the potential for increased erosion from drops falling from forest canopies was demonstrated almost fifty years ago by *Chapman* (1948). However the importance of species in determining drop size and erosive impacts has not always been well understood. There have been claims that the drop size spectra of drops falling from vegetation are largely independent of vegetation type, (*Brandt*, 1989). The logical consequence of this line of thought is that erosivity would be considered to be unrelated to the type of vegetation.

New theory derived from observations developed from disdrometer observations of the modified drop size spectra beneath canopies of different tree species (*Hall* and *Calder*, 1993), suggests a different perspective. These measurements show a well defined, repeatable relationship between the spectrum of drop sizes recorded for a particular tree species, termed the characteristic spectrum, Figure 3. This same below canopy spectrum is obtained irrespective of the size spectra of drops incident on the canopy.

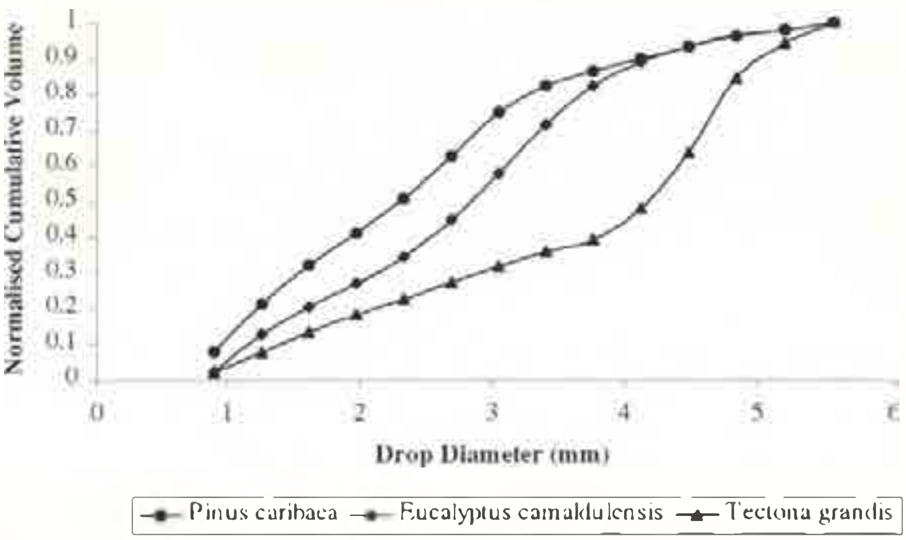

Fig. 3: Characteristic net-rainfall drop-size spectra for Pinus caribaea, Eucalyptus camaldulensis and Tectona grandis (from Hall and Calder, 1993).

These characteristic spectra can also usefully be compared, Figure 4, with the spectra expected in natural rainfall as predicted by the Marshall-Palmer equation (*Marshall* and *Palmer*, 1948). Clearly the vegetation of these tree species will not always reduce the drop size of the incident rainfall. For *Pinus caribaea*, a rainfall intensity exceeding 50 mm h^{-1} will be required before any diminution of drop sizes will occur. For *Eucalyptus camaldulensis* the "break-even" intensity is about 200 mm h^{-1} whilst for *Tectona grandis* it would be 3000 mm h^{-1}, an intensity which could never be reached in natural rainfall.

If it is assumed that the height of vegetation is sufficient for all drops to have reached terminal velocity it is possible to show the characteristic spectra in terms of kinetic energy. In Figure 5 the fraction by volume of the sub-canopy drops having kinetic energies exceeding a specified value are shown. This shows how important species differences are in generating drops with different kinetic energies. Median volume drops from Tectona grandis will have *nine times* greater kinetic energy than those from *Pinus caribaea*.

Evidence for how severe splash induced erosion beneath forest canopies can be was provided by observations beneath a teak forest in Karnataka, southern India in 1993. During the dry season of 1993 a fire, a common occurrence in teak plantations, had removed the protective litter layer and understorey veg-

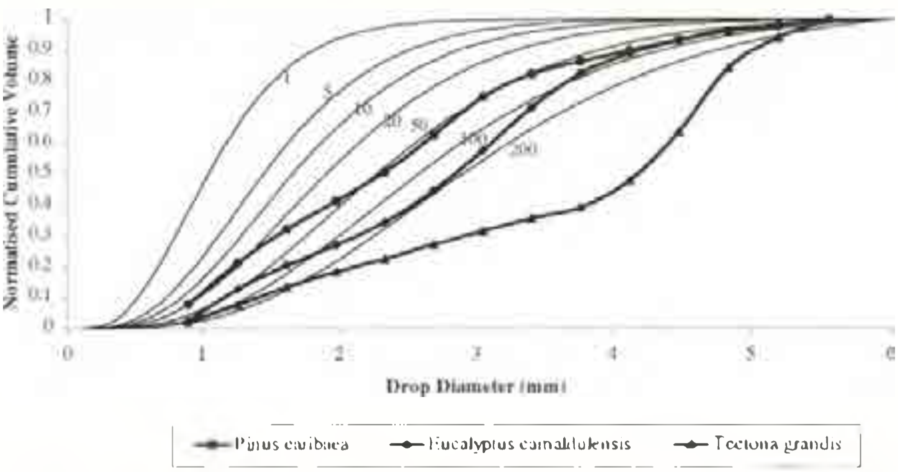

Fig. 4: Characteristic net-rainfall drop-size spectra recorded for Pinus caribaea, Eucalyptus camaldulensis and Tectona grandis and rainfall spectra predicted by the Marshall-Palmer equation for different rainfall intensities.

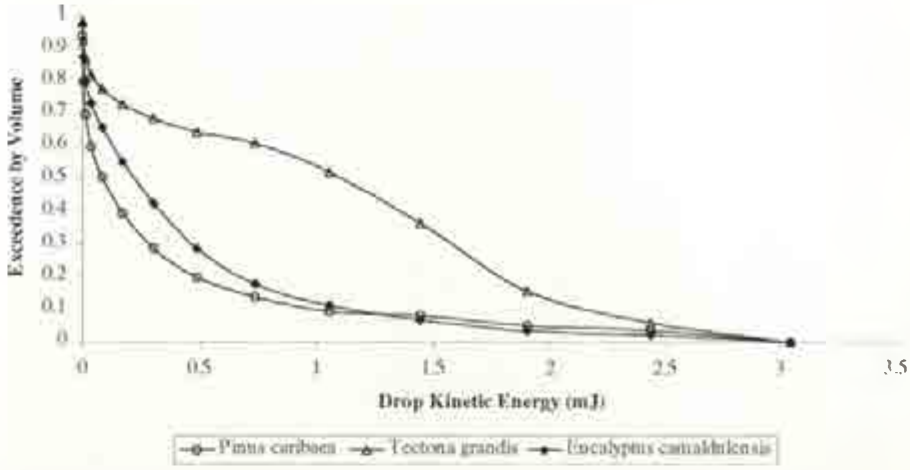

Fig. 5: Equivalent drop kinetic energy spectra for Pinus caribaea, Eucalyptus camaldulensis and Tectona grandis assuming all drops have reached terminal velocity (from Hall and Calder, 1993).

etation. Some regrowth of the understorey had started to take place prior to a major night time storm at the outbreak of the monsoon. Major sheet erosion had clearly taken place overnight particularly from the soil which had not been protected by regrowth vegetation, Figure 6. The "columns" of soil beneath the protective leaves of the regrowth vegetation were approximately 2.5 cm high indicating that, overnight, approximately this depth of soil had been eroded away by sheet erosion. Observations in other parts of the plantation indicated, from root exposures, that erosion to a depth of two metres had occurred from the plantation since it had been planted some 80 years earlier.

Summary

The effects of catchment deforestation on erosion, and the benefits gained by afforesting degraded and eroded catchments will be very dependent on the situation and the management methods employed.

Quoting *Bruijnzeel* (1990) "In situations of high natural sediment yield as a result of steep terrain, high rainfall rates and geological factors, little, if any influence will be exerted by man". Also in situations where overland flow is negligible, in drier land, little advantage will be gained from afforestation. *Versfeld* (1981) has shown that at Jonkershoek in the Western Cape of South Africa, land cover has very little effect on the generation of overland flow and soil erosion. On the other hand , in more intermediate conditions of relatively low natural rates of erosion and under more stable geological conditions man-induced effects may be considerable. In these situations catchment degradation may well be hastened by deforestation and there may also be opportunities for reversing degradation by well-managed afforestation programmes.

Even in these situations afforestation should not necessarily be seen as a quick panacea. In heavily eroded catchments, such as those on the slopes of the Himalayas, so much material will have already been mobilized that, even if all the man induced erosion could be stopped immediately, it would be many decades before there was any reduction in the amount of material carried by the rivers (*Pearce*, 1986, *Hamilton*, 1987). The choice of tree species will also be important in any programme designed to reduce erosion and catchment degradation.

Recent theoretical developments and observations confirm that drop size modification by the vegetation canopies of trees can be a major factor leading to enhanced splash induced erosion. These observations indicate (Fig. 4) that the degree of modification is species related, with tree species with larger leaves generally generating the largest drop sizes. The use of large leafed tree species such as teak (*Tectona grandis*) in erosion control programmes would therefore be ill advised, especially if

Fig. 6: Splash induced erosion under a teak forest in southern India following an understorey fire (Photo I.R. Calder).

there is any possibility of understorey removal taking place.

Conclusions: It would be expected that competing processes might result in either increased or reduced erosion from forests. The effect is likely to be both site and species specific. For certain species, e.g. *Tectona grandis*, forest plantations may cause severe erosion.

Caveat: Although conventional erosion modeling methods such as the Universal Soil Loss Equation (*U.S. Department of Agricultural Research Service*, 1961) provide a practical solution to many problems associated with soil loss from agricultural lands it may not be adequate for the prediction of erosion resulting from afforestation activities. Process understanding of the erosive potential of drops falling from different tree species is not adequately appreciated and soil conservation techniques related to vegetation type, soils and slope characteristics have not yet been fully developed.

Forests reduce floods?

It is a widely held view, propagated by foresters and the media, that forests are of great benefit in reducing floods. Disastrous floods in Bangladesh and northern India are almost always associated with "deforestation of the Himalayas"; similarly in Europe floods are often attributed by the media to "deforestation in the Alps". However hydrological studies carried out in many parts of the world: America (*Hewlett* and *Helvey*, 1970), South Africa (*Hewlett* and *Bosch*, 1984), UK (*Kirby* et al., 1991, *Johnson*, 1995) and New Zealand (*Taylor* and *Pearce*, 1982) do not support this view; generally hydrological studies show little linkage between land use and storm flow.

From theoretical considerations it would be expected that interception of rainfall by forests reduces floods by removing a proportion of the storm rainfall and by allowing the build up of soil moisture deficits. These effects would be expected to be most significant for small storms and least significant for the largest storms.

The high infiltration rates under natural forests also serve to reduce surface runoff and flood response. Certain types of plantation forests may also serve to increase infiltration rates through providing preferential flow pathways down both live and dead root channels. (Through the use of border trees around agricultural fields subject to surface runoff generation there may be some prospect for runoff and flood response mitigation whilst not introducing excessive evaporative losses from wide expanses of trees.)

However field studies generally indicate that it is often the management activities associated with forestry: cultivation, drainage, road construction (*Jones* and *Grant*, 1996), soil compaction during logging which are more likely to influence flood response than the presence or absence of the forests themselves.

Conclusions: For the largest, most damaging, flood events there is little scientific evidence to support anecdotal reports of deforestation as being the cause.

Caveat: Carefully conducted controlled catchment experiments with different climates/soils/species will be required to resolve this issue but species impacts are probably not as significant as often portrayed. Management activities are most likely to be paramount.

Forests "sterilize" water supplies – improve quality?

Forests were historically the preferred land use for water supply catchments because of their perceived "sterile" qualities associated with an absence of livestock and an absence of human activities. More recently the generally reduced fertilizer and pesticide applications to forests compared with agricultural lands has been regarded as a benefit with regard to water quality degradation of runoff and recharge. Reduced soil erosion from natural forests can also be regarded as a benefit.

Offsetting these benefits, management activities: cultivation, drainage, road construction, road use, felling, are all likely to increase erosion and nutrient leaching. Furthermore deposition of most atmospheric pollutants to forests is higher because of the reduced aerodynamic resistance of forest canopies compared with those of shorter crops. In high pollution (industrial) climates this is likely to lead to both long-term acidification of the catchment and acidification of runoff.

Conclusions: Except in high pollution climates water quality is likely to be better from forested catchments. Adverse effects of forests on water quality are more likely to be related to bad management practices rather than the presence of the forests themselves.

Caveat: Studies may still be required to determine the magnitude of the impacts for specific sites and the means to minimize adverse impacts.

Discussion

Forestry interests have often been slow to acknowledge the possibility of adverse hydrological impacts associated with forests. An acceptance of this possibility opens the doors to new opportunities for integrated land use and water resources management. Clearly we need forests for a multitude of reasons but they may not always be the best option in situations where, for example, water resources are scarce.

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Forests and Water Supply

S. John Joseph

The most acute areas of destruction, resulting both from population increase and the misuse of resources, are reported from the rainfed tropical croplands of Africa south of the Sahara, Andean South America and Mexico and parts of southern Asia, including *the Himalayan lower slopes*. Land degraded to desert-like conditions, some of it irretrievably lost, continues to increase at 6 million ha p.a. Much of this latter category could be restored to productivity by rational management.

The large part of India with the exception of Western Ghats, North-East Region and Himalayas is dry and arid. Water from rain and land and its conservation management and sustained yield is the primary need of people. The arid and desert climate prevalent in India is anathema to the human body and under these conditions, without water or shelter, a person would not last for more than a few hours. When the water lost by sweat is not replaced, the body gives up water stored in fat, in tissue, and in the blood itself. Hot arid lands where the rate of evaporation far exceeds the rate of precipitation are often dotted with dry lake beds that are temporarily covered by shallow water after a heavy rainfall.

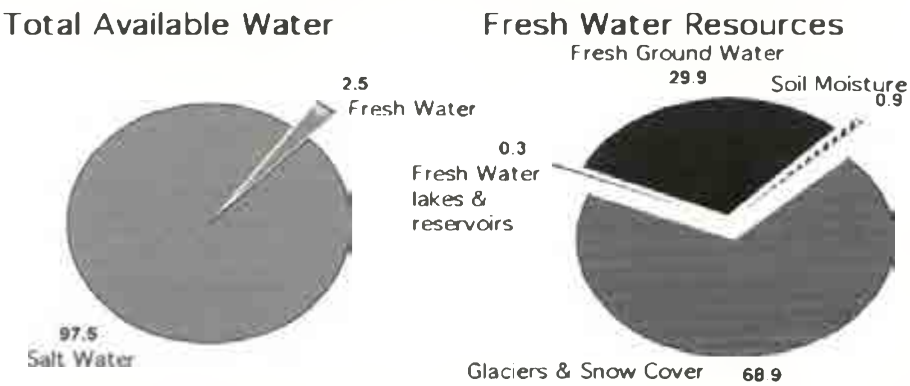
The issues of water are becoming increasingly important to human health, food security and the environment. Water is becoming more scarce, and more difficult to access. Less water is available for maintaining ecosystems (UNESCO Assessment for 21st Century).

For this reason, the World Water Council has convened a World Commission on Water for the 21st Century which is co-sponsored by FAO, UNDP, UNEP, UNESCO, UNICEF, WHO, WMO, and the World Bank. The Commission assisted by a secretariat in Paris will be developing a long term vision on Water, Life and the Environment in the 21st Century (Ismail Serageldin, Chairman, Water Commission).

Watershed Problems of Drylands – *Management Problems in Semi-arid Lands:* A characteristic problem of tropical drylands is the extreme difficulty of protecting stream source areas. Many isolated hill features of small ranges promote rainfall enough to sustain local forests and to supply streamflow to dry plains. The streams are critically important for graziers (herdsmen) and their livestock but the trees are vulnerable to attack by herdsmen seeking fuelwood and fodder.

Forests and Erosion

Popular wisdom insists that planting trees will *prevent* erosion and that removing trees, per se, results in drastic erosion leading to land degradation. Trees, and particularly trees in forest stands do indeed reduce the amount of erosion, and conventional wisdom does coincide with proven effects. Soil erosion under dense natural humid and seasonally humid forest is usually less than one



Sources : *Shiklomanov (1998) World Water Resources: A new Appraisal and Assessment for the 21st Century, UNESCO, Paris*

Fig. 1: Global Water Availability.

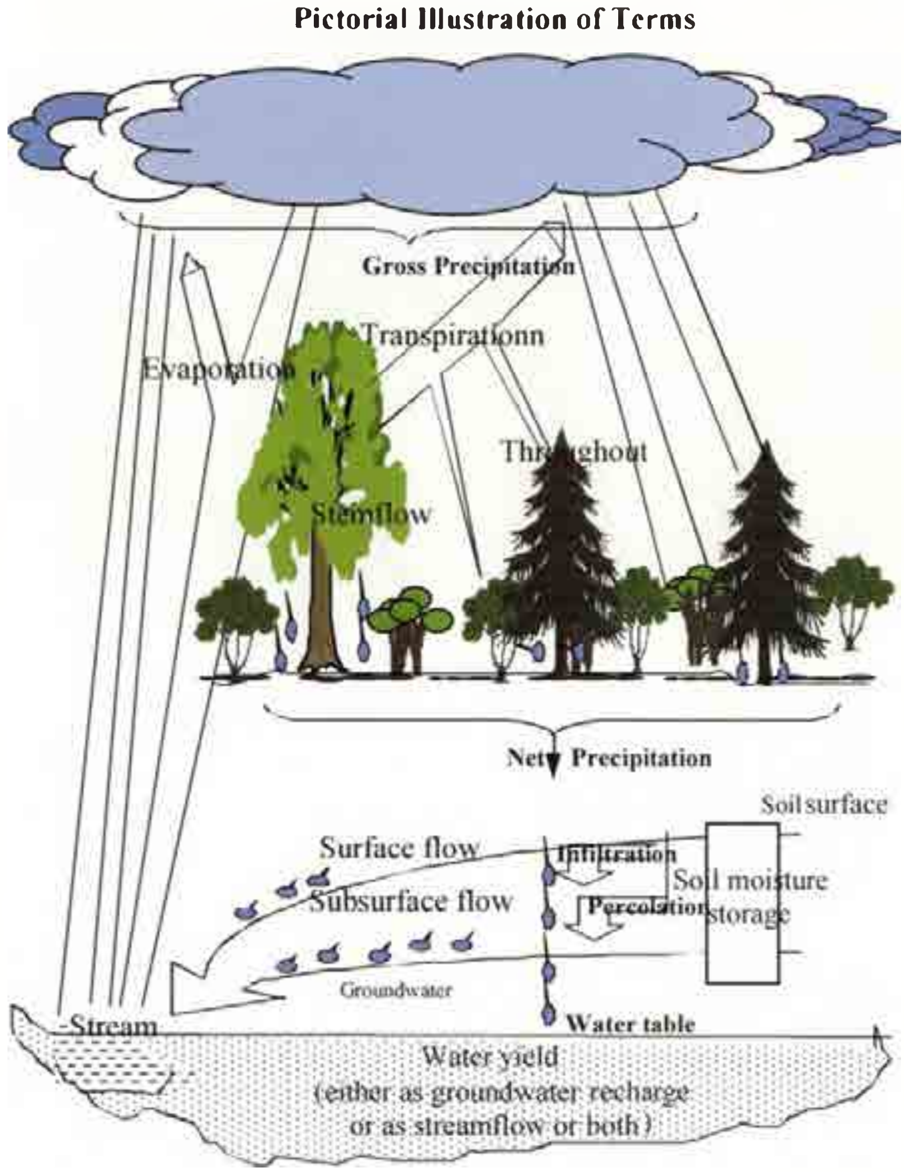


Fig. 2: Forest Hydrological Cycle.

ton per hectare per year (*UNESCO/UNEP/FAO*, 1978). However, substantial surface erosion can occur in undisturbed forest (*Lal*, 1983), as can landslides and debris avalanches on forested unstable slopes (*Lin*, 1984). Nonetheless, the undisturbed forest is an excellent watershed cover from the erosion standpoint, but it is more appropriate to speak of forests as having *low* erosion rather than no erosion; and when putting forest back on land to talk about erosion *reduction* rather than *prevention*. To be more precise it is also necessary to separate three classes of erosion: (a) *surface* (sheetwash and rills), (b) *gully*, and (c) *mass wasting* (landslips, slumps, debris flows, etc.).

Wiersum (1984) has synthesized much of the research literature on erosion under various forest and tree crop systems and presented an interesting table of averages (lumping all data, even though derived from different slopes and soils – Table 1). Note that as soon as the litter is removed by cultivation or weeding or burning, the erosion rate increases substantially.

Bosch and *Hewlett* (1982) have reviewed 94 controlled catchment studies from many parts of the world and reinforced this relationship. They have even indicated some predictive quantification as to the amount of increase.

Theory

The hydrological cycle is summarized, usually on an annual basis, by the equation:

Precipitation = Streamflow + Evaporation (Evapotranspiration) ± Changes in storage of soil moisture and of groundwater.

The part of the hydrologic cycle which is directly related to forests is shown in Figure 2. In a forest area, the precipitation can either fall on the canopy of trees or directly down on the undergrowth or on the ground. The part retained on the canopy and later evaporated is called interception. Drip and rain falling directly on the ground is called throughfall. Water caught by the leaves, trunks and stems of the trees, which is not interception, continues in a downward movement as stemflow or falling drops. At ground surface, there are three alternative directions for the water – either it evaporates, infiltrates into the soil or runs off on the surface. Evaporated water will again enter the atmosphere, and surface runoff will be drained out from the area through streams and rivers. Water that infiltrates will either enter soil moisture storage

Tab. 1: Erosion in various tropical moist forest and tree crop systems (ton/ha/year).

	Minimal	Median	Maximal
Multistoried tree gardens (4/4)*	0.01	0.06	0.14
Natural forests (18/27)	0.03	0.30	6.16
Shifting cultivation, fallow period (6/14)	0.05	0.15	7.40
Forest plantations, undisturbed (14/20)	0.02	0.58	6.20
Tree crops with cover crop/mulch (9/17)	0.10	0.75	5.60
Shifting cultivation, cropping period (7/22)	0.40	2.78	70.05
Taungya cultivation (2/6)	0.63	5.23	17.37
Tree crops, clean-weeded (10/17)	1.20	47.60	182.90
Forest plantations, burned/litter removed (7/7)	5.92	53.40	104.80

* (x/y) x = no. locations, y = no. treatments or observations. From Wiersum (1984).

or percolate further down to form groundwater.

The most likely impact on the hydrological parameters if an existing forest cover is removed, is shown in Figure 3.

The impact of forest cover on *rainfall* is not considered in Figure 3. The question whether there is such an influence or not has been intensively discussed lately, especially in India. Unfortunately, little quantitative data has been compiled on this.

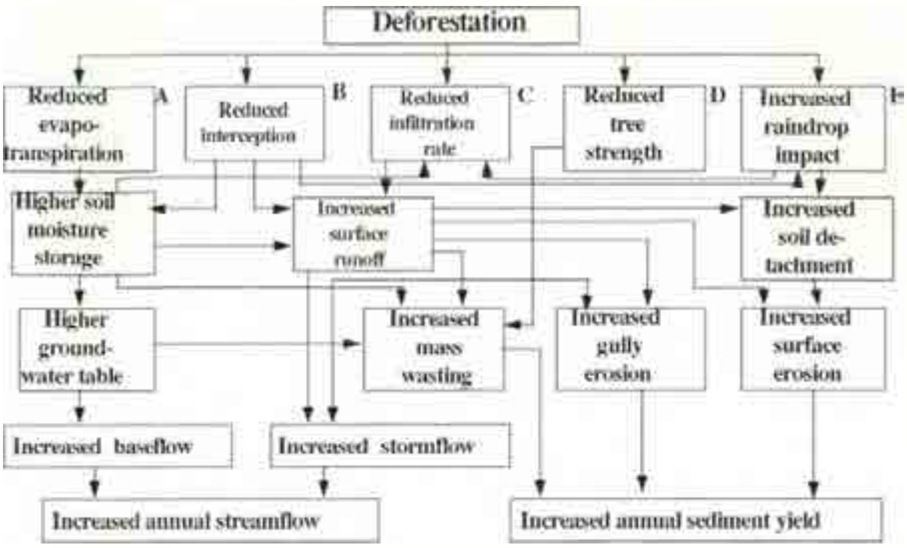
There is some evidence to suggest that trees can make use of air moisture by so-called "occult precipitation". This means the collection on tree crowns and stems, of big-sized droplets moving horizontally into the vegetation, and condensation of water vapour on leaf surfaces. Examples of such precipitation include the report of 950 mm of fog drip under a ponderosa pine tree in southern California during the period May–October, which is more than 2.5 times the "normal" precipitation. In Japan, belts of trees are planted along the coast to intercept the inland drift of sea fog.

The quantity of water lost by *interception* depends primarily on the type of cover and the intensity and frequency of rainfall.

In light rain, almost 100 % of the rain may be lost by interception followed by evaporation of the intercepted rain. Generally, the annual interception losses may range from 3 to 25 % of the precipitation. Transpiration is reduced during periods of interception. Therefore, the effective loss of water may be substantially less than these figures. Deforestation leads to an increased raindrop impact and higher erosion following the absence of interception. Due to changes in radiation and wind conditions, deforestation will lead to increased evaporation from the land surface.

In most years, enough water from the precipitation trickles down through the soil to make up for the water ordinarily withdrawn from aquifers. In arid and semiarid regions however, little or no water trickles down through most soils from precipitation, so aquifers are replenished very slowly. Water withdrawals from some of these aquifers in recent years have far exceeded deposits.

Running Water: Running water creates a wide variety of biological niches, each one home to specially adapted flora and fauna. By flowing at different



Where deforestation is followed by severe land degradation, some reduction in both volume and duration of dry season flows ultimately may be predicted.

Fig. 3: Likely Impact of Forest Removal on Hydrological Parameters.

speeds, it provides different environments for fish species and for the many families of insects whose immature aquatic stages play a key role in stream ecology. And by reshaping the stream through erosion and deposition of sediments, running water furnishes diverse habitats – bare rock, cobbles, gravel, sand, silt, or mud – for organisms that live on or beneath the stream bed. Largely as a result of the creation of such diverse environments, the stream is richer in life-forms than the still waters of lakes. Rivers are abiding evolutionary havens for many varied groups of freshwater animal life. Few aquatic organisms are not found there. Nearly all species of fresh-water fish – including most of the 2,000 species of minnow, the largest family of fish – live in running water. Insects too, reach maximum variety in flowing water. In fact, the young of the insect family *Simuliidae*, which consists of no fewer than 300 species of biting blackflies, exist only in swift currents.

Degraded Forest Lands: The most important source of good water are the watersheds managed as forest. Existing forests in upper watersheds produce a number of substantial benefits which should not lightly be discarded, as increasing amounts of forest come under planned or unplanned forest conversion to agriculture and grazing.

Natural "Shola" forests: A characteristic feature of the Western Ghats in India is the occurrence of "Sholas" above 1500 m. They are found in patches in hollows and sheltered folds surrounded by rolling downs in the Anamalais, Nilgiri and Palni Hills and the high ranges of Kerala and Karnataka. These evergreen forests are with thick undergrowth and the trees are short-boled and attain a low height of 15–20m.

The recycling of nutrients in "Sholas" keeps the forest under high fertility status with rich top soil and dense vegetation. Thus, there is no erosion problem in protected "Sholas". They provide *perennial unpolluted, crystal-clear water* to the hill streams of Nilgiris and various villages and towns are dependent on these streams. Hence, it is absolutely necessary to protect these "Sholas" as they are protective in nature and are of paramount importance for soil and water conservation in the hills and in addition, they are India's national assets with aesthetic, recreational and anti-pollution value.

Shola pack-up: The undisturbed, closed forest is unquestionably the best situation in watershed cover, for this permits the canopies, litter, soil organic layer and root systems to have the greatest roles in minimizing erosion of all kinds. A hierarchy of human uses can be considered, each with an increasing order of disturbance to this protective function. These might range from scientific study and wilderness recreation, through minor forest product harvesting, to logging and shifting cultivation.

The foresters of the 19th century believed that the presence of the forest itself caused an increase in rainfall. They used this argument sincerely to defend their forests against invasion and destruction. Scientific study of the atmosphere was not then capable of testing this theory, which was enshrined in the early forestry textbooks. Today we are used to seeing satellite photographs of the world's weather systems, with vast swirling patterns of convergence generating rainfall on a scale several orders of magnitude greater than that of the forested areas.

The Forest Survey of India (FSI 1988) has estimated that almost half of the forest area has a crown density of less than 40 per cent. The National Remote Sensing Agency has found (NRSA 1985) that the area under good forests declined from 46 to 36 million ha from 1970–73 to 1980–82. There must have been further denudation of forest lands since 1982, as Social Forestry Projects did not cover forest lands. Therefore we accept the National Wastelands Development Board's estimate that 36 million ha out of the total of 67 million ha of forest land are degraded (NWDB 1988a: 26).

It should be possible to estimate the value of the sustainable forestry production, which is lost annually as a result of denudation. However, to get some idea of the full extent of the losses caused by deforestation and denudation, our economists must think of placing a price tag – howsoever small and arbitrary it may be-on *each ton of* the irreplaceable top soil, and *each cubic metre of the sweet water* which is needlessly lost to the sea as a result of the degradation of catchment erosion and excessive run off which takes place on denuded slopes. It is certain that such an exercise – which would incidentally demand that avoidable losses of top soil and run-off should be systematically estimated and monitored, and not completely ignored as at present – would reveal losses of the order of tens of thousands of millions every year. It needs to be appreciated that it is these losses of soil and precious water which to a large extent explain the endemic poverty of the Indian people, and must therefore be halted and reversed at all costs, if we are to survive – let alone flourish – as a self-respecting country.

Some idea of how big these losses are, will be obtained from the fact that according to the latest available information, the total amount of soil eroded in the Ganga Basin is around 6 billion tons per annum. Since this basin drains around 25 % of the country's surface, including some of the most erosion-prone parts of it, it would be safe to assume that the total amount of soil erosion in the country is of the order of at least 12 billion tons a year. Even if we assume a ton of top soil to be worth only Rs.5/- which is a fraction of what even ordinary sand sells for at the site where it is collected or mined. The value of 12 billion tons works out to Rs.6,000 crores ($1.5 billion). A similar exercise for water would reveal even bigger unreported and unquantified losses.

There is a widespread belief that forest covered upland watersheds will *prevent* floods on the mainstream, downstream, on major rivers. This belief is also translated to "floods are *caused* by forest cutting, and flood damage can be *eliminated* by large scale reforestation or afforestation of upland catchments." For instance, monsoonal floods in the Ganges and the Indus (which have always occurred) have been attributed to tree cutting in the uplands (*World Water*, 1981). A statement by *Openshaw* (1974) that "the principal cause of the recent floods in the Indian subcontinent was the removal of tree cover in the catchment areas for fuelwood", was repeated at the 1978 World Forestry Congress (*Avery*, 1978).

For an audience concerned principally with forestry, the watershed management we are concerned with is that of the forested areas, or of areas which could usefully bear trees. We need to consider the environmental role of forests, especially their hydrological effects and their importance as sources of clean water, fuel, fodder and minor forest gatherings as well as major commercial timber crops.

Post Green Revolution Dryland Watershed Management: After achievement of the national goal of self-sufficiency in the matter of food grains through the development of irrigated agriculture in the early 1970's, an all India Coordinated Research Project was launched at 23 participating research centres in the country. In the vicinity of these centres, pilot projects of integrated watershed* development were launched to test, adapt and refine the research findings. The results brought out good potential crop varieties, moisture conservation measures and input oriented cropping system and above all sustained flow of water. Because of the inherent uncertainties in the amount and intensity and distribution of rainfall, coupled with resource poor conditions of dryland farmers, the technology could not be adopted in a big way. However, by the end of 1970's, *it became clear that water was the most critical factor and unless rain water is managed scientifically*, the future of rainfed crops would continue to fluctuate.

Therefore, in the early 1980's, during the period of the Sixth Five Year Plan, the Department of Agriculture and Cooperation launched a pilot project for propagation of water conservation/harvesting technology in rainfed areas, in 19 watersheds located in 15 states, representing major agro-climatic regions of the country. The Department of Rural Development also adopted this scheme and 23 watersheds were selected in the Drought Prone Areas Program (DPAP) – areas for development as models. Thus, a total number of 42 model watersheds were developed. The central point was *water conservation and water harvesting*. Field studies of tropical watersheds, using combined budgets of energy and water, have already permitted the calibration of predictive computing models for streamflow. Good results were obtained and the need for adopting *afforestation approaches* and for *bringing vegetative conservation measures* and promoting a simple and low cost water management technology was highlighted.

On the basis of accumulated experience, the National Watershed Development Program for Rainfed Agriculture was launched during the Seventh Plan in 89 in selected watersheds of the country. As per project design only non-

* Watershed: This is the basic unit of implementation of research projects and development programmes. Watersheds habe varying treatable areas and extend from 2000–4000 ha. In the Integrated Watershed Programmes various treatment measures namely agriculture, forestry, pasture development, horticulture development and engineering measures are identified and implemented depending upon the need of degraded areas.

arable lands (non agri-lands) were to be developed by funds provided from other schemes. It was, therefore, felt that a single window financing and a task force approach was needed for sustainable development of the entire rainfed areas.

Watershed conservation was the main pursuit and all the three spatial components of the land mass, namely arable land, non-arable land and drainage lines, were planned and developed as one organic unit, applying technology that is low cost and simple and easily adopted by the farmers. The main approach of water conservation involved more reliance on traditional dug-out sunken structures like water conservation ponds, trenches and wells to promote around them, and utilization during the months of winter and summer. This was followed with intensified afforestation vegetative conservation measures support, wherever necessary, with minimum structural systems to promote green cover.

Water Harvesting and Afforestation Techniques: Contour trenches are best suited for plantation crops, afforestation works and for pasture land. These trenches are meant to intercept the runoff and convey it to vertical disposal drains, excavating at intervals wherever necessary, ranging from 100 m to 200 m without causing soil erosion. Contour trenching is adopted for slopes greater than 33 % in high rainfall hilly regions with badly eroded soils. These are practised for afforestation works wherein seedlings of economic tree species are planted in the trench with half filled excavated earth for areas wherein plantation crops such as tea, coffee, etc., are raised or sometimes even for pasture.

The runoff from steep slopes and rocky areas is required to be safely drained through diversion drain or diversion bund at non-erosive velocity to avoid damage to flat lands. Peripheral bunds should be constructed along the gully and permit water to enter only at safe points with sufficient protection.

Contour trenches of 4.0 m × 0.5 m × 0.5 m (trapezoidal cross section) at 10 m horizontal interval are to be made for conserving rainwater with an equalizer every 4m apart. The end of these trenches are to be hooked up (Figure 4).

In between the trenches, pits of 0.5m x 0.5m x 0.5m are to be made in a row at a spacing of 4 m. In trenches and pits,

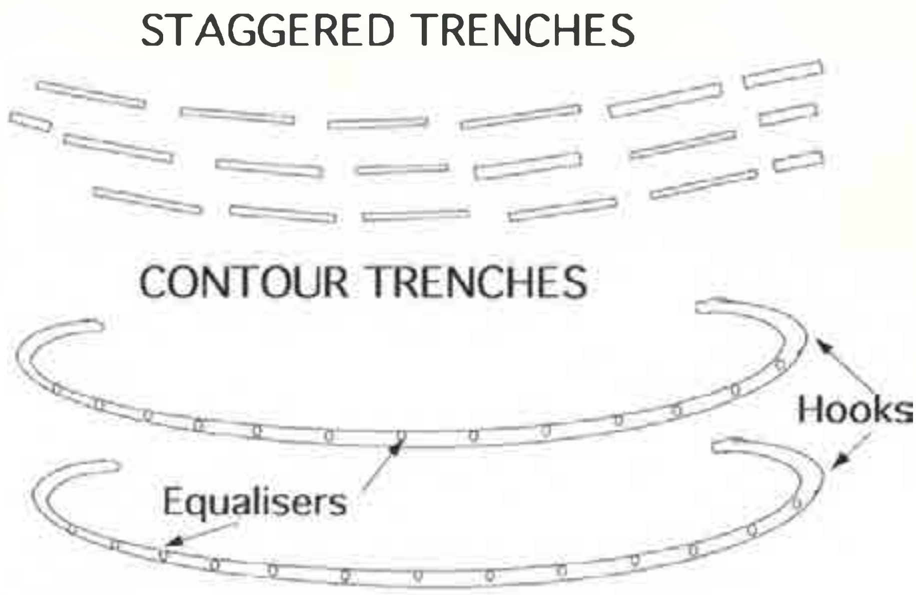


Fig. 4: Forms of trenches.

tree seedlings may be planted after filling half of them diagonally with soil and utilizing the remaining soil to form a level mound on the downhillside to encourage water collection.

In slopy areas, as an alternative for simple pit planting, container tree seedlings can be planted in pits of 30 cm^3 after forming semi circular terraces with 90 cm diameter (45 cm radius with inward slope having 4.5 cm depth of cut in the middle) for effective moisture conservation along with a grass strip formed on the lower portion of the mound.

Graded Trenching: Graded trenches are identical to contour trenching in all respects, except that they are excavated with a longitudinal bed grade designed by Mannings formula.

$*V = 1/n \times R^{2/3} \times S^{1/2}$

where V = average velocity of flow in m/second.
n = roughness coefficient of channel.
R = cross sectional area divided by wetted perimeter in metres.
S = slope of the channel or hydraulic gradient.

The grade is given so that the intercepted runoff from above will be carried rapidly to the vertical disposal drain without overflow. The interspaces between the trenches are cultivated with annual crops. The vertical interval followed is 1.5 m. The cross section is trapezoidal with 60 cm top, 30 cm bottom and 45 cm height. These trenches are suited to areas receiving more than 150 mm annual rainfall.

Staggered Trenching: In poor and medium rainfall region and on lands put under plantation crops, staggered trenches can be excavated at suitable vertical intervals for effective conservation of moisture. For staggered trenching, it will be generally equal to twice the row spacing for plantation crops such as tea and coffee. The trenches are staggered between rows so that there will be no slope longer than the length covered by the 4 rows of bushes. In Nilgiris, vertical interval generally adopted is 1.5 m, with 2.5 m length trenches.

A list of tree species suitable for different habitat are given below.

Erosion & Landslip Control

Ailanthus excelsa	*Lannea grandis*
Derris trifoliata	*Populus ciliata*
Erythrina variegata	*Salix* spp.
Filipendula spp.	*Vitex negundo*

Agroforestry: Agroforestry is the need of the present time when the country needs increased production per unit area per unit time. Agroforestry has been specially beneficial on lands subject to erosion and under situations when crops fail due to aberrant weather conditions. In agro-forestry practices, in addition to crop production, the farmer gets fuel and fodder. Because of pressure of human and animal population on the land, agro-forestry has gained importance as a practice for producing foodgrain, fuel and fodder simultaneously. There are fragile hilly ecosystems like the one existing in this region where there have been considerable misuse of arable lands along with degradation of forest cover. This has led to tremendous amount of soil erosion and the accompanying problems.

The conservation of land and water resources with silvipastoral, agroforestry and afforestation measures in catchments of these hills is of vital importance to the prosperity of the people residing in the locality. It has a direct bearing on the population in the lower reaches of the river system as it greatly influences, the flow in the streams and the frequency and severity of the floods.

It will be necessary to focus greater attention on agroforestry for the utilization of wastelands in this region where pressure of human and cattle population is very high on the land-water-plant systems. It will be necessary to identify multi-purpose trees with two or more uses as fuel, fodder, fruit, fibre, industrial raw material or timber etc., since there is a shortage of fuel and fodder production.

Silvi-Pasture: A silvi-pastoral system is a kind of agro-forestry, practised in degraded lands. It is a combination of trees and grasses-in natural grasslands or by planting selected grasses along with trees. The multipurpose (MPT's) trees and grasses are usually raised for fodder and fuel and sometimes for fruits and other uses.

The result of the work in the last 2½ decades over the length and breadth of our country and achievements thereon especially in watersheds with forestry treatments are brought out in the following 4 examples in states like Rajasthan, Madhya Pradesh, Tamil Nadu and Haryana. These are real life situations with implications on livelihood security needs of poverty ridden areas.

I. Where Deserts and Mountains Bloom and Green – (Aravalli Hills Region – Rajasthan State)

S. S. Dhabariya, former head of the Remote Sensing Division of the Birla Science and Technology Centre, Jaipur, observes: *"The Aravalli hill region had thick forest cover during earlier decades. It helped in protecting the soil cover and water aquifers and provided favourable conditions for the regeneration of tree-stock and pasture."*

In 1980–82, only 1.7 per cent of the area specified as forest in Rajasthan had actual green cover. Remote-sensing data showed that the Aravalli was brown in colour. In 1984, only 28.6 per cent of the notified forest area on the Aravalli was green – the National Forest Policy specifies that 60 per cent area in hills should be under forest. From 1970s to 1980s, the Aravalli lost around 40 per cent of its forests. Every year, four per cent of Aravalli was becoming a wasteland, according to Dhabariya.

On the lap of the barren Aravallis, around 650 villages faced an acute water shortage. The rainwater used to run off, taking away the fertile top soil. Hardly 10 per cent of the cultivable land was ploughed and the yield was discouragingly low. People migrated to nearby urban areas like Jaipur and Delhi for work. "When we started our water harvesting programme in the villages, not a single soul was there to talk. All of them migrated", remembers Kanheya Lal of the Tarun Bharat Singh Society (TBS), an environmental organisation.

"The traditional knowledge of water harvesting was given a burial by the government, and villagers were never consulted." The irrigation department had labelled it a *"dark zone"*. No new wells were allowed to be dug, while the existing ones were dry. The five rivers – Bhagani-Teldehe, Arvari, Jahajwali, Sarsa and Ruparel – which once formed the lifeline of these villages were dead. Groundwater was available only at a depth of 60 metres or more.

TBS started work at Gopalpura in 1985. Check dams were built to stop rainwater run off. Today, after 12 years, there are around 3,000 water harvesting structures in more than 750 villages and more than enough water to last the entire year. Groundwater is available at five to six metres and the five dead rivers have become perennial. The irrigation department recently declared it a *"white zone"*.

Villagers were made equal partners in sharing the water. Water harvesting structures were made with villagers contributing 25 per cent of the cost through labour participation and the rest coming from the TBS. The *gram sabha* (an assembly of villager elders) was made the nodal agency for looking after such structures and villagers were made the partner in their own progress. Green patches in the barren Aravallis are a reminder that "if villagers wish, it would be all over the Aravallis".

Some 22 per cent of the district's land area has been brought under the Rajiv Gandhi Watershed Development Mission (RGWDM) by April 1998. Some 374 villages have got involved in developing 249 micro-watersheds. "Once water is assured, the life around it prospers", says Rajendra Singh, Secretary of TBS.

The efforts of the villages and a local NGO leader Tarun Bharat Singh (TBS) has regenerated 6,500 sq km of land in 650 villages. The Aravalli is getting green again. Villagers now protect forests and there is a ban on stray grazing. "The forest cover around the villages in the core area has really risen as people are now protecting it themselves", says B. M. Sharma, the deputy project director of Sariska Tiger Reserve. Official documents say that the forest cover is 40 per cent now, a rise of 33 per cent in the past 15 years for the Aravalli.

"Birds have again started circling the hills as the old forest is regenerating. One can also hear a leopard roaring", says Rajnath Meena, 40, who is seeing green cover on the hills for the first time. According to TBS assessment, over 60 per cent of the 6,500 sq.km-area in which it has worked is under forest cover, both regenerating and planted.

Thanagazi, a *'dark zone'* in the 1980s, was recently declared a *'white zone'* by the irrigation department, indicating the wealth of groundwater. Water tables are constantly rising. In Jaganathpura village, farmers are again restoring wells that had gone dry earlier. For the first time, Bishnu, a farmer in the village, felt tempted to cultivate his barren two hectares of land. He has started digging an abandoned well, spending Rs 10,000. "I saw water oozing out of my totally dried up well", he says.

"There is a direct correlationship between the works on johads and rise in groundwater table" feels G. D. Agrawal. According to him, each johad with a storage capacity of 1,000–1,500 cubic metre per hectare has raised annual average groundwater table by about six metres. All the 36 villages studied by

Agrawal reported rise in water table by an average of about six metres, who has done an independent assessment of TBS's works.

II. Jhabua Case – Path to Green Health

Today, Jhabua is truly a temple of modern India, to use Nehru's phrase, which shows how poverty can be eradicated from its roots by empowering the local people to manage their environment. Jhabua is an outstanding example because it is an effort by the State Government to involve the people in land and water management. Already, satellite imagery is showing changes in the number of water bodies and the extent of the green cover.

The foundation of any watershed programme is water and soil conservation. In the case of Jhabua, it means arresting the water that falls on the hill-slopes and instead of allowing it to run, carrying with it precious topsoil, the water is made to percolate into the land and recharge the groundwater wells.

The protection of the land in the watershed and planting of various species of benefit to the local people (like bamboo, amla, *Acacia catechu* and neem) has shown a 66 per cent reduction in wasteland area. In the 11 micro-watersheds studied district officials' estimate show that over two million trees have regenerated. The regeneration rate has been far more rapid as compared to lands where only joint forest management programmes have been implemented because the water conservation efforts increase soil moisture and, therefore, plant growth. In turn, there is a *more rapid increase in economic returns to the poor people* involved in watershed management.

Possibly the biggest benefit has come from the rapid regeneration of grass and, therefore, increased fodder availability. Some estimates suggest a 5–6 times increase in grass from the regenerated lands.

An ecological-economic change has come about in Jhabua district, Madhya Pradesh, through a *massive people's movement*. This is a path to Green Wealth by Massive People's Movement.

TAMIL NADU

III. Interface Forestry Programme (IFP) – Forestry Model in Salem District for Forest and Water Supply

The total amount of rainfall over any area is more or less fixed. This is particularly so in Tamil Nadu, where the main part of the rainfall comes during the monsoon season. But the moment water reaches land, its distribution and storage can be manipulated to a large extent in Tamil Nadu – water harvesting has been a part of the traditional water management system in the area for ages. Tanks, percolation ponds and anicuts are found all over the plains. When one turns to the hills and forest areas, however, the manipulations are of a more negative type. In large parts, the forests are heavily degraded. Indiscriminate tree felling for industry and fuelwood, and clearing of forests for agricultural purposes, has rendered barren those areas which were earlier covered by forests. Grazing of cattle and browsing by goats, in combination with forest fires, has added to this degradation.

Topographically, most parts of Tamil Nadu are dominated by two features: vast plains, and hills rising abruptly from the plains. The plains are intersected by rivers of a sand-river type, which feed the surrounding aquifers. From the air one can see the light-grey river beds surrounded by green patches of land irrigated by groundwater. The distribution of water flow in the rivers, which is related to the conditions in the catchments, has important implications on the water supply for people in the plains.

There is a clear conception among people in Tamil Nadu that there has been a dramatic change in the total amount of water available for consumption as well as in the distribution of flow in the rivers during the last few decades. Previously, it is held, when there was a good forest cover in the catchments, the hill streams and rivers on the plains were perennial, whereas now they carry water only during the rainy season and for a short time after that.

Interface Forestry Programme (IFP) is one such endeavour in Southern India. Tamil Nadu, the southernmost state of Indian peninsula, is endowed with 22,700 sq km of tropical forests replete with biodiversity. Over 6,000 sq.km of these forests adjoining 3,000 villages remain degraded due to anthropogenic factors such as illicit felling, over-grazing and recurrent forest fires. Tamil Nadu Forest Department embarked on restoration of such degraded forests on watershed basis with people's participation through Interface Forestry Programme under SIDA aided Social Forestry Project. About 35,000 ha of degraded forests have been treated under this programme since 1988.

Socio Economic structure of the sample villages: IFP in four sample villages viz., Jalluthupatti (JP), Allikuzhi (AK), Sigaramahanapalli (SP) and Thagarai (TG) were taken up for the current study. All these villages are socio-economically backward with predominance of tribals and backward communities. Homogeneity of the population makes it easier to identify appropriate claimants as evidenced from Sukhomajri experience (*Levine*, 1986). This is also true of JP and AK which have homogenous population.

While JP has 83 per cent of its population as tribes, AK has 1 % tribes and the other two villages have no tribal population. The schedule caste population is 90 % in AK, 40 % in TK and 15 % in SP. The landless agricultural labour and marginal farmers outnumber the other two classes of small farmers and big farmers in the villages studied barring SP where the number of small farmers is high.

The tribals in the above three hamlets have got only 55 open wells for irrigation. 22 Electribal pumps and 25 Diesel pumps have been used for bailing out water from the wells for irrigation. Paddy has also been cultivated in a smaller extent with the available irrigation facilities.

Investment: The project was initiated in 1988 in JP and AK while it was extended to SP and TG in 1991. The total investment in all the four villages is Rs.22.60 million over seven years (Table 2). JP received a major share of this to the tune of 6.57 million. The major investment was on *reforestation coupled with soil and moisture* conservation works such as construction of percolation ponds, check dams, random rubble check dams and contour stone walls.

Tab. 2: Investments in the sample villages.

Sr.No.	Years	JP *(in Rs.)*	TK *(in Rs.)*	SP *(in Rs.)*	AK *(in Rs.)*	Total *(in Rs.)*
1.	1988–89	211920	–	–	428000	639920
2.	1989–90	872879	–	–	1284000	2156879
3.	1990–91	1022790	242900	94008	1455000	2814698
4.	1991–92	1232628	1448000	689449	1112000	4482077
5.	1992–93	1390126	1539000	939038	750000	4618164
6.	1993–94	1220620	905000	1326401	523000	3975021
7.	1994–95	628949	1306000	1066071	980000	3981020
	Total *(in Rs.)*	6579912	5440900	4114967	6532000	22667779

Tab. 3: Income of tribal people from agricultural land and agricultural labour.

Year	Income of the tribal villagers from (RS)	
	Agricultural Land	Agricultural Labour
1987–88	3,82,600	41,500
1988–89	4,17,200	49,000
1989–90	4,93,550	52,000
1990–91	6,27,300	65,200
1991–92	7,97,900	79,200
1992–93	8,86,590	1,09,100
1993–94	9,85,100	1,36,275

Afforestation and Other Works: Asset building in the form of plantations have been raised over 834 ha to meet the forest based needs of the tribal villagers.

Soil and moisture conservation works like construction of check dams, retaining well, contour stone wall, catch pits and gully plugs were carried out to augment the ground water potential and to arrest the soil erosion.

Benefits

1. **Water level:** The most important benefit that could be perceived by the people immediately is substantial increase in water availability due to afforestation and soil conservation measures. The increase in water level varies between 25–200 % in JP, 0–25 % in SP, 25–100 % in AK and 20–25 % in TG.
2. **Agriculture Improvement:** The augmented water supply has lead to improved agriculture. The total area under crops has increased, the number of crops the cropping pattern and crop mix in these villages have changed towards economically valuable crops. For instance, JP grew 93.8 ha of tapioca, 31.92 ha of paddy during 1993-94 compared to 37 ha and 6.2 ha in 1987–88. As a consequence the land value has increased by about 50 %. Migration level has come down from 61 persons in 1987 to 10 persons in 1993 as a consequence of improved employment.
   Regeneration of forests has improved the floral diversity markedly redeeming over 30 different native species. Illicit felling has stopped. A steady flow of income to the tune of about Rs.50,000 is being realised by the locals as each watershed from Non Timber Forest Products (NTFP) collection. Gap planting with NTFP plants like tamarind and gooseberry in future will further augment this income.
3. **Increase in the Earnings of the Tribal People:** On account of the interface forestry activities, the land put to agricultural uses have increased considerably over the years from 1987-88 to 1993-94 resulting from increased earnings from the agricultural lands from cultivation as well as the income of agricultural labourers. The details showing the income of tribal people from agricultural land and agricultural labour are shown in Table 3.
   The income from agricultural land during 1989–90 has been increased gradually and doubled in 1993–94 and income through agricultural labour increased by more than twice during the same period.
4. **Migration Decreased:** The migration of the hill tribes for their livelihood, to other districts has been reduced considerably due to generation of employment. The details showing the migration over the years are shown in Figure 6.
5. **Increase in the Cultivable land use pattern:** The soil and water conservation works carried out in this village has augmented the ground water potential resulting an upward trend in the cultivable lands. The details showing the different types of major crops raised with area are shown in Table 4 and Figure 7 and 8.

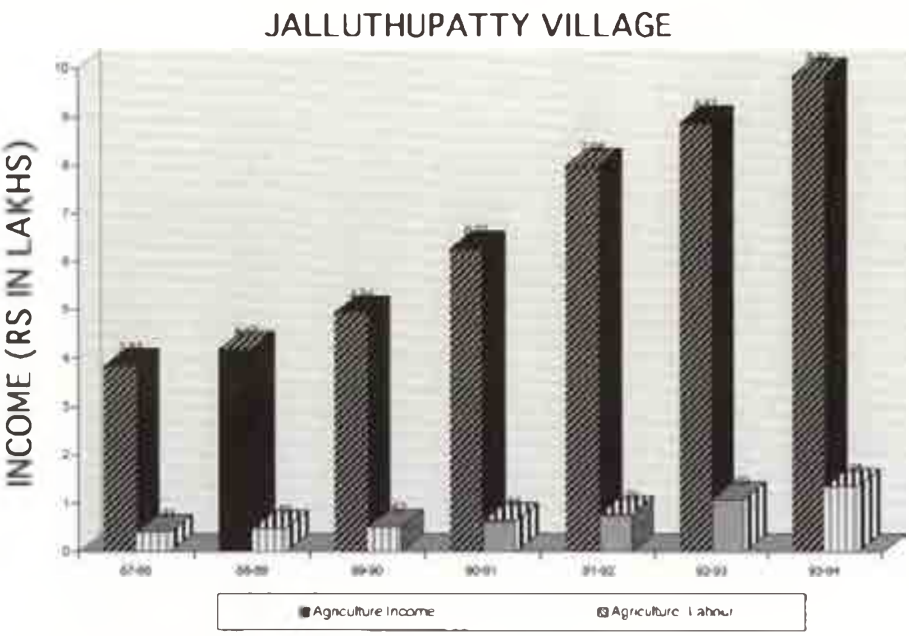


Fig. 5: Income of the Tribal Villagers.

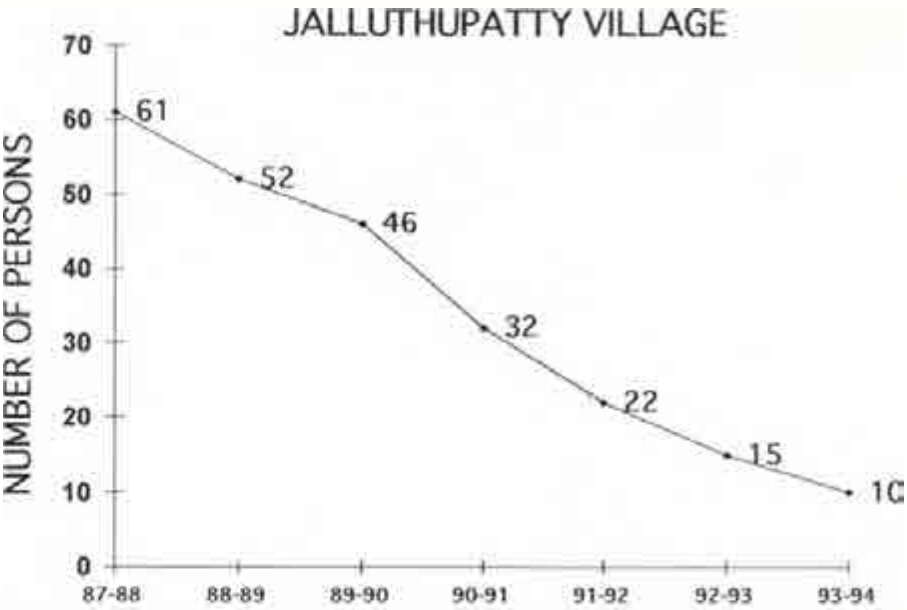


Fig. 6: Migration.

Tab. 4: Cultivation area of major crops.

Year	Tapioca	Paddy	Millets	Flower (Rose)	Total
1987–88	92.50	15.50	6.00	–	114.00
1988–89	97.25	17.60	7.20	–	122.05
1989–90	117.50	21.40	7.80	–	146.70
1990–91	149.30	29.60	6.70	–	185.60
1991–92	189.90	41.80	5.40	2.00	239.10
1992–93	211.10	59.40	6.50	3.00	280.00
1993–94	234.60	69.80	3.75	3.50	311.65

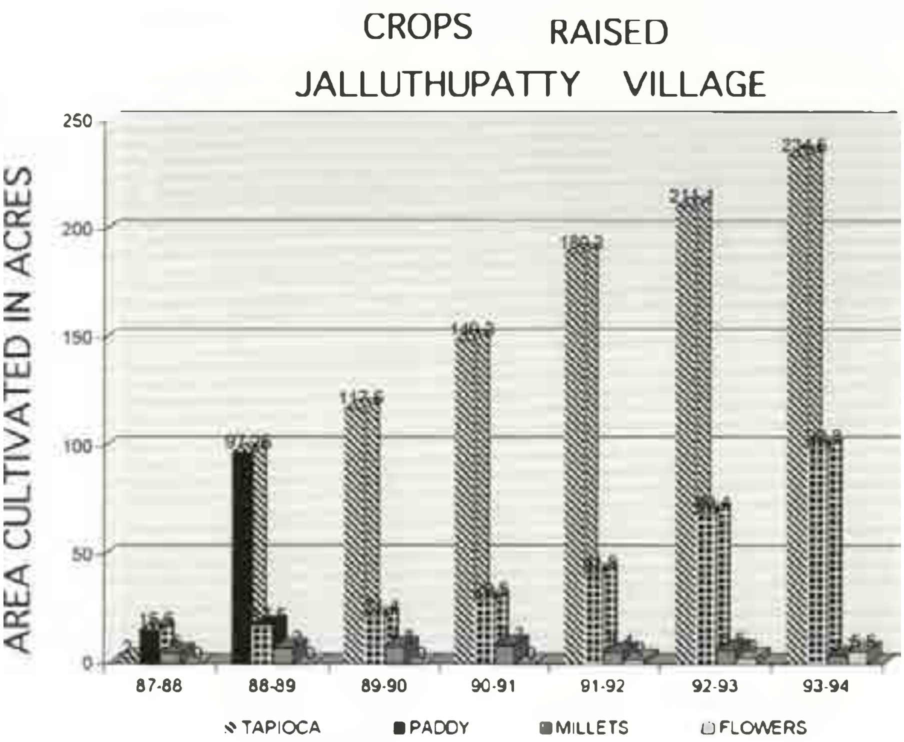


Fig. 7: Crops raised between 1987 and 1994.

Rose gardens have been raised since 1991–92 only on account of availability of assured water sources and the rose flowers have been sent to Salem and Madras cities.

There are several intangible benefits such as reduction in soil erosion, a more evenly distributed water supply, well distributed rainfall, improved species diversity in the forests, a positive external effect (aesthetic landscape) and improved living standard of the people. If these intangible benefits are also taken up into consideration the net benefits will increase.

The forests have become well wooded now due to involvement of the local people.

IV. A Case Study in Joint Forest Management – Sukhomajri Model of Haryana State

Joint Management of Forests in Haryana began in the early 1980s when, as an experiment, the forest department sought to involve local people in managing the watersheds of Sukhomajri and Nada in the lower Siwaliks which constitutes the outer Himalayas. The experiment was successful, and led the Haryana Forest Department to adopt the participatory mode of forest management in an effort to regenerate degraded forests in the Siwalik hills.

The Story

The Operational Research Project (ORP) Sukhomajri was officially launched on 15th May 1975. Professor P. R. Mishra and Dr. S. P. Mittal from the Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh, were the first to be associated with the project.

The primary objective of the project was to manage the heavy silting that was filling up Sukhna Lake in Chandigarh. Two thirds of the capacity of the lake had been lost on account of siltation. Dredging was found to be a non feasible option on account of the cost involved and the non-sustainability of such an operation. The Chief Commissioner of Chandigarh, Shri M. C. Mathur, approached the Institute to help find solutions.

"Degradation of the hills near Sukhomajri was found to be most acute

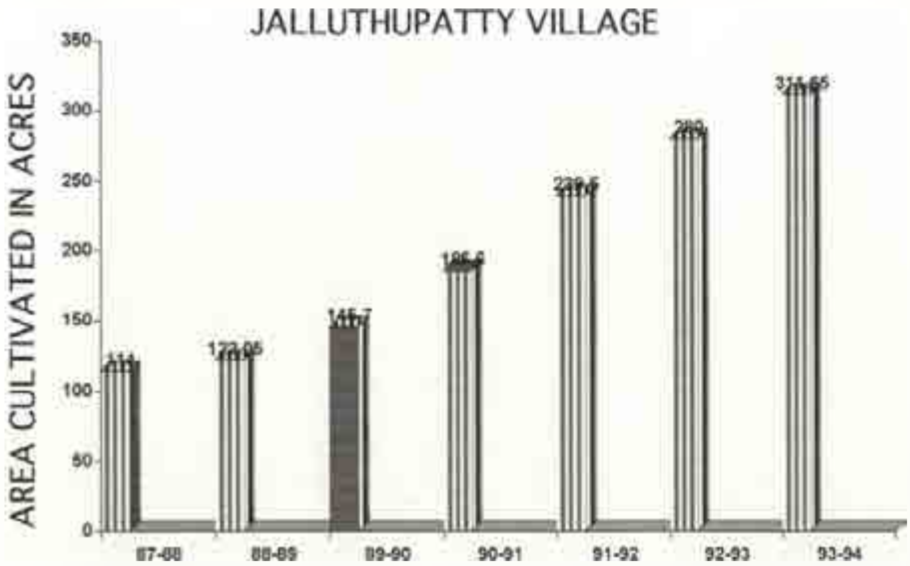


Fig. 8: Area Cultivated.

in the whole catchment of the lake. Barely 5 % of the slopes had any vegetative cover. The hills were totally cut up into pieces with tall, bare, vertical walls. A big gully was found to have entered the village after breaking the boundary of Sukhna Lake's watershed. Here, the water from the hilly system which should have flown to the village side, had started flowing into the lake. In the process, the farmers of Sukhomajri had started losing their fields. In 1974, a 35 feet wide piece of agricultural land was found converted into a 30 feet deep gully in just one year from uncontrolled rain water flow from just 10 acres of hilly land."(*Mishra* et al, 1987). Grazing and illicit felling were found to be the major culprits behind the sedimentation menace.

Around this time, the Ford Foundation came forward to fund projects for controlling and reducing sedimentation. Two hundred thousand dollars were provided to the Institute for Operational Research Projects (ORPs) at Chandigarh and Narendranagar. The Sukhomajri project was aimed at transferring technologies for *effective watershed management* and for the rehabilitation of the Shivalik hills with the specific objective of saving Sukhna Lake.

During the first two years, the project could not make any headway because of the traditional manner in which the work was undertaken. The traditional approach focused on the building of debris basins, check dams and other engineering and structural measures. This was supplemented by plantation of trees and grasses, construction of contour trenches, gully plugs etc. Thousands of trees were planted in 1975 and thereafter.

These efforts and initiatives resulted in vegetation cover in the catchment area which in turns resulted in flow of clean water to the Sukna lake in a regulated manner. By 1977 the water from this storage was supplied to the fields. Wheat yields of 44 quintals per hectare were recorded and so the idea was extended. A site for the first dam was surveyed and selected. In March 1978 construction of the dam was started. By June the dam was completed. In all about Rs.1.09 lakhs was spent. 20 hectares of land was irrigated. That very year water was provided for the wheat crop. Average wheat yields of 35 quintals per hectare were achieved. This had never been possible in the village. For the first time, *forty families out of sixty families got water*.

After this the team held a meeting with the villagers. This time it was the villagers who listened. The team asked the villagers whether they wanted clear water from the dam. If the villagers did not protect the catchment, they were told, they would lose the water. If they wanted clear water they had to stop grazing and the felling of trees. The villagers promised. But how would they meet their requirements of fodder and fuel? They were told that they could cut the grass and bring it on headloads to feed the animals, but under no circumstance should they permit grazing. For fuel wood they could prune the branches, but not cut the trees. This was the first initiative in joint forest management.

Rain water had worked as a catalyst. The dam and the water was there. They got 35 quintals of wheat per hectare and that was a fact. An alternative had been provided.

The forest surrounding Sukhomajri is Reserved Forest. The villagers had the traditional rights of cutting the grass and picking up deadwood. Now 18 years since the project began one can see a beautiful forest around Sukhomajri. The project received very good cooperation from the Forest department. During the initial period the Conservator, Shri Gurnam Singh, facilitated the team to do what it planned to do. The local DFO at Pinjore was always with the team. In the absence of such cooperation, external agencies often find it very difficult to work in the forest.

Initially lots of goats were being reared by the villagers. Between 1975 and 1985 the number of goats came down from 246 to 8. With greater income in their hands, the villagers started procuring buffaloes. Soon, milk became the main source of their income. There are now about 250 buffaloes owned by 90 families compared to 129 in 1977. The local boys purchase the milk at Rs. 7–8 per litre and sell it at Rs. 11–12 per litre in the nearby urban areas of Pinjore and Chandigarh. Veterinary cover is available at Pinjore at a distance of 4 kms. Today one can see a healthy stock of stall fed buffaloes in the village. The biggest farmer has about 14–15 buffaloes.

To meet the fodder needs of the animals, the villagers began growing green fodder and Barseem (*Egyptian clover, Trifolium alaxandrinum*). Wheat and Barseem are now the major Rabi crops. Barseem fetches Rs. 2000 per bigha at Pinjore. In 1987 there was a serious drought. Because of the availability of water in the village, 35 bighas of land were put under Barseem that year. In the absence of this water the villagers would have spent Rs. 70,000 for purchasing the Barseem from Pinjore.

Now there are two small dams and one big one at Sukhomajri. Two tubewells have been installed because of the rising water table. For financing the tubewells no outside agency has come to the village. As a policy, no credit institution, no milk cooperative, no IRDP financing has been encouraged in the village. The experiment aimed at making the village self sufficient.

A visit to Sukhomajri by Mrs Trivedi from the Planning Commission brought about the chain of developments which strengthened the peoples participation in Joint Forest Management. She appreciated the fact that it was the society which was providing social fencing/protection to the forest. In this context it appeared to be fair to provide the monetary benefit from the forest to the society, instead of to an outside contractor. As a consequence of this visit, the Government decided, that, if the society was willing to pay the same amount as the lease amount for the past years, they would get the lease for the grass. The same argument was extended to the other three villages which had rights in the forest lands in question. Societies were thus constituted for Lohgarh, Dhamala and Jattan Majri.

The fact is, that apart from the effective social fencing created by the project through the mechanism of integrated watershed management and the involvement of the people through the institution of the HRMS, the village has pursued the normal path of development to be found in most villages of Haryana and Punjab. The innovative work done during the 70s and 80s has left it's impact on *halting the denudation of the hills around Sukhomajri and in providing water* to the villagers.

Benefits of forests

In summary, forests cannot prevent floods but they can and do prevent accelerated soil erosion and destructive sediment transport by floodwaters. They give valuable protection to water resource investments in irrigation, hydropower and urban water supply.

There are many excellent reasons for reforesting or afforesting upland watershed lands, and the clarion call to embark on large-scale tree planting programs makes good sense. As a strategy to establish "wood factories" to meet needs for fuel, timber and other wood products, these programs are very much needed. Such actions may relieve some of the pressures on the remaining bits of natural forest.

Deep-rooted vegetation promotes high transpiration losses, irrespective of the type of species. Replacement with shallow-rooted vegetation will promote base flow and increase water yield during the dry season.

Regarding differences in *total water flow* from forest and non forest catchments, the literature is categorical; due to losses through transpiration by trees, and evaporation losses caused by interception, the total stream flow from afforested watersheds is lower than that for non-afforested watersheds. In Western Ghats, a change from evergreen forest to cultivation resulted in decreased transpiration which caused an overall increase in base flow by 100 percent. A review of 94 catchment experiments (*Bosch & Hewlett*, 1982) from many parts of World showed in number of experiments, with the possible exception of one *"small watershed cutting experiments have given increased total water yields over the year with the greatest proportional increases usually in the low flood months"*.

However, the above examples represent arid and semi-arid areas with fragile environmental conditions. It should be stressed that the benefits of tree planting for erosion control, flood prevention and microclimate improvement, may far outweigh the direct negative effects on total water flow from the catchments.

Tree & Tree Farming: Cultivation of tree crops on farm lands assumes greater importance. Trees being perennial plants, are better adapted than annual crop plants to tide over adverse weather conditions. Thus, even when annual crops become a total failure, tree crops continue to survive and yield some return on a later date. There are some other technical advantages also. Trees send their roots to deeper layers of soil and thus exploit the naturally available plant nutrients more fully. Among socio-economic advantages of raising tree crops, mention can be made regarding their lower costs of cultivation, comparative freedom from pests and diseases, their lower demands for human labour and above all their adaptability to postponement of harvesting.

Though there are numerous advantages of planting trees on the catchments, it is sometimes argued that fast growing trees take up and transpire more water than other vegetation and this may adversely affect the stream flow and water table. Since each case and site has its specific attributes, no generalisation can be made. Sometimes exaggerations or even erroneous statements can result from such generalisation not based on a scientific study. A case in point is that of Nilgiris wherein it has been apprehended by some people that the reported recent water shortage in the Nilgiris is attributable to large scale planting up of bluegum and wattle which, however, is debatable. Nevertheless, it is argued that these tree species, being fast growing consume considerable amount of water. Similar apprehensions are expressed in some other states also. Therefore, the effect of bluegum on water yield was studied systematically by the Central Soil and Water Conservation Research and Training Institute, Research Centre, Udhagamandalam.

Large scale conversion of grasslands into bluegum plantations (*Eucalyptus globulus*) brought a reduction of about 16 % of the expected water yield (87 mm per year) for the first rotation of 10 years (1972–82) and the trend of increase in reduction of the expected water yield is to the tune of about 25 % under the first coppice rotation (1982–92). Therefore, caution may have to be exercised while planning large scale conversion of natural grasslands of the Nilgiris into bluegum plantations.

The dryland farmer and the economically marginal farmer are the vulnerable sections of our society. It is precisely this group that has already recognised the advantages of *tree farming* and has already taken to a mixed farming system involving trees, annual crops – and raising of cattle and goats, in several pockets. One such examples is the Palladam – Kangayam areas of the Coimbatore district where the farmers raise annual crops like Sorghum, *Pennisetum typhoides*, etc., in fields scattered with trees of white babul (*Acacia leucophloea*), deriving benefit from both components of the system. It is thus clear that the practising of silvi-agriculture, involving the cultivation of useful species of trees along with annual crops, is the solution for improving the economy of rural population.

National Commission on Agriculture (1974) while giving a good break through in forest planning, gave intensified planning for tree resource development through social forestry, farm forestry and agro-forestry outside the forest areas.

Conclusion

Tropical mountain watersheds with both high rainfall and temperatures permitting all-year-round plant growth show ecological advantages for forests or for tree crops. Many well-engineered estates where tea, rubber, cocoa, or oil palm replaced forest have demonstrated for more than a century the stable control of soil and water regimes. Paired-valley catchment or watershed experiments in tropical Africa have demonstrated that with skilled development both tea estates and pine plantations could be hydrologically equivalent to natural forests (Charles Pereira).

Acute and widespread shortages of fuelwood in most countries of Asia and Africa provide a vast lowland market which offers opportunities to restore mountain watersheds to productivity and to provide employment by the replanting of steep wastelands. *Here economics and ecology are complementary.*

Not all of the fuelwood planting is on forest departmental lands. There has been a strong movement towards persuading village communities of subsistence farmers to regard firewood as a crop. The help and guidance of trained foresters in setting up nurseries and in supplying seed of fast-growing tropical species is still necessary, but the costs of establishment and maintenance are to be greatly reduced. When the community owns the plantations these costs of timber and fuel plantations are minimized. In India, for instance, the government has responded to the fuelwood shortage by budget allocations for an ambitious national programme of plantations.

There are very many excellent reasons for maintaining undisturbed or "protection" forest on watersheds. They may be habitat for endangered species that require undisturbed forest for their existence. They may represent important *in situ* gene banks of material for present or potential great usefulness in fields of forestry, agriculture, industry and medicine. They may be among the last wild places where a country's urban citizens can find a sane sanctuary from crowded and stressful living conditions; or where similarly stressed tourists from other countries can find similar recreation. They may be "sacred" forests, held in reverence by local residents or an entire religious group.

Some other good reasons pertain to the function of protected forests in connection with their influence on soil and water, though not all of these reasons, though often alleged, are in fact valid. Undisturbed forest gives the greatest amount of protection against surface erosion. Undisturbed forest, though using more water than other types of cover, does delay peak flows, and usually reduces peak flows and stormflow volumes more than other cover or logged forest (Charles Pereira). This effect occurs primarily in the streams emanating from the forest. As stormflows are routed down the watershed, these effects become increasingly smaller as other factors come into play. Protected "cloud" forest can capture more occult precipitation from the atmosphere, giving a net addition to the water budget.

When forests are disturbed, as in production forests and community fuelwood forests, some of the aforementioned benefits are foregone. The impacts can be minimized by zoning out "critical areas" and by careful adoption of performance standards on areas that are disturbed. Religious or cultural values usually would be an exception, for in this case, probably any human intervention would be completely destructive.

It is important, however, in justifying or advocating reforestation or afforestation projects, that unrealizable claims of some other benefits *not* be made. Tree planting has not been shown to increase local rainfall (may capture occult precipitation, however, in certain locations), to prevent floods, to increase the flow of streams.

Problems in achieving sustainable development and conservation of soil and water resources in the tropics are legion enough, without being plagued by misunderstanding, myth and misinterpretation. *Semantic fuzziness* adds to the scene. The consequences may be seen in *fruitless disagreement between interest groups*, propaganda instead of education, *bad policy making because of shaky scientific base*, or even good policy making but for the wrong reasons – an action that may backfire. Perhaps foresters have been guilty of acquiescing by silence in the use of some misinterpretations and misunderstandings, because the arguments or rhetoric being used were aimed at protecting forest resources or at establishing new forests – surely actions worthy of nations and statesmen. There are many eminently sound reasons for forest conservation and reforestation in the tropical developing countries.

However, by biological manipulations on the slopes of watersheds in the hill areas, it may be possible to increase water flow in the streams for a longer period. The hydrological issues related to such manipulations, however, are very intricate. It is, for instance, often claimed that afforestation will increase the availability of water in downstream areas. Experience from experiments carried out in India (Bluegum plantations of Nilgiris) and elsewhere shows that this may not automatically be so. The hydrological response depends on a wide range of physical conditions, one of the most important being the type of vegetation that is being developed (Sivanappan, R.K.).

Solving the problem of increased competition for the available water is a matter of policy decisions and improved water management practices. Improving the catchment conditions and thereby the flow of water to the plains, becomes a matter of designing optimal treatment models for the catchments. The biological treatment will be the *most important part of such models*. Optimal combinations of tree species that do not consume much water but still have favourable erosion protection characteristics, and undergrowth of a type that binds the *soil* and decreases evaporation should be developed. Grasses would probably be important in this context. Mechanical soil and water conservation techniques, and water harvesting should complement the biological efforts. They should be oriented in two different directions. Firstly, they should improve the water availability directly through the structures as such, and secondly, they should increase the moisture available for the tree plants at a micro scale. At the same time, socio-economic and production aspects have to be seriously considered and addressed as there is good evidence that forests have an important beneficial role to play in reducing the downstream social and economic costs of unwanted sediment.

Why should flood be allowed to take place when the water that they carry away is desperately needed to recharge ground water aquifers which sustain more than half of the country's irrigation? Why should the springs and wells which are the only source for drinking water in many parts of the country be allowed to dry up, as a result of thoughtless deforestation in the neighbourhood? It is also a fact that in many parts of the Ganga Basin fuelwood has become so scarce, that the poor are finding it difficult to even cremate their dead.

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Air Pollution and their Impacts on Forests in South East Asia: An Overview

Shambhu Prasad Sah

Abstract

Anthropogenic acid precursor emissions (SO_2 and NO_x) in SE Asia are currently increasing at significant level. Accordingly, acid deposition must be considered to be one of the potential significant environmental issues in SE Asia as elsewhere. This paper reviews over the present status of air pollutants emission and acidic deposition in SE Asia and their impacts on forests. According to recent studies made in China, Japan, S. Korea, Taiwan, Japan, Indonesia and others, acidic precipitation is comparable to those found in the Europe and N. America. While precipitation in S. Korea and Taiwan is marginally less acid, China's situation is getting worse. So far China has already been ranked third for SO_2 emission. However, the enforcement of emission control measures have led to significant decline in SO_2 in some countries such as Japan, S. Korea and Taiwan, but the figures for NO_x have yet to show an improvement. The impact of pollutants on forest vegetation such as sissoo (*Dalbergia sissoo*) forest of Nepal, pine decline in Japan and others are also reviewed.

Key-words: Air pollution, acid rain, SO_2, NO_x, Asia, forest decline

1. Introduction

Acid rain has become one of the most important problems in the recent global chemistry. Acidic deposition began to attract attention as a regional scale environmental problem during the 1970s in western Europe and N America. The experience in N.E. America and Europe confirms both the adverse environmental consequences of acid rain and the fact that it transcends national boundaries which therefore requires attention at a regional to hemispherical scale. The possible linkage of acidic deposition to forest decline has been intensively studied in Europe and N America. These studies have proposed several pathways by which acidic deposition. Especially N and S, could be detrimental to forest ecosystems in many ways: soil acidification and Al-toxicity (*Ulrich*, 1987), direct and indirect influence of pollutants on the photosynthetic activities of the trees (*Eames* and *Muray*, 1991) and others.

More recently, this problem has also occurred in SE Asia. Compilation of reliable quantitative emission data is a basic tool in environmental policy to prevent the adverse environmental consequences of pollutants emission. Such a database can be used for the elaboration of realistic national emission reduction possibilities, the regional air quality problems, the assessment of contribution of transboundary fluxes to national air pollution loads and the development of emission control scenarios for areas (*Lubkert* and *Tilly*, 1989).

Anthropogenic acid precursor emissions (NO_x and SO_2) in South East Asia are currently increasing at significant rates. *Arndt* and *Carmichael* (1996) have reported appreciable amount of SO_x even at higher altitude and fairly remote regions of Malaysia and Nepal.

The high rate of economic development in the Asian region has resulted in increasing anthropogenic emission of acid precursors. Consequently, adverse environmental consequences of acid deposition has become now growing concern in Asian region, too. The current scientific knowledge on acid deposition and their impacts on forests in SE Asia will be reviewed in this study.

2. Trend and status of emissions of NO_x, and SO_2

In Europe and N America anthropogenic emissions of SO_2 have now started to decline following a rapid increase during 1940s, 50s and 60s. However, the NO_x emission does not show similar decrease. Similar trends are also observed in the case of SE Asia, except in the case of China. where the emissions of both NO_x and SO_2 have continued to increase rapidly (see below), although on a per capita basis the emissions are much smaller than in Europe and N America. Projected emissions of acid rain precursors in Asia are shown in Table 1, indicating that China might have the highest rate of emission of SO_2 as well as NO_x in the coming years.

Figure 1 contains a model predicted map of total sulfur deposition (wet plus dry) based on DARLAM and RAIN-ASIA Model (*Avers* et al., 1996). This model predicts annual total deposition of sulfur in the range of 10–30 meq.$m^{-2}yr^{-1}$ in Indonesia and 30–100 meq.$m^{-2}yr^{-1}$ in Malaysia and more than 100 meq.$m^{-2}.yr^{-1}$ in some places of China.

In S Korea, the annual average increase rate of emissions of SO_2 has been 1.25 %. However, the annual increase rate has slowed down after 1990 (Fig. 2). Similarly, the annual mean value of SO_2 concentration in the urban areas of the country gradually dropped from 0.094 ppm to 0.035 ppm in 1992 (Fig. 3).

In Taiwan, SO_2 and NO_x emissions (Fig. 4 and 5) over the last decades have remained almost the same (*Cen* and *Fang*, 1993).

China has already been ranked third in the world for SO_2 emission (in 1986).

Table 1: Projections of acid rain precursors emission (million tons/yr) in Asia (Acid Rain and Emission Reduction in Asia 1994).

Countries	SO_2		NO_x	
	2000	2010	2000	2010
China	14.0	48.8	15.3	21.9
India	5.4	8.8	5.5	9.3
S. Korea	2.7	3.3	1.3	1.6
Taiwan	1.7	2.2	0.6	0.8
Indonesia	1.9	3.2	1.7	3.1
Pakistan	1.7	2.5	0.3	0.4
Thailand	2.6	3.0	1.5	3.5
N. Korea	0.9	1.3	0.9	1.2
Total	**52.0**	**76.2**	**27.1**	**44.2**

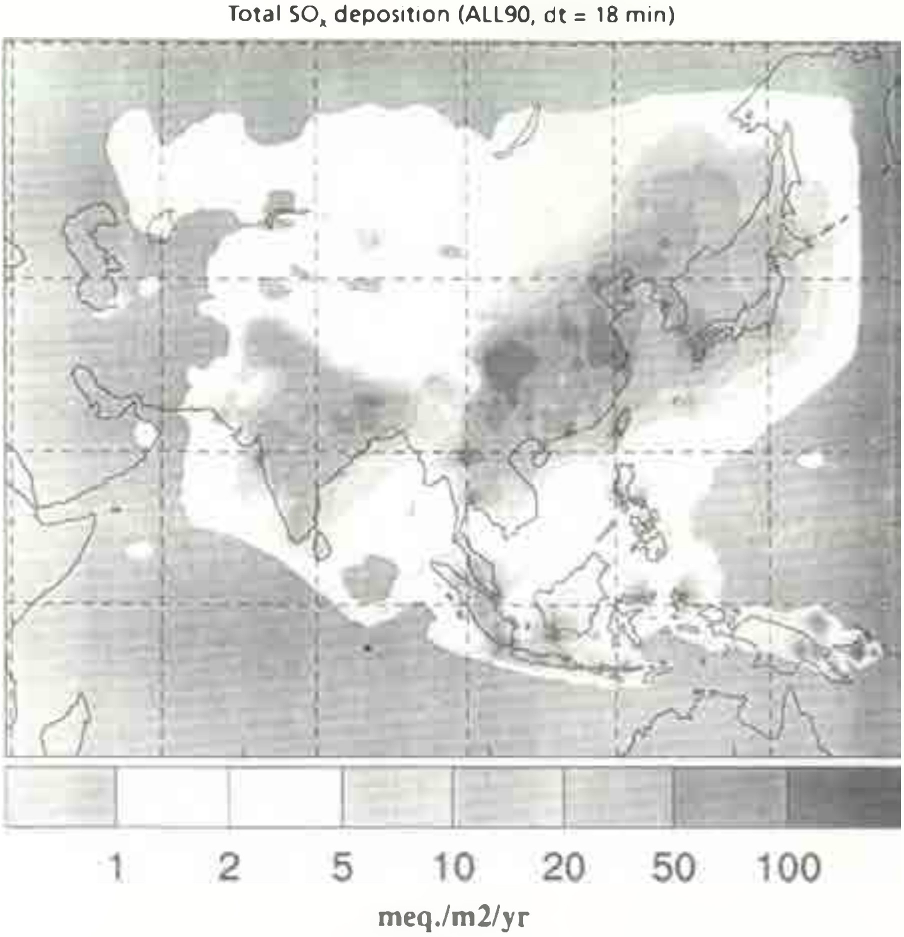

Fig. 1: Total deposition (meq.m^{-2}.yr^{-1}) of sulfur (wet plus dry) for the month of September 1989 (Ayers et al., 1996).

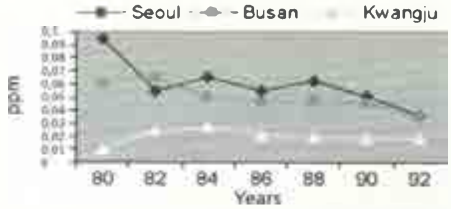

Fig. 3: Annual mean SO_2 concentration in the major cities in S. Korea (Han, 1993).

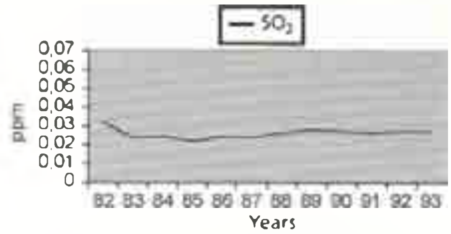

Fig. 4: Annual mean SO_2 concentration in Taiwan during 1982–1993 (Chen & Fang, 1993).

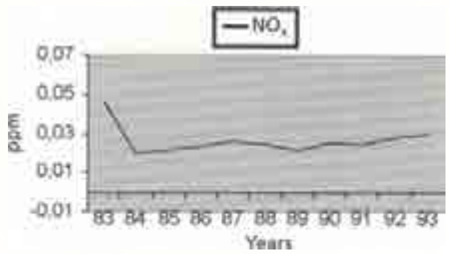

Fig. 5: Annual mean NO_x concentration in Taiwan during 1982–1993 (Chen & Fang, 1993).

The SO_2 concentration during the period of 1981–1990 ranges from 0.03 ppm to 0.05 ppm and NO_2 from 0.03 ppm to 0.07 ppm (Fig. 6 and 7). However, the figures indicate further that there is no decline in SO_2 and NO_x concentration levels.

In Japan, SO_2 emission was a national problem with a peak of 0.059 ppm in 1967. The situation has gradually improved to an annual average concentration of 0.10 ppm in 1990 (Fig. 8). In the case of NO_x, its concentration remained almost the same during the period 1970–1991 (Fig. 9).

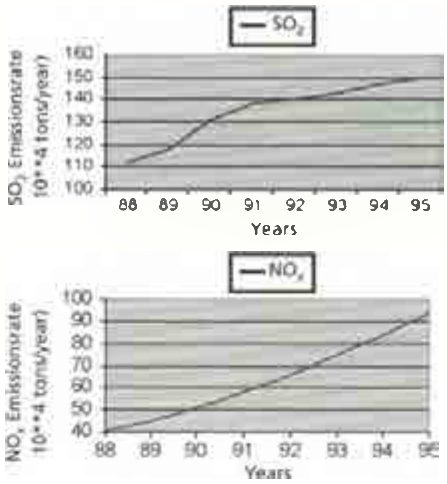

Fig. 2: Interannual variations of SO_2 and NO_x concentrations in S. Korea (Park, 1996).

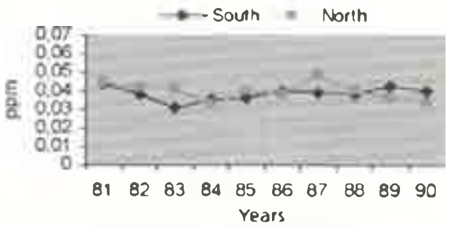

Fig. 6: Annual mean SO_2 concentration in China during 1981–1990 (EPA China, 1995).

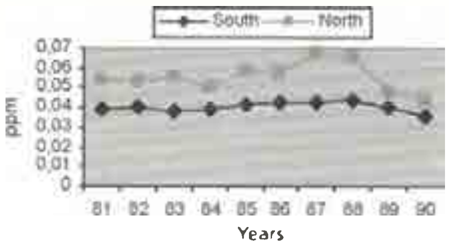

Fig. 7: Annual mean NO_x concentration in China during 1981–1990 (EPA China, 1995).

3. Status of acidic precipitation

According to recent studies made in China, Japan, S. Korea and Taiwan, acidic rain in East Asia is comparable to those in the worst affected areas of N America and Europe. An overview in the present study indicates that the pH values of rainfall in different Asian countries range from 3 to 5 which is similar to Europe and N America (see below).

In Taiwan, the acid rain is evidently prevalent in most parts of the island, especially in major metropolitan cities (Taipei and Kaohsiung) having a pH range of 4.06 to 4.37, while rural locations have a range between 4.50 and 5.24. Isopleths of the pH of precipitation both in 1990 and 1993 indicate that Northern Taiwan has more acidic precipitation than the South and the acidity of rainfall has decreased in this part of the country in 1993 (Fig. 10 and 11).

In Japan, the pH level in rainfall ranges from 4.6 to 5.5 (Fig. 12). The iso-

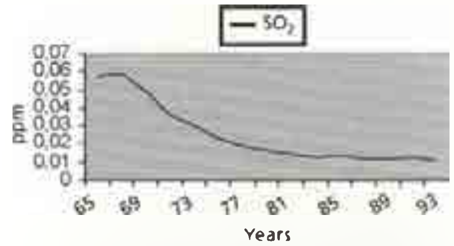

Fig. 8: Annual mean SO_2 concentration in Japan during 1965–1993 (JEA, 1995).

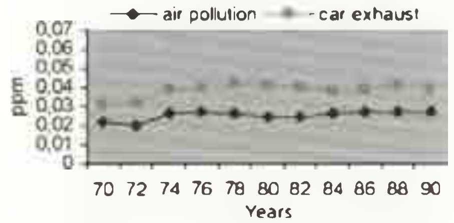

Fig. 9: Annual mean NO_x concentration in Japan during 1970–1990 (JEA, 1995). Averages for 15 air pollution monitoring stations and for 21 automobile exhaust monitoring stations.

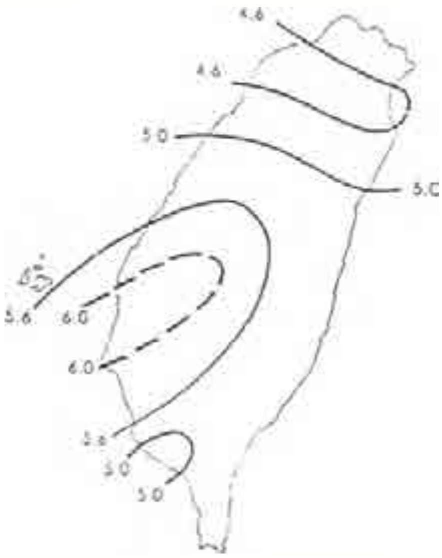

Fig. 10: Isopleth of the pH of precipitation in Taiwan in 1990 (based on data from Chen & Chen, 1993).

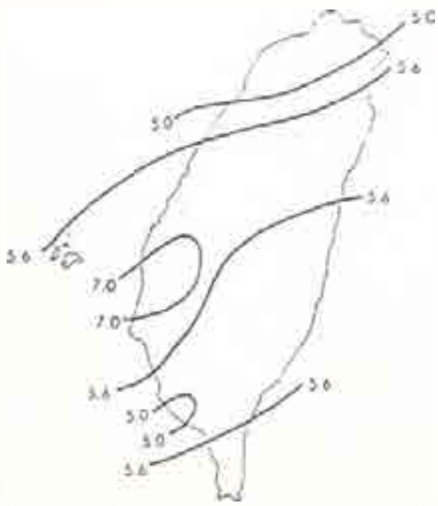

Fig. 11: Isopleth of the pH of precipitation in Taiwan in 1993 (based on data from Chen & Chen, 1993).

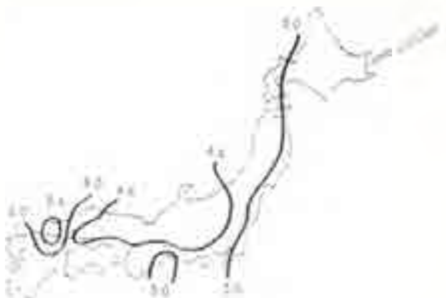

Fig. 12: Isopleth of the pH of precipitation in Japan in 1992 (based on data from JEA, 1994).

Fig. 13: Isopleth of the pH of precipitation in China in 1982 (Cheng, 1993).

Fig. 14: Isopleth of the pH of precipitation in China in 1992 (Cheng, 1993).

Fig. 15: Isopleth of the pH of precipitation in S. Korea in 1986 (Lee, 1993).

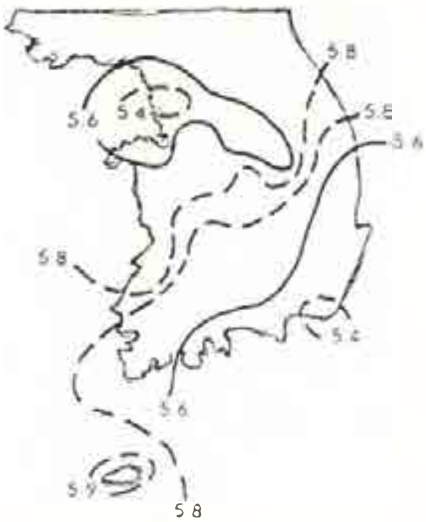

Fig. 16: Isopleth of the pH of precipitation in S. Korea in 1992 (Lee, 1993).

pleth of pH of precipitation of the country points out towards more acidic rain in the south-western part of the country.

In China, the acidic rain has mainly been confined to the south-eastern part of the country (Fig. 13 and 14). It is clearly revealed in the figures that for the last ten years (1982–1992) the pH 5.6 line has expanded drastically with further lower annual pH averages between 4.0 and 4.5 in the southern part of the country (*Cheng* 1993), which are comparable to those in the highly polluted regions of Europe and N America. While the South experiences acidic rain as a growing regional problem, the North has very little if any acid rain.

In South Korea, the comparison of the isopleth (based on data: *Lee*, 1993) contours from 1986 to 1992 show that the acidity of rainfall shrunk drastically during this period (Fig. 15 and 16). Therefore, in S. Korea acidic precipitation is far milder than that of China. Japan and Taiwan.

In the context of India, the pH of rainfall is higher than the acidic level, in the range of 5.31 to 7.34 (*Jain* et al., 1996). Similar results have been obtained from Nepal (pH 5.6 to 6.68) (*Upadhyay* and *Sharma*, 1995).

4. Status of air pollution High Himalayan peaks of Nepal

Nepal Himalayas contain almost all the higher mountain peaks of the world, including the highest mountain peak Mt. Everest (8848 m). Many reports on the acidic deposition have been published on the industrialized or highly populated areas. However, only few data are available from remote sites like the high mountain peaks, mainly owing to difficulties in getting the snow samples, although they are very important for the background information.

Dokiya et al. (1992) reported concentrations of some air pollutants in the snow of some Himalyan peaks of Nepal (3000–5000 m) in Ngozumpa valley (south of Mt. Everest), which has been even higher than that in the snow and rainfall in Japan. Concentration ratios of NSS-SO_4^{2-} (Non-seasalt) to SO_4^{2-} in the snow of Nepal Himalayas are found to be similar to those of Mt. Fuji of Japan (Table 2), one of the highly polluted peaks in the country (3776 m). Furthermore, the equivalent ratios of NO_3^- to NSS-SO_4^{2} ranged from 0 80 to 1 06 in the snow of Nepal Himalayan peaks (Table 2), which are comparable to those found in the deposition of Kanto area in Japan, suggesting anthropogenic sources of air pollution of SO_4^{2-} and NO_3^-. Compared to the snow samples of other parts of the world, the equivalent ratios of NO_3^- and NSS-SO_4^{2-} were relatively higher in the Himalayas (for example USA 0.75–0 05, Europe 0.14–0.64 etc.), suggesting local anthropogenic sources of air pollution. In the lowland regions of Nepal, source of NO_x is mainly transportation, however, in mountains, other sources should be looked for. *Dokiya* et al. (1992) suggests oil smoke coming from Gulf countries as a result of the Gulf war. Whatever the reasons behind this fact are, it is clear that Nepal also suffers from a pollution even in high mountain peaks.

Table 2: Non-seasalt sulfate and nitrate in snow samples of Nepal in the Himalayan Peaks of Nepal (Dokiya et al., 1992).

Mountain peaks	NSS-SO_4^{2-}(mg.l^{-1})	Ratio of NO_3^-/NSS-SO_4^{2-}
Dole (4050 m)	0.46	0.88
Gokyo (4700 m)	0.18	4.12
Khumjung (3900 m)	0.12	1.67
Mt. Fuji (Japan)	0.03–0 70	0 04–0.84

NSS = Non-seasalt

5. The forest decline due to air pollution in Asian perspectives

A number of decline events have been reported from the forests of Asia. While these events have not been widely reported in the scientific literature as have events in Europe, N America and the Pacific region, they have been subject of considerable local concern. Case histories from Bangladesh, Bhutan, China, Japan, India and now in Nepal are presented in Table 3.

Forest decline in Japan

Decline of *Cryptomeria japonica*: The decline of *Cryptomeria japonic* began to appear during the 1970s and 1980s (*Morikawa* et al., 1990). Soil compaction, air pollutants (especially SO_2) and fluctuations in water table were suggested as possible causal factors.

Shimagare dieback: In Japanese, Shimagare means stripes of dead trees On Mt. Shimagare (2395 m), 4–5 bands of dieback, which run parallel to contour, occur in natural subalpine forests of *Abies veitchii* and *A. mariesii*, more or less at intervals of 100 m. It is also supposed to be caused by air pollutants., which is virtually identical to the fir waves of *A. balsamea* forests of N.E. America.

Forest decline in China

Pine decline: According to *Bain* and *Yu* (1992), large areas of forest decline have not been found in China, however, there are localised areas of declining forests which have been detected near large cities, industrial areas and mining regions. For example: decline of *Pinus massoniana*, an area of forest decline on approximately 2000 ha, composed of mainly *P. massoniana* in Sichuan province. Another sp. of pine decline is *P. armandi*, which was planted in 1958 in the Wushan mountains of Sichuan province (*Ma Guanging*, 1990). Elevated S (mainly from coal burning) and Fluorine (glass and cement factories) levels have been attributed to such decline. This area receives high levels of SO_2 (90–350 mg.m^{-3}). Soil acidification has been regarded to be the main cause of decline. Levels of Mg, K and Zn were very low in current year's needles and Mg deficiency has been regarded as the main cause of this decline.

Table 3: Forest decline events in Asia by possible causal factors.

Decline events	Forest	Predisposing factors	Inciting factors	Contributing factors
JAPAN				
a) *Cryptomeria japonica*	PL	low pH of soils	overmaturity air pollution?	none given
b) Fir waves	N	cohort senescence	high winds	none given
CHINA				
a) *Pinus massoniana*	?	air pollution	insect defoliators	bark beetles
b) *P. armandi*	PL	air pollution	nutrient deficiency	none given
BHUTAN				
Abies densa	N	overmaturity	drought	root disease
INDIA				
Shorea robusta	N	poorly drained soils	drought & fire	none given
BANGLA DESH				
Heritiera fomes	N	none given	reduced fresh water	gall fungus
SRI LANKA				
Montane forest	N	cohort senescence	drought	none given
NEPAL				
Dalbergia sissoo	PL	soils (?) drought	none given	root disease

Forest decline in Bhutan

Decline of *Abies densa*: Decline and mortality of *A. densa* was reported in high elevation forests in Bhutan in the 1980s. Overmaturity of the trees has been regarded as the main cause of this decline. An outbreak of a bark beetle has also occurred in forests of *Picea spinulosa* in the same location and during the same period that symptoms of decline appeared on *A. densa*. This decline has also been attributed to drought condition (*Schmutzenhofer*, 1987).

Forest decline in India

Decline of *Shorea robusta*: It has been reported as early as 1907 (*Joshi*, 1988). Symptoms included dieback of branches in the upper crown extending to the lower crown over time. Such type of decline has been reported to be caused by the prolonged drought conditions, overgrazing, fire and insects. Improper soil texture (i.e. soils with high silt and clay content) hias also been regarded as the cause of decline.

Forest decline in Bangla Desh

Top dying of *Heritiera fomes*: Top dying of *Heritiera fomes* has been found to be the most serious of all tree diseases in Bangla Desh, which occurred in the Sunderban region of the country (*Rahman*, 1990). Dieback and mortality of this species was first of all recorded in 1915. No particular reasons have been forwarded to this decline, however, possible causes of such decline have been suggested as insect borers, and reduction in freshwater discharge through the Sunderban.

Forest decline in Sri Lanka

Canopy dieback in upper Montane Rain Forest: The upper Montane forest cover the highlands above 1500 m. This forest is also called "Mossy" forest occurring in a zone of frequent fog and rainfall. Patches of dead and dying trees were first reported on the slopes of the mountain Thotupolakanda in 1978 and continued up to 1980/81. By 1981, virtually the entire upper canopy was killed in the affected areas. Werner (1988) reported that the cause of this canopy dieback was not due to air pollution or due to human activities, but he related the incidence of dieback to a period of exceptionally dry weather between 1971 and 1983 and suggested that this event is an example of cohort senescence triggered by drought.

Forest decline in Nepal

***Dalbergia sissoo* decline:** This is the most important tree species for the farmer both for timber as well as non-timber forest products in Nepal. But for the last 5 years, the trees are dying very fast in plantation forests. However, their status in natural forest is still unknown. Preliminary studies indicate that in some plantation forests the main causes of decline has been found to be due to unsuitable soil conditions, having higher contents of silt and clay (*Sah*, 1999). He related the height of the trees and the soil texture components and concluded that the higher percentage of the clay caused the stunt growth of trees.

6. Conclusions

Anthropogenic perturbations to the global atmospheric S and N cycles have produced levels of acidic deposition in some highly populated and industrialized regions of Europe and N America that have contributed significantly in deterioration of terrestrial as well as aquatic ecosystems. Similar effects appear to be possible in larger parts of Asia with analyses presented above, suggesting that this conclusion also applies to at least some parts of SE Asia.

The enforcement of admission control measures has led to significant decline of SO_2 in some countries, but the figures for NO_x have yet to show any improvement (similar to Europe and N America. While precipitation in S Korea and Taiwan has marginally less acidic rain, Chinas situation is getting worse.

In the context of Asia in general, air pollution has also been observed to be the prime cause of forest decline in the industrialized countries (such as Japan, Taiwan, China etc.), whereas in case of non-industrialized nations climatic factors, soils and over-utilization of forests have been found to be the main causal factors involved in forest mortality (such as Bangla Desh, Sri Lanka, Bhutan, etc.).

While the pollutants emitted into the atmosphere tend to remain confined to the local areas, they can also be transported over long distance and spread as regional problem. Although many countries have air pollution monitoring networks within their own territory, a long-range transboundary monitoring cooperation would be necessary to deal with the above environmental impact. The present study reveals that even the remote areas of Nepal contain atmospheric deposition of air pollutants.

Acidic inputs have a direct and indirect effect on ecosystems. The direct effects of increased acidic deposition in tropical terrestrial ecosystems appear to be significant for vegetation. Some of the ecosystems of the tropical countries may be similar to those found in Europe and N America, but many other ones are very different and researches have to be conducted to analyze and assess the relative sensitivity of these species to acidic inputs.

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Scenarios of the Regional Impacts of Climate Change on Forests in the Federal State of Brandenburg, Germany

Marcus Lindner, Petra Lasch and Anke Wenzel

Abstract

As part of a regional impact assessment of possible climate change impacts in the Federal State of Brandenburg a forest simulation model has been applied to assess impacts of a changing climate on species composition and productivity of natural and managed forests. The gap-type model FORSKA was linked to a GIS that included soil and groundwater table maps, as well as climate data. The forest model was applied on the polygon coverage to simulate a steady-state species composition. Different climate scenarios were used to assess the sensitivity of species composition to climate change. Furthermore, the implications of vegetation changes for other forest functions were analysed by means of several indicators.

Since the majority of forests in the state of Brandenburg have been intensively managed in the past, it is important to include managed forests in the regional impact assessment. At present, large areas of Brandenburg's forests are dominated by pure stands of Scots pine, but current forest management practice aims at increasing the share of deciduous and mixed forests. In order to analyse the possible consequences of climate change on forest management, forest inventory data were used to initialize the model with representative forest stands and simulation experiments were run with different adaptive management strategies.

The results indicated that climatic warming would lead to a shift in the natural species composition in the state of Brandenburg towards more drought tolerant species. The simulated diversity of the forests was reduced, and both carbon sequestration and groundwater recharge decreased. However, the simulation experiments with managed forest stands showed that the short to mid term effects of climatic change in managed forests were not as drastic. The regional impact assessment yielded interesting insights into possible trends for the forest resources and it underlined the importance of adaptive management strategies to help forestry to cope with climatic change.

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Groundwater Protection Strategies of a Water Supplier

Günter Schröder

At the end of this very interesting conference day I would like to inform you in a few words about the groundwater protection strategies of a water supplier. I am a staff member of the Stadtwerke Hannover AG and in charge of the utility's own forestry operations on an area of about 1,500 hectares.

I will come back to that later. First of all I would like to give you a rough picture of the company as a whole. Stadtwerke Hannover AG is a municipal utility company which supplies 730,000 people living in the Lower Saxonian capital and parts of the surrounding area with a total of around 50 million m³ of drinking water per year.

Raw water is delivered from 110 wells located in the water supply zones north and south of Hannover and distributed via water pipes with a total length of 2,000 km. Some 75 % of the distributed water is produced in the water protection zone 'Fuhrberger Feld'.

Over the past ten years there has been a decline in consumption in all three of the Stadtwerke's consumer groups, that is households, small industries, and large customers. Altogether the drinking water volume delivered dropped from 57.5 million m³ in 1976 to 48.0 million m³ in 1995, and this despite a growing population. This shows very clearly that water consumers have learnt to use this vital resource more economically in the course of time. With annual decline rates of up to 5 % during the past years, we obviously have to adjust our prognosis of water demand downwards.

But let us return to 'Fuhrberger Feld' water protection zone: here the Stadtwerke are co-operating with land users to work out strategies for optimising groundwater protection. With its 30,000 ha this is the most important water supply zone of Stadtwerke Hannover AG. Land use here is characterised by agriculture, on an area of 12,000 ha, and forestry, on an area of around 15,000 ha (50 %).

The quality of the groundwater is determined by geogenic conditions in the groundwater aquifer and by agricultural land use. The input of substances from agriculture, in particular nitrogen from organic and inorganic fertiliser, has meanwhile made it necessary to implement additional water treatment processes and has markedly increased analysis costs.

From the viewpoint of the water supplier, the aims of groundwater protection as a means of securing water quality in the 'Fuhrberger Feld' can be classified into four groups:

1. Agriculture: measures for controlling pollutant input, in particular extensification measures.
2. Forestry: optimising forest management with a mind to water quality and groundwater recharge.
3. Water management: measures for controlling runoff, in particular by naturalising canals and optimising well operation with respect to both quality and quantity aspects.
4. Catchment area management by collecting surface unit data and combining these data to predict the impact of a given intervention on the land use system (on soil and groundwater).

At this point I would like to speak in particular about our activities in the forestry sector. Quite at the beginning of water production, in the year 1908, the Stadtwerke began to buy farmland and forestland in the immediate surroundings of the wells. Today, the Stadtwerke owns almost 2,000 ha here, mostly forestland. All the wells are located in the forest. The groundwater that recharges beneath the forest, mostly pine forest, by the way, is very clean and low in nitrate. It provides a valuable counterweight to the relatively heavily polluted groundwater beneath the farmland areas. The need to optimise groundwater quality has meanwhile led to the founding of agricultural and forestry co-operatives whose purpose is to define the aims of future land management in concert with the land users.

Our current forestry activities are geared to the following aims:

Over the medium term the existing pure coniferous stands are to be transformed on the model of the potential natural forest community. Under natural conditions, that is in absence of any kind of human intervention, the type of forest community which would presumably develop here today on more than 6,000 ha is a woodrush-beech forest. As a result of human overexploitation during the Middle Ages this type of forest vegetation has virtually disappeared in this area. Over the past three years, therefore, as part of a pilot project, we have introduced deciduous tree species, mainly beech, to suitable pine stands on more than 200 ha. The deciduous trees now growing under the pine canopy will in future serve the following functions of groundwater protection:

1. No use of plant protectants in the now developing more stable and vital, rich structured mixed stands.
2. Reduction of atmospheric pollutant deposition. The long-term decrease in the forest's coniferous population has begun to reduce pollution through atmospheric deposition and will continue to do so in the future.
3. Enhanced groundwater recharge: the rate of groundwater recharge beneath deciduous forest is about 80 mm a year higher than it is beneath pine forests. This effect is attributable to the lower evaporation rate and the absence of foliage in winter in deciduous stands.

   If it proves possible to grow deciduous stands consisting mainly of beech on about 60 % of forestland, this will lead to a sustainable additional groundwater recharge of around 4.8 million m³ per year (800 m³ per ha and year). This additional groundwater will be of high quality and will thus contribute to minimising the environmental impact of water withdrawal. The enhanced recharge rate will also efficiently complement consumers' water saving measures.
4. Estimation of the impact of forest transformation on groundwater quality and quantity in scientific studies.
5. Increase in species diversity due to a greater structural variety of forests.
6. Establishment of continuous forestry without clear cutting.
7. Enhanced carbon dioxide fixation. Beech trees developing under the pine canopy add to the fixation of

carbon dioxide, making a valuable contribution to climate protection in the region.

Internal studies have shown that purposeful measures for groundwater protection in forests are very efficient over the long term because of their long-lasting effects. The Stadtwerke Hannover therefore sees forestry as an optimal partner for its groundwater protection strategy.

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Workshop Forests under Mixed Inputs of Pollutants and Nutrients

Critical Loads and Levels – S, N and O_3 Principles, Status, Practical Use and Future

Knud Tybirk and Eva Thörnelöf

Abstract

This paper gives a brief historical flashback of the last 30 years of air pollution debate and initiatives in Europe. In 1995 it was concluded in Gothenburg that air pollution still was a serious issue to be dealt with although a number of agreements had been signed to reduce emissions. The critical loads and levels have facilitated the development of truly integrated strategic environmental planning. The targets are based on what the environment can sustain and the reductions are distributed between countries and compounds in an economically optimised procedure. The Multi-pollutant – Multi-effect Protocols and the EU Acidification Strategy will reduce the exceedances of acidifying substances and ozone by the year 2010 if fully implemented.

The eutrophication problem persists, however, arising mainly from increased and intensified emphasis on animal production in agriculture in large parts of Europe. The critical loads concept has shown to be useful, but now time has come to reconsider scientifically its fundamental criteria which probably has been too simplified. New methods are needed seeking also to preserve biodiversity and the dynamic processes of nature in the critical loads models.

Introduction

Historically, air pollution influence on human health and forest has been known locally during more than a century. For example, H. C. Andersen wrote in his diary from a visit to Paris in 1866: '... looking at some apparently dead trees, which had not been able to withstand the air in Paris, and when they couldn't leave, they died'. Air pollution was locally well known, already in the 19th century.

Since the 1950ies air pollution has grown into an international problem demanding international solutions. In the 1960ies the term transboundary air pollution was coined when it was realised that the acidification of the rain in Sweden was due to long-range transported air pollution (*Bernes* 1991). In 1969, Sweden became the first country to regulate acidifying inputs to the atmosphere: Sulphur content of oil should not exceed 2.5 %. Environmental regulation changed from dissolution of the problem into end-of-pipe restrictions which was a sign of a new era in environmental planning that has been followed since. In 1979 the UN/ECE Geneva Convention on Long-Range Transboundary Air Pollution was established and the transboundary nature of air pollution was officially acknowledged. The Geneva Convention became the formal international body working seriously on air pollution abatement. Since then, UN-ECE has been supplemented by important initiatives of the European Union.

The 1995 Gothenburg Conference Acid Reign '95? on the acidification problem concluded, however, that air pollution indeed still is an issue to be taken care of (*Rodhe* et al. 1995). Positive signs are seen now in the reduction of acidifying substance in Europe, but the economic growth in Asia will increase the problems of sulphur emissions very much in the future. For ammonia, the emissions are constant in Europe, but increasing in USA and Asia due to increased animal husbandry.

Some conclusions from the Gothenburg conference relevant for critical loads and levels in a broad sense can be identified:

- acidification can not be looked at in isolation since the same pollutants that cause acidification have an impact on other important environmental areas as climate, ozone, eutrophication and increased availability of heavy metals.
- along with the decrease in SO_2 emissions in Europe and North America a decrease in the deposition of base cations with particles also occurs. In some areas the deposition of fly ash completely neutralises the acid deposition. There are gaps in knowledge on the sources of base cations in different parts of the world. In several tropical and subtropical countries soil-derived alkaline dust particles are abundant in the atmosphere. The neutralising effects of such particles have to be taken into account in acidification studies.

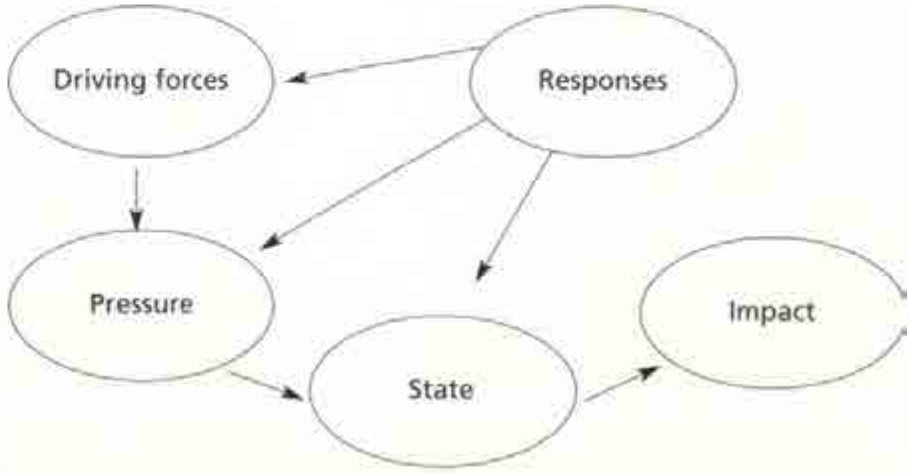


Fig. 1: The DPSIR-chain of integrated assessment models. (EEA, 1997).

■ so far only preliminary estimates of critical loads are available outside Europe and North America. The concept should be developed further for other regions. In addition it is important that ecosystem-oriented monitoring and experiments also are carried out in tropical and subtropical areas subjected to increased acid deposition.

■ research co-operation between scientist in developing and developed countries can help to transfer experience.

■ Environmental education at all levels has to be a central part of any long-term policy strategy. Scientist from developed nations, already exposed to such air pollution problems, have a special responsibility to participate in such programs.

At an international symposium on "Acidic deposition and its Impacts" in Tsukuba, Japan 1996, several interesting facts from Asia were presented, they strengthen the conclusions from the Gothenburg conference in 1995. Some examples:

■ There are model calculation where Chinas contribution to the sulphur deposition in Japan varies from 3.5 to 50 % of Japan's total sulphur deposition. This is due to differences in removal rates and chemical conversion rates for sulphur (*Carmichael & Arndt*, 1996).

■ A try to use the Steady State Mass Balance Models for calculating critical loads only gave a very ruff estimate due to uncertainties as to which basic criterion was the most suitable for Japanese ecosystems. Further improvements are needed concerning basic data (*Shindo & Hakamata*, 1996).

The 6th conference on Acidic deposition, Acid Rain 2000, will be held in Japan in December 2000. The conference will focus on recent findings with respect to the origin and effects of acidic deposition and countermeasures against the problems it creates. New topics will be – Acidification in temperate regions, especially Asia and – how to address acidification in environmental education.

Critical loads and levels in practical use

The problems treated in previous protocols has principally been acidification and eutrophication resulting from indirect exposure to pollutant acting through soil – mediated changes (indirect critical loads). Further, tropospheric ozone has received attention acting directly on vegetation and human lung function (direct critical levels). However, the relationship between these pollutants are quite complex as Nox both has acidifying and eutrophying effects and are one of the precursors of ozone. Therefore, the forthcoming protocols integrate these different effects in Multi-pollutant – Multi-effect protocols in slightly different approaches both under the auspices of UN-ECE and the EU.

The problems that have been faced are primarily

■ Acidification: Leaching of nutrients, release of toxic metals, decreased forest health, damage to plant and animal life in lakes

■ Eutrophication: Excess nitrogen deposition in terrestrial and aquatic ecosystems, altering of nutrient balances, threat to ecosystem processes and biodiversity

■ Ground-level ozone: Concentrations are 3–4 times above pre-industrial levels, impaired lung function and other respiratory problems for children and asthmatics, damage to sensitive plants (agricultural crops, trees)

The relationship between these different compounds emitted to the air and the effects are complex. SO_2, NO_x and NH_3/NH_4^+ are acidifying substances, Nox and NH_3/NH_4^+ are also eutrophying and NO_x and VOC are involved in the formation of ground level ozone. So efficient actions have to be taken on a number of sectors and compounds.

The international solutions agreed upon so far are:

UN/ECE Convention on Long-range Transboundary Air Pollution

■ SO_2 protocols 1985, 1994

■ NO_x protocol 1988

■ VOC protocol 1991

■ Protocols on heavy metals and POPs 1998

EU Legislation

■ Air Quality Directives (1980–1998)

■ Technology-related Directives (LCP, IPPC, solvents, Auto-Oil, etc.)

■ Acidification Strategy

■ National Emission Ceilings

Most of these have been ratified and therefore been put into force some years later.

The first of these international agreements have been based on general decrease (flat rate) in emissions of all countries. The 1994 sulphur-protocol was the first to be directly based on effects in the ecosystems as calculated with the critical loads for acidification. The critical loads for acidification. The critical loads is defined as *'A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'* (*Nilsson & Grennfelt* 1988).

Integrated assessment

Such a flexible and 'soft' definition is quite difficult to put into practice. However, the work towards these protocols are based on integrated assessment models taking into consideration the *Driving forces* in the economic sectors, the *Pressures* (emissions to air the State and Impact (deposition and effects in nature) and economically optimised *Responses* to obtain the most cost-efficient reductions (Fig. 1).

The RAINS model developed by International Institute for Applied Systems Analysis (IIASA) in Laxenburg incorporates these DPSIR indicators in one model making the basic calculations for the protocol negotiations. The model has been accepted scientifically and politically as the best available instrument to take into account projections for development in the economic sectors, emission control options, resulting emissions and costs, the following atmospheric dispersion, the environmental impacts, and the environmental targets formulated. Finally, RAINS has an optimisation module to calculate the most cost-efficient solutions between the countries and compounds included. Only in this way we can get as much environmental benefit as cheap as possible.

Of course, a model taking into account so many aspects have numerous simplification and some of these will be touched upon below.

The Multi-pollutant Multi-effect Protocols

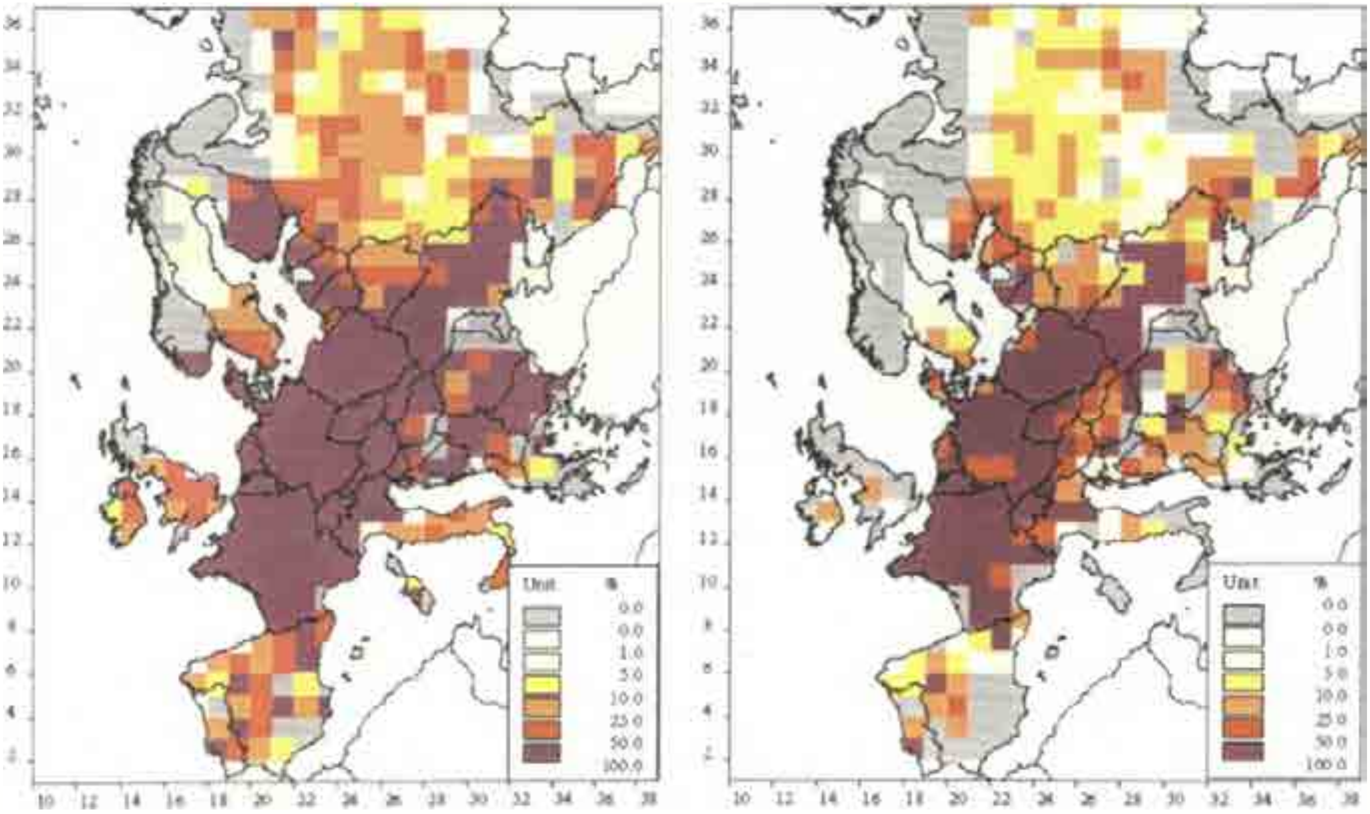
The environmental targets are based on the critical loads and levels for impact on ecosystems and humans.

The ultimate goal for EU and UN-ECE is to eliminate harmful effects of air pollution to humans and nature. However, quite ambitious interim goal has been put forward for the EU Acidification strategy. The interim goal by the year 2010 is to reduce the area of ecosystems not protected against acidification by $\frac{1}{2}$ and excess nitrogen deposition (eutrophication) by 60 % as compared to 1990. For ozone, the interim goal is to reduce health-relevant excess ozone exposure by $\frac{2}{3}$ and vegetation-relevant excess ozone exposure by $\frac{1}{3}$. These goals are based on critical loads and levels exceedances, and the environmental planning is therefore effect-based.

For these multi-effect protocols the base line year chosen was 1990. In addition, all national and international legislation (e.g. for EU members states) and other national policy targets have been incorporated into a reference scenario already showing considerable reductions of emissions. However, to obtain the defined interim environmental goals, further actions are needed and this is reflected in the scenario G5/2 (IIASA) homepage). The results of the two scenarios on emissions and control costs are presented in Table 1. The additional costs of the G5/2 scenario is less than 15 % of already agreed costs.

The environmental impacts of the G5/2 scenario is very promising for acidification and grounded level ozone. The areas with exceedances will be drastically reduced between 1990 and 2010. However, for eutrophication, the results are more discouraging. Still in 2010 large parts of central Europe are faced with problems of eutrophication of terrestrial ecosystems. The reason for this is clear: the intensive animal husbandry in large parts of Europe, with the highest emissions in North-west continental Europe, Ireland and Northern Italy (Fig. 2).

However, numerous possibilities for reducing ammonia emissions exist. Firstly, the intensity of animal production in general should be considered. Secondly a number of abatement techniques are



1990 G5/2 – 2010

Fig. 2: Environmental impacts (% Ecosystem not protected against eutrophication). The ammonia problem will still persist in Europe even after implementation of the forthcoming Multi-effect protocols (Maps from IIASA homepage, Amann et al 1999).

Table 1. Results in 2010 of the Reference scenario including already approved national and international legislation for emissions and control costs compared to the G52 scenario (data from IIASA homepage).

	Emission reductions (compared to 1990)		Control costs (billion EURO/yr)	
	REF	G5/2	REF	G5/2
SO_2	−60 %	−70 %	14 0	+1.8
NO_x	−35 %	−42 %		
VOC	−37 %	−45 %	52 6	+3.3
NH_3	−12 %	−24 %	0 7	+3.4
total			67 3	+8.5

available reducing emissions from the stables, the manure storage and manure applications in the field (Table 2).

The present status of the negotiations for the Multi-effect protocols is that the G5/2 scenario is the basis for political negotiations during the last half of 1999. The EU Commission has approved the Acidification Strategy now awaiting the signature of the Council of Ministers. This will result in directives with binding emission ceilings for member states. The political negotiations of UN-ECE Multi-pollutant-protocol started in June 1999. This protocol can only give recommended emission ceilings for member countries and the implementation cannot be assured.

The process of practical application of the critical loads and levels has now been taken over by politicians. Time is ready for scientific reconsideration and improvements of criteria and methods for the next generation of protocols.

Problems with the present approach

At present critical loads for acidification and eutrophication can be assessed in three ways

- *Level 0:* Empirical data for changes of vegetation, forest health etc.
- *Level 1:* Steady-state modelling: Mass-balances (SSMB)
- *Level 2:* Dynamic models including temporal variation, episodes etc.

Level 0 is restricted to observations in the environment of effects observed and correlation to known depositions of air pollutants. However, such documentation is often very difficult as the effects of the indirect critical loads are mediated via soil changes and therefore significant time lags (often decades) are expected to observe effects. It is impossible to give hard-core scientific evidence that this effect in the environment is derived from this certain air pollution because changes in e g. forest health is multi-factorial including the various air pollutants, climatic changes, changes in land use etc. But enough evidence has been presented to indicate that there is a correlation between air pollution levels and forest health decline (like in the black triangle), vegetation changes in nature and increased nitrate concentration under forest etc (*Bobbink* et al 1996, *Erisman* et al 1998, *Gundersen* et al 1998) The precautionary principle would demand action to be taken.

In the first attempt to make environmental actions effect-based the Steady State Mass-Balance calculations have been developed. This is in principle based on 200 years of calculated mass-balances for forest where input and output should balance. This can be done for acidifying and eutrophying inputs for forest and lakes. Empirical studies in the 1980ies showed that a Base-Cation/Aluminium ratio of >1 was a determining factor for forest growth and this was selected as the setting criteria in the calculation and mapping of critical loads and exceedances. This criteria is being discussed in scientific circles (*Løkke* et al 1996, *Bastrup-Birk* et al 1999) and will be further addressed during the coming years.

SSMB is a very simplified way of calculating critical loads over Europe. Simplified, and thereby enabling models to be developed to make comparable and sufficiently robust calculations for international agreements. But perhaps it has been a too simplified criteria not able to take into account dynamic aspects of forest growth, conservation of biodiversity, changes in management and episodes of extreme conditions.

Time for reconsideration

The specified sensitive element of ecosystems that have been selected for protection is values of nature for humans, such as forest production, fishery and clean ground water. The present criteria for critical loads can be said to be based on a human utilitarian paradigm. However, since the 1992 Rio Conference, biodiversity has gained attention as an important aspect to be protected also from changes due to human environmental impact, such as air pollution. But the protection of biodiversity needs fundamentally other ethical paradigm to be put forward, because the protection of biodiversity is also to protect inherent and intrinsic values of nature independently of human use. If critical loads are supposed to include the preservation of inherent values of nature, other more specific criteria such as operationalised nature quality indices (*Nygaard* et al 1999, *Mark & Strandberg* 1999) are to be developed.

The critical loads of today are based on rather weak sustainability principles. Broader ethical consideration are gain-

Table 2. Emission control options for ammonia (IIASA and NERI data).

Low nitrogen feed	multiphase feeding, synthetic amino acids
Animal house adaptations	improved design, floor modifications, low NH_3 poultry housing, regulation of temperature and water content of faeces etc.
Covered outdoo manure storage	rigid lids, floating covers
Low ammonia application techniques	immediate incorporation, deep and shallow injection etc.
Fertilizers	Urea substitution

ing space in environmental planning, and perhaps stronger sustainability principles should be behind the critical loads of tomorrow. The value of nature in itself – the species, the ecosystems, the natural processes should be protected as well requiring new biological indicators of critical loads exceedances.

It can be concluded that critical loads and levels are successful limits for strategic environmental planning as political results have been obtained in Europe. However, the basic criteria and methods are too simplified, and therefore scientists should reconsider and improve the criteria and methods for assessment of critical loads and levels.

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Nitrogen Turnover and Effects in Forest

Jan Willem Erisman and Wim de Vries

Abstract

Apart from effects on the crown condition, atmospheric deposition also affects the nutritional status of forests. This refers specifically to the impact of N deposition that has gained in importance since the last decades due to steady decline in S emissions over that period. Preliminary data of bulk deposition and throughfall at some 60 Intensive Monitoring (level II) plots suggest that the average input of N and S is about equal. At low N deposition, an increase may be beneficial for forest growth, whereas the reverse may be true at elevated deposition. The relative contribution of the different fluxes in the nitrogen cycle is reasonably well known, with the exception of denitrification. The quantification of the input and output fluxes and the allocation of deposited nitrogen in the forest ecosystem prove to be difficult. Although knowledge on the response of forest ecosystems to N inputs has increased over the last decade, there is still a lack of information on (the dynamics) in critical N loads over a large range of environmental conditions. Furthermore, a European wide perspective of N saturation is still lacking.

1. Introduction

Influences of elevated N and S deposition on forest ecosystems has gained large attention since the beginning of the eighties, induced by the reported decrease in forest condition. In the eighties much emphasis was laid on the acidifying impact of sulphur in relation to the release of toxic Al in the soil, that was considered a possible factor for forest decline. Insight in the quantitative relationship between atmospheric input and the fate of Al was gained by input-output budgets that have been derived for several intensive monitored ecosystems over Europe (e.g. *Van Breemen* et al., 1984; *Berden* et al., 1987; *De Vries* et al., 1995). In the last decade, the fate of nitrogen has gained an increasing attention. The reason for this is (i) the large decrease in S emissions since the introduction of the first sulphur protocol in 1985, whereas the emissions of NO_x and specifically of NH_3 hardly changed and (ii) the results obtained from forest ecosystem research indicating that the (potential) effects of eutrophication by N deposition on forests

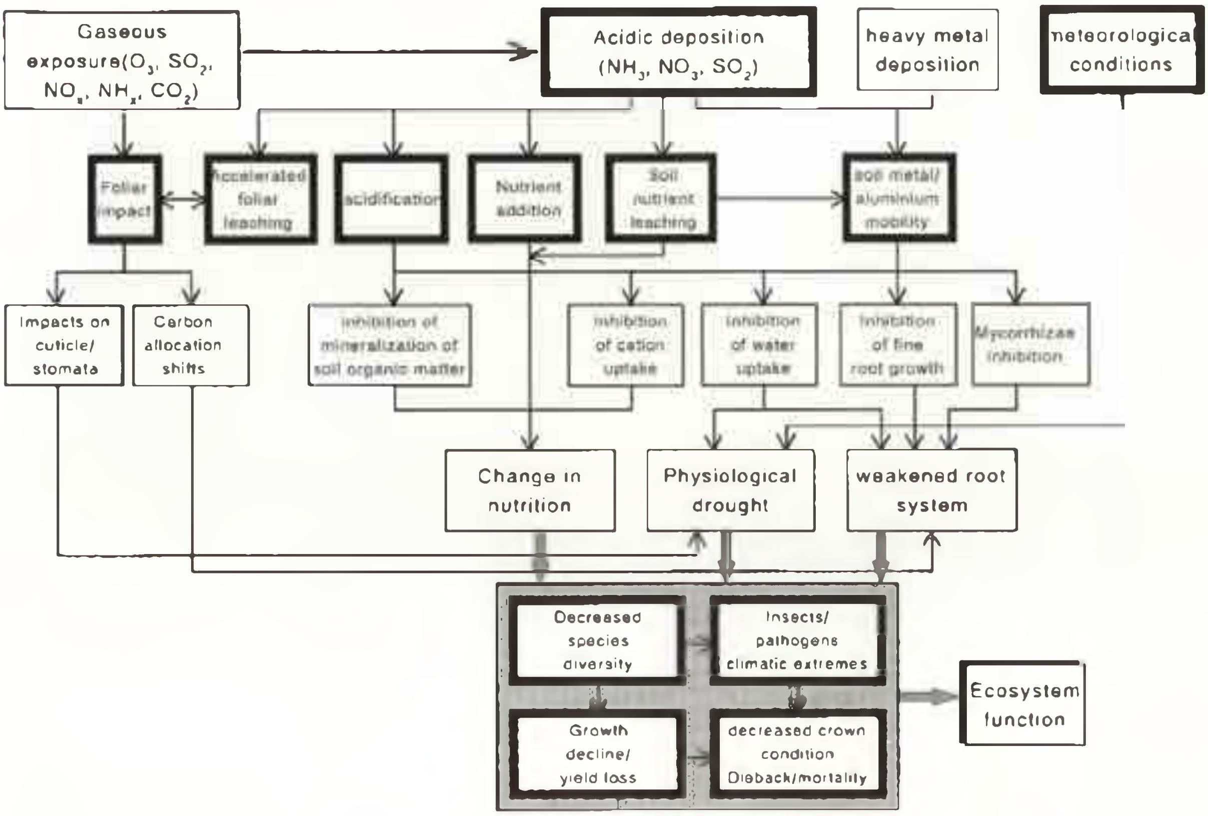

Fig. 1: Conceptual overview of the principal pathways and hypothesised mechanisms of forest ecosystem response to air pollutant stress (after de Vries, 1999).

may be larger than that of acid deposition. A further aspect is that N is generally largely retained in the ecosystem to a certain level, whereas S mostly behaves as a tracer. The potential effects of N accumulation may thus occur for a longer time. In forested catchments, for example, the decrease in surface water acidification caused by a lower S deposition is partly off set by an increasing leaching of N from the ecosystem.

In this review we will focus on the role of nitrogen compounds in affecting forest ecosystems. In chapter 2, first an overview is given of different hypotheses explaining forest decline, to put the possible adverse impacts of nitrogen on forest ecosystems into perspective. In chapter 3 the relevant processes of nitrogen turnover in forests are first explained. Methods to quantify N inputs to forests are discussed and the increasing role of nitrogen in forest inputs will be demonstrated. Furthermore the output of nitrogen in response to the input is discussed in this chapter. In chapter 4 the possible effects of nitrogen input to forest ecosystems are described. The review ends with a discussion and conclusions focusing on the major gaps in present knowledge with respect to nitrogen (chapter 5).

2. Impacts of nitrogen in view of different hypotheses explaining forest decline

Annual assessments of the crown condition in Europe indicate a general decline in forest health in terms of increasing defoliation and discoloration (UN/ECE and EC, 1998). Hypotheses that refer to air pollution as causing forest damage are still discussed controversially. Effects of air pollution might show up with a considerable time delay, especially where concentrations are low (UN/ECE, 1991). At present, most scientists agree that forest condition is influenced by a multitude of different stress factors including air pollution (e.g. *FBW*, 1989; *Schulze*, 1989; *UBA*, 1994; *Landmann* and *Bonneau*, 1995), the dynamics of which are partly not understood for their non-linear characteristics. It seems most appropriate to assume that forest ecosystems do respond to various stress factors, but that the contribution may differ depending on the geographic region. For example, direct impacts of sulphur dioxide and soil acidification may dominate in parts of Central Europe, euthrophication by nitrogen in parts of Western Europe, ozone in parts of Southern Europe, whereas natural stress is occurring all over Europe.

To get more insight in the role of nitrogen in this context, an overview is given of the major hypotheses explaining forest decline. Figure 1 presents a conceptual overview of the hypothesised mechanisms of forest ecosystem response to natural stress (meteorological conditions) and stress induced by mankind (gaseous exposure and pollutant inputs: acidifying and eutrophying compounds and heavy metals). The inputs influence the foliar and soil composition, which in turn affect the fluxes and processes necessary for an optimal functioning of the forest ecosystem. This might eventually lead to decreased species diversity, increased sensitivity for insect attacks, diseases and climatic extremes, growth decline, dieback and mortality, which affect ecosystem functioning. It is hypothesised that forest growth and forest ecosystem condition is affected by a combination (multiple stress) of i) natural stress, ii) direct air pollution impacts, iii) soil acidification, iv) eutrophication. The impacts of various stresses differs depending on the region. In all situations, nitrogen does, however, play an important role in explaining effects on forests. These will be explained in the next sections.

2.1 Natural stress

The hypothesis of natural stress focuses on the adverse effects of unfavourable weather conditions, especially drought, and on pest infestations or fungi attacks as a major cause for damage. In this hypothesis, there is not an overall deterioration of forest health on a large scale, but a stochastic variation induced by these natural stresses. *Auclair* et al. (1992) blamed unfavourable weather conditions, especially drought for damaging the forests. *Kandler* (1992; 1994) hypothesised that fungi are a major agent affecting forests. Research performed to evaluate the impact of insects on forests generally gave evidence that especially trees already affected proved sensitive to insect attacks (e.g. *Speight* and *Wainhouse*, 1989). Some authors suggested that pest infestations or fungi attacks following drought periods cause the overall deterioration of forest health (e.g. *Houston*, 1981; 1992). *Van Goor* (1985), *Nys* (1989) and several others discussed the role of forest management practices as adversely influencing forest health. Results indicate, however, that there is an interrelationship between natural stress and anthropogenic stress, specifically in terms of an increased nitrogen exposure. It generally reduces the resistance of the system to natural stress by drought, frost and the occurrence of pest and diseases, as illustrated in the section on the eutrophying effects of nitrogen (Section 2.4).

2.2 Direct air pollution impacts

This hypothesis focuses on the direct adverse impact of elevated concentrations of SO_2, NH_3, NO_x and O_3 on the forest canopy. This includes impacts on (i) the leaf cuticle/stomata causing physiological drought, (ii) carbon allocation shifts leading to a weakened root system and (iii) accelerated foliar leaching affecting the nutrient status (Fig. 1). *Burton* et al. (1983) proposed heavy metals as impairing forest health. *Manion* (1981) and *Evans* (1984) suggested that the oxidation of SO_2 and NO_x to strong acids might directly destroy the leaf cuticle and thus cause damage to trees. *Smith* (1981) discussed SO_2 and NO_x as responsible for affecting biochemical pathways and so damaging foliage. At very high levels of NH_3 leaves of trees might show browning due to the toxification of ammonia (*van der Eerden*, 1982, *Fangmeier* et al., 1994). *Matyssek* et al. (1990) proposed ozone as agent damaging foliage. The oxidising effect of strong acids on leaf cuticles has been observed in extremely polluted areas (review given e.g. by *Innes*, 1993). The role of nitrogen in direct air pollution effects is not only that high concentrations of NO_x, HNO_3 or NH_3 can have direct effects but also that NO_x is a precursor of O_3, which is the most phytotoxic gas affecting forest ecosystems. Results of a European wide study relating crown condition to environmental stress factors specifically showed a significant impact of ozone on forest vitality in terms of an increased defoliation (*Klap* et al., 1998).

2.3 Soil acidification

This hypothesis focuses on the indirect soil-mediated acidifying impacts of S and N deposition. This includes (i) the loss of base cations from the soil causing deficiency of these nutrients (notably Mg), (ii) the release of toxic aluminium affecting fine root growth and inhibiting the uptake of base cations and (iii) a decrease in pH that may affect mineralization processes and thereby nutrient availability. In the context of Al release, the role of heavy metals is also mentioned (Fig. 1). In the eighties, several authors (for example *Ulrich* et al., 1979; *Hutchinson* et al., 1986) considered soil acidification, associated with a decrease in pH and base cation saturation as well as an increase of the concentration of Al^{3+} in the soil solution, responsible for forest decline since Al^{3+} is very likely to be toxic to plant roots (*Cronan* and *Grugal*, 1995; *Marschner*, 1990; *Mengel*, 1991). Several authors (e.g. *Roelofs* et al., 1985; *Schulze* 1989) suggested that acidification of soil and excessive N inputs causes nutrient imbalances. This coincided with field observations and foliage analyses that deficiencies of Mg and K caused yellowing of needles of Norway spruce (*Bosch* et al., 1983; *Zöttl* and *Mies*, 1983). In general nitrogen contributes to soil acidification and eutrophication (see further). The combination of the two processes lead to the imbalance of nutrient availability (e.g. *Heij* and *Erisman*, 1997).

2.4 Eutrophication by nitrogen

The role of nitrogen as fertilising agent was considered as causing forest damage by several authors (e.g. *Nihlgard* 1985). In this respect *Ulrich* et al. (1979), *Ellenberg* (Jr.) (1983, 1985 and 1991) and *Tamm* (1991) stressed that the increase of nitrogen in the environment leads to changes in vegetation as well as damage to trees. A continuous high input of N, may cause damage to forests due to: (i) water shortage, since a high N input favours growth of canopy biomass, whereas root growth is relatively unaffected (*De Visser*, 1994), (ii) nutrient imbalances, since the increase in canopy biomass also causes an increased demand of base cation nutrients (Ca, Mg, K) whereas the uptake of these cations is reduced by increased levels of dissolved NH_4 (*Boxman* et al., 1988) and (iii) an increased sensitivity to natural stress factors such as frost (*Aronsson*, 1980; *Bruck*, 1985) and attacks by fungi (*Roelofs* et al., 1985). An excess input of N can finally cause pollution of ground water and surface water due to NO_3 leaching. Although nitrogen is not the only component inducing effects to forest ecosystems it plays an important role in the multiple stress forests are exposed to.

3. Nitrogen input, turnover and output in forests

3.1 The nitrogen cycle

Most of the nitrogen of the earth is present as fixed nitrogen in the earth crust in rocks and sediments. The second largest pool of nitrogen is N_2 in the atmosphere. A relatively small amount of nitrogen is available for life in oxidised or reduced form. Nature in its pristine conditions was adapted to the low availability of nitrogen and more than 90 % of plant N uptake is provided by internal cycling (*Clark* and *Rosswall*, 1981). The nitrogen cycle was dominated by internal cycling with very low inputs of reduced nitrogen originating from wild life and oxidised nitrogen originating from forest fires and lightning. Another input is nitrogen fixation through micro-organisms. Estimates of N fixation by forests varies widely, from 50–600 kg/ha (*Hauck*, 1971). Output of nitrogen under pristine conditions was negligible small and the forest ecosystem use different processes to use and re-use the low amount of nitrogen available. An example of this is the translocation of nitrogen from the leaves to the woody tissue that occurs before leaf senescence (*Bormann* et al., 1977).

A simplified N cycle is shown in Figure 2. The main processes in the internal cycle are decomposition, mineralization, nitrification, and immobilisation by micro-organisms, plant uptake, and release of litter. Mineralization is the transform of organic nitrogen in ammonium. Immobilisation is the transformation of nitrate into organic nitrogen. Since organic matter is accumulated in the soil, mineralization is the rate limiting process of the internal cycle. The N (ammonium or nitrate) released by mineralization is readily taken up by plants and micro-organisms. Nitrogen losses from forest ecosystems are thus small at pristine or N limited conditions and the N cycle is virtually closed.

An important process in the soil is the nitrification of ammonium into nitrate by nitrifying organisms. Nitrate is relatively mobile in soils and is easily leached by percolating water, whereas ammonium is retained in the soil by cation exchange. The conversion of ammonium to nitrate by the nitrification process is, therefore, a prerequisite for N losses from the ecosystem by leaching. Other losses from the system occur by denitrification (Figure 2), which is generally less important than leaching of nitrate and is dependent on nitrification and the availability of nitrate. The strong competition for ammonium N between plants and microflora in an N limited system may suppress the nitrification process and in this way restrict the N losses. Fluxes of NO and N_2O from the soil are the result of denitrification and might be indicators for the N status of the system. NH_3 emissions from the stomata are the result of the high ammonium content of the leaves, which in turn is the result of high nitrogen uptake from the soils through the root system (*Schjorring*, 1998). The other outputs of

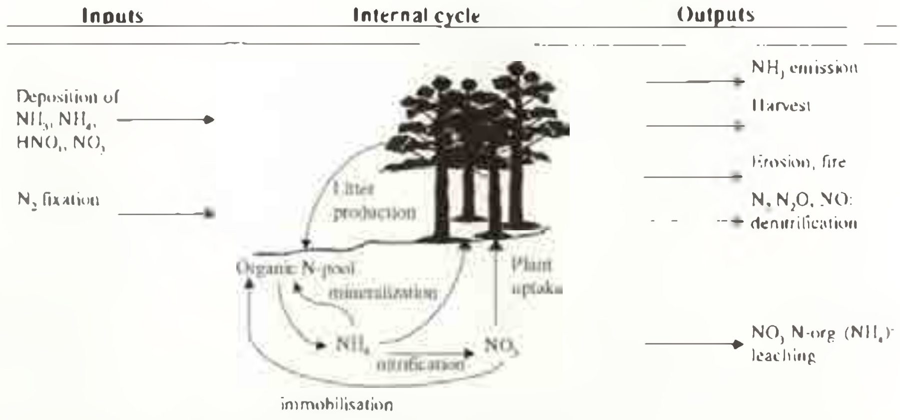

Fig. 2: Simplified illustration of the nitrogen cycle in forests.

nitrogen from the system are the result of forest fires of management practices.

The proton transfers connected to the process of the N cycle are somewhat complicated (*Binkley* and *Richter*, 1987; de *Vries* and *Breeuwsma*, 1987; *Reuss* and *Johnson*, 1987; *Gundersen* and *Rasmussen*, 1990). The net proton production in an ecosystem as a result of atmopheric N or nitrification of the soil N pool only occurs if NO_3 is leached from the system. The proton production then equals the equivalents of nitrate leached (*Gundersen* and *Rasmussen*, 1990). Accumulation of atmospheric N inputs in the soil may, however, in the long run increase the potential for nitrate leaching and, subsequently, acidification. It must be noted that input of NH_4 is also acidifying when accumulated in the system by uptake or ion exchange. The proton associated with NH_4, however, originates from an acid (mainly H_2SO_4). In case of nitrification and NO_3 leaching two protons are produced, the other originating from NH_3.

As the result of increasing reactive nitrogen production and imports of nitrogen in reactive form the inputs in forests are increased and the nitrogen cycle is influenced. The nitrogen input to terrestrial ecosystems from the atmosphere has increased from 5–10 kg $N.ha^{-1}.yr^{-1}$ in the 1950s to 20–40 kg $N.ha^{-1}.yr^{-1}$ today over large parts of Europe (*Erisman* and *Bobbink*, 1997). The input even reached more than 100 kg $N.ha^{-1}.yr^{-1}$ in parts of the Netherlands (*Erisman*, 1993). As the input in the system increase, the internal cycling increases and as the system gets saturated the output increases. The dramatic change in input of an essential plant nutrient may have significant impacts on plant growth, ecosystem functioning and stability, and nitrogen leaching. The current N load from N deposition is a substantial continuous addition to the flux of mineral N from mineralization, which normally amounts to 30–50 kg $N.ha^{-1}.yr^{-1}$ in coniferous stands (*Gosz*, 1981), and to 50–150 kg $N.ha^{-1}.yr^{-1}$ in deciduous stands (*Melillo*, 1981). In the long term, these additions may change the pattern of internal cycling and exceed the capacity of plants and soils to retain N.

3.2 Methods to quantify the total N input to forest ecosystems

General approach

Information on atmospheric deposition is of essential importance to understand the biogeochemical cycle in forest ecosystems. There are currently two methods to estimate deposition from measurements: micrometeorological methods and throughfall (e.g. *Erisman* and *Draaijers*, 1995). Both methods are used for different purposes. Micrometeorological studies are used to understand and parameterise the dry deposition processes, whereas the throughfall method is used to determine soil fluxes and the influence of parameters or conditions determining deposition, in cases where micrometeorology fail, such as complex terrain or forest edges. Both methods are needed to develop, parameterise and evaluate deposition models. Models (or measurements) are needed to determine the total inputs to forests and to determine how management of forests can reduce inputs by deposition. Deposition models currently used to determine site specific deposition are the so-called inferential models (e.g. *Hicks* et al., 1987; *Erisman*, 1993; *Erisman* and *Draaijers*, 1995). There are very little micrometeorological studies on the deposition of nitrogen components to forests (see *Erisman* and *Draaijers*, 1995).

Large-scale measurements of deposition have been made during recent years using the throughfall method (*Ivens*, 1991; *Erisman* and *Draaijers*, 1995). By measuring the amount and quality of the rain water passing through a forest canopy, an estimate of the total (i.e. wet + dry + fog/cloud water) deposition onto this canopy can be made. Water dripping from leaves/needles and branches, and falling through gaps in the canopy is referred to as through-fall, whereas water running down tree trunks is called stemflow. In most cases, stemflow is not measured since it is only 10–15 % of the throughfall (*Ivens*, 1990). It is well known that throughfall is a reasonable indicator for inert components, such as sulphur, sodium and chloride (*Draaijers* et al., 1996). Nitrogen compounds and base cations, however, can either be taken up or leached by the canopy affecting the throughfall composition. For these components, throughfall can only be used as a measure for soil input.

An estimate of the total deposition can be derived from the sum of throughfall and stemflow, corrected for a calculated canopy uptake or canopy release. A procedure for calculating canopy interactions is the canopy budget model. This model was initially proposed by *Ulrich* (1983), to calculate total base cation deposition, and further developed by *Van der Maas* et al. (1991) and *Draaijers* and *Erisman* (1994) to account for canopy uptake of N (in particular NH_4^+).

Assessment of canopy exchange to derive total deposition from throughfall

In order to determine the atmospheric input of nitrogen to forests the canopy exchange has to be determined. The rate of canopy exchange depends on tree species and ecological setting. For example, during the growing season deciduous tree species tend to lose more nutrients from the crown foliage through leaching than coniferous tree species. Conifers, however, stay green all year round and continue to lose nutrients throughout the dormant season (*Smith*, 1981). The age distribution of leaves and soil nutrient status also affects the magnitude of leaching largely. Young immature leaves/needles tend to lose less nutrients compared to older ones (*Parker*, 1990), and fertilisation is found to enhance canopy leaching considerably (*Matzner* et al., 1983). Biotic stresses as insect plagues may initiate large canopy leaching. Furthermore, abiotic stresses like drought and temperature extremes are found to enhance canopy leaching (*Tukey* and *Morgan*, 1963). Moreover, the amount and timing of precipitation is found to be relevant with respect to canopy leaching. Relatively long residence times during drizzle account for relatively high leaching rates compared to short rain periods with large rainfall intensities. Large amounts of rain may deplete leachable pools within the canopy, thereby inhibiting ion leaching (*Lovett* and *Lindberg*, 1984). Losses from leachable pools within the canopy are believed to be replenished within 3–4 days after a large storm by increased root uptake or translocation from other parts of the tree (*Parker*, 1983).

There is considerable experimental evidence for significant uptake of inorganic nitrogen by canopy foliage, stems, epiphytic lichens or other micro-flora. Much insight has been gained from experiments with radio-labelled ^{15}N. Canopy foliage has been demonstrated to be capable of absorbing and incorporating gaseous NO_2 and HNO_3, as well as NO_3 and NH_4^+ in solution (*Reiners* and *Olson*, 1984; *Bowden* et al., 1989). In laboratory experiments, NH_4^+ in solution was found to be exchanged with base cations present in leaf tissues (*Roelofs* et al., 1985). Epiphytic lichens have also been shown active absorbers of NO_3^- and NH_4^+ in solution (*Lang* et al., 1976; *Reiners* and *Olson*, 1984).

Erisman and *Draaijers* (1995) compared atmospheric deposition measurements and throughfall measurements at Speulder forest in the Netherlands. Differences found between NO_y dry and fog deposition estimates and NO_3^- net throughfall fluxes would suggest that approximately 50 % (400 mol.ha^{-1}.yr^{-1}) of the total NO_y deposition is irreversibly retained within the canopy. Differences found between dry and fog deposition estimates of NH_x and net throughfall fluxes of NH_4^+ were not statistically significant. According to the canopy exchange model of *Ulrich* (1983) and *Van der Maas* et al. (1990) canopy uptake of NH_4^+ in the Speulder forest amounts to 255 mol.ha^{-1}.yr^{-1}. *Ibrom* et al. (1994) estimated the deposition of different nitrogen compounds and compared it with the fluxes derived from the throughfall measurements at Sollingen. They found that as much as 30–60 % of the total atmospheric input of 3200–4600 mol.ha^{-1}.yr^{-1} was retained in the canopy as only 2100 mol.ha^{-1}.yr^{-1} was measured in throughfall. This seems, however, an overestimate, since *Eilers* (1992) estimated a much lower uptake (approximately 600 mol.ha^{-1}.yr^{-1}).

Based on information available in the literature, *Ivens* (1990) suggested the aboveground uptake of inorganic nitrogen to be between 150 and 350 molc.ha^{-1}.yr^{-1}. *Johnson* and *Lindberg* (1992) conclude that, on average, 40 % of all inorganic nitrogen input to the IFS forests was retained by the vegetation, whereas 60 % is found back in the throughfall data as NO_3 and NH_4^+. Total inorganic nitrogen uptake amounted up to 850 molc.ha^{-1}.yr^{-1}, with a strong positive relationship between deposition and uptake for spruce and spruce-fir stands. Other tree species showed a rather constant inorganic nitrogen uptake (200–300 molc.ha^{-1}.yr^{-1}), with only little response to deposition amount (*Johnson* and *Lindberg*, 1992). Part of the inorganic nitrogen retained by the canopy may be converted into organic substances and subsequently leached. Total nitrogen (organic + inorganic) in throughfall and stem flow is found to be about 84 % of the total inorganic nitrogen deposition (*Johnson* and *Lindberg*, 1992). Microbes were assumed to play an important role in the conversion of inorganic to organic N, if it occurs. However, it was recognised that organic N in throughfall also arises from internal pools and surfaces of plant and lichens and from micro-particulate detritus and pollen (*Johnson* and *Lindberg*, 1992).

From all studies, it is difficult to get a direct relationship between N input and N uptake. It seems that the coniferous forests take up nitrogen effectively as a fraction of the deposition up to a certain level, whereas the uptake in deciduous forests is a constant level. Ni-

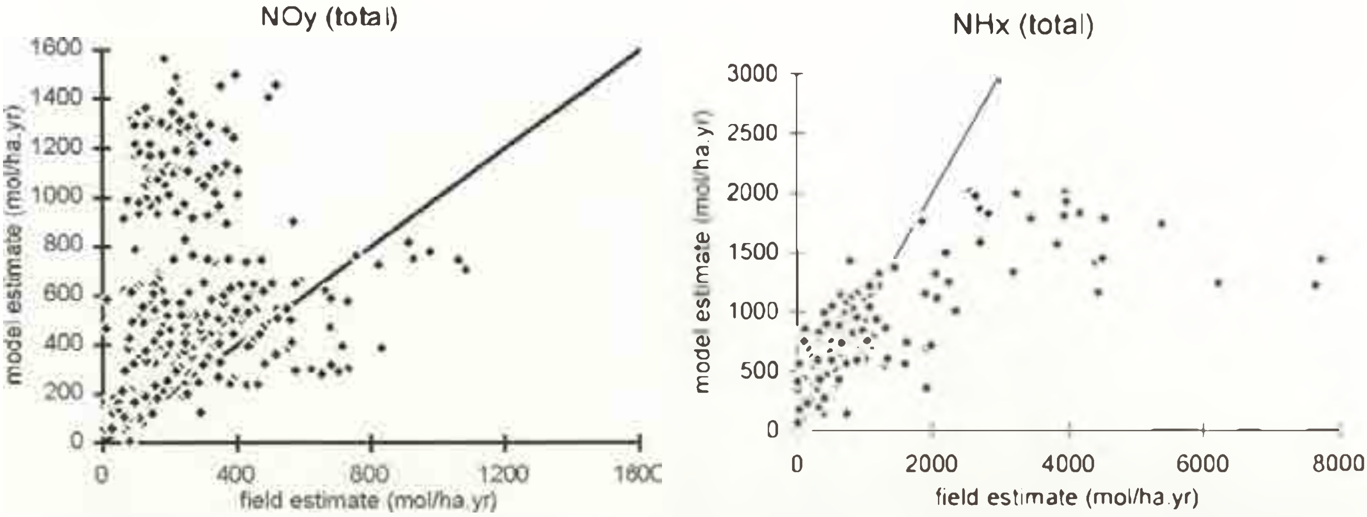

Fig. 3: Comparison between modelled total deposition and total deposition estimated from throughfall and bulk precipitation measurements for NO_y and NH_x

trogen cycles within ecosystems are very complex. Up to now, no reliable estimates for inorganic nitrogen deposition can be made (using the mass balance method?).

Comparison of model estimates with throughfall fluxes

A final approach to gain insight in total deposition on forests is the use of 'inferential' deposition models. Application requires a thorough validation of those models, which can only be done using throughfall data. A validated model is a suitable means to gain insight in the geographic variation of N deposition. NO_y dry deposition estimates from micrometeorological measurements made above forest in the Netherlands were somewhat lower compared to NO_y deposition estimates from an inferrential model. NH_4^+ net throughfall fluxes were not significantly different from NH_x dry deposition estimates, but their correlation was rather poor. NH_3 deposition estimates from micrometeorological measurements made over heather and forests in the Netherlands were found both lower and higher compared to inferential model estimates. This is attributed to the large spatial variability in NH_3 dry deposition amounts due to the impact of local sources and short atmospheric residence times of NH_3 (*Erisman*, 1993 A). In comparing throughfall with model estimates of nitrogen input to forests in Europe, *Ivens* (1990) found no significant difference between NO_3^- throughfall fluxes and NO_y (= total oxidised nitrogen) deposition estimates, but NH_4 throughfall fluxes were significantly lower (on average, 70 %) compared to NH_x (= total reduced nitrogen) deposition estimates.

Van Leeuwen et al. (1999) compared modelled atmospheric deposition estimates with more recent throughfall measurements made in Europe. In total, results from 296 different throughfall measurement plots were obtained, though at several of the plots only data on one year were obtained. The measurement plots are not equally distributed over Europe, as most plots are located in Scandinavia, Germany, The Netherlands, France, Ireland and Switzerland. The majority of the plots (82 %) were situated in coniferous forest stands; only 11 % in deciduous forest stands and 7 % in mixed forest stands. Monitoring took place between 1986 and 1995 for a period of at least one year. Total NO_3 and NH_4 fluxes are compared in Figure 3.

For NO_y two groups of plots can be distinguished: one group scattering around the 1:1 line (which is included in each plot), where both model and measured estimates are low, and another group where modelled values are high, whereas measured data are much lower. This might be explained by canopy uptake. Most throughfall measurements are obtained in relatively low NH_x deposition areas. At stands where the deposition is higher than about 1500 $molc.ha^{-1}.yr^{-1}$, the throughfall estimates

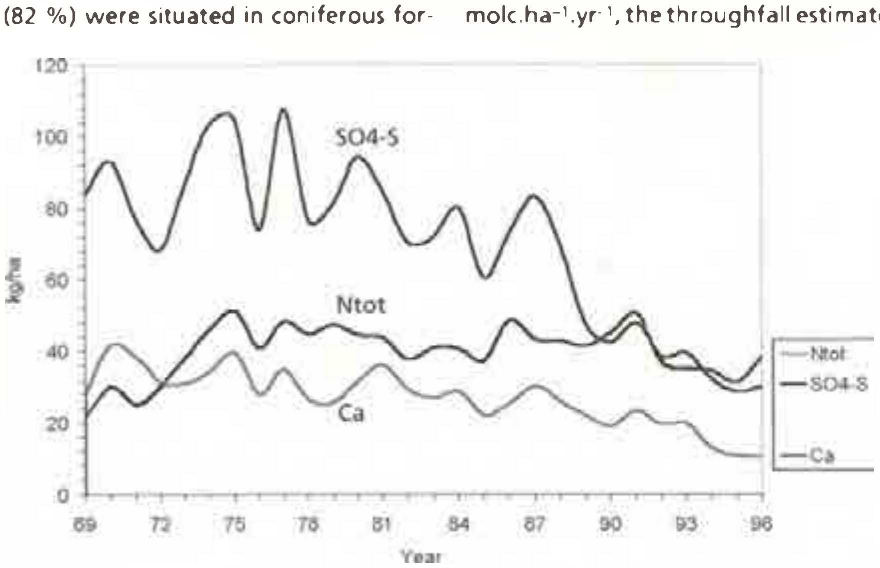

Fig. 4: Trends in annual throughfall fluxes in SO_4, N and Ca at the Solling spruce site over the period 1973–1996 (Data from the Forest Experiment Station of Lower Saxony; Meesenburg, pers. comm.).

are much higher than the modelled estimates, despite the expected canopy uptake. This is caused by underestimation in high emission areas of the concentrations resulting from the concentration model resolution. Results given above indicate that models may give a reasonable estimate of total deposition, but a thorough validation is not possible due to the inadequacies in throughfall estimates.

3.3 Evidence of the increasing role of nitrogen in forest inputs

Site level

One of the longest time series of throughfall measurements is available at the Sollingen site in Lower Saxony (Germany) (*Meesenburg* et al., 1995). In the beginning of the seventies the sulphur input in this spruce forest amounted to about 3000 mol.ha^{-1}.yr^{-1} (approximately 100 kg.ha^{-1}.yr^{-1}), which decreased by about 70 % to about 1000 mol.ha^{-1}.yr^{-1} in 1996 (Fig. 4). No clear trend in the N inputs was observed over the same time span. The average annual throughfall flux of N equals 2360 mol.ha^{-1}.yr^{-1} (33 kg.ha^{-1}.yr^{-1}).

In 1987 the University of Wageningen started a monitoring programme of exposure and gradient measurements on a mast in the Speulder forest in the centre of the Netherlands. Since then several deposition monitoring programmes were executed using the throughfall method, micrometeorological methods and model estimates (*van Aalst* and *Erisman*, 1991; *Duyzer* et al., 1994, *Erisman* and *Draaijers*, 1995; *Erisman* et al., 1998). The annual variation in SO_x, NH_x and NO_y fluxes is displayed in Figure 5. The figure shows that, despite the year to year variations due to variations in meteorology and the different methods used during the years, the deposition of SO_x decreased between 1988 and 1995. If the trend could be corrected for the forest growth, the decrease in deposition would be expected to be somewhat higher. For NO_y and NH_x no trend can be detected from these data. The throughfall data for NH_4

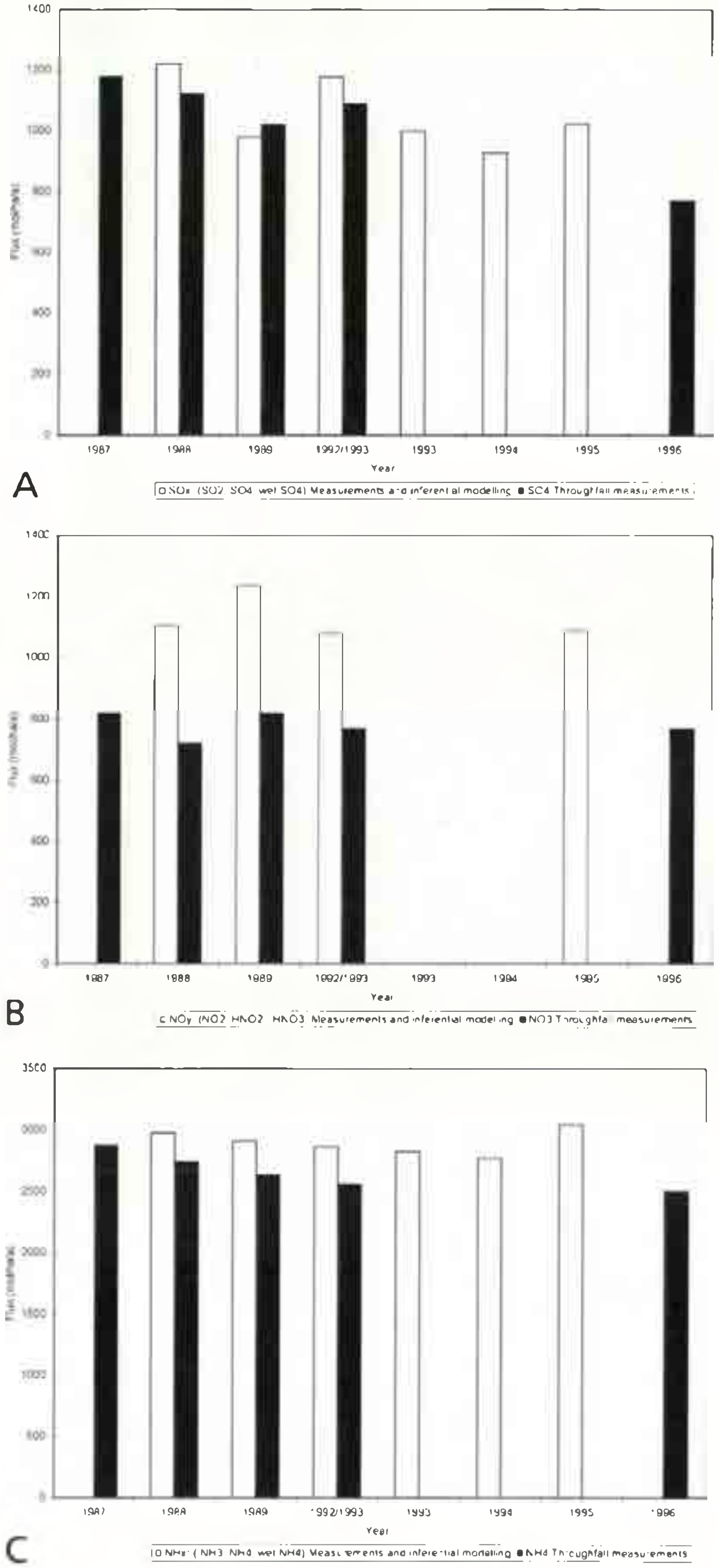

Fig. 5:. Annual variation in total deposition measured over Speulder forest: A SO_x, B: NO_y and C: NH_x

show a slight decrease between 1987 and 1996, whereas no trend could be detected in the NO_y deposition. The data show that nitrogen became more important during recent years.

Transnational and European level

An indication of changes in N and S deposition has been derived from a comparison of annual throughfall fluxes assessed at some 120 plots in the eighties (*Ivens*, 1990) and at 163 plots in 1996 (*De Vries*, 1999). The first set of data consists of a literature compilation, whereas the latter dataset is based on a European wide monitoring programme in forests (See also Section 3.4). A comparison was made by requiring that stands with similar forest types (pine, spruce and broadleaves) were located within a distance of 10 km. Results for a total of 59 plots showed a clear decrease for SO_4 but also of N. remained constant (Fig. 6 A, B). Results of the different N compounds showed a strong decrease on NO_3 (Fig. 6 C), whereas NH_4 remained mostly constant (Fig. 6 D).

A similar trend was derived by modelling the N and S deposition on forested plots at a systematic 16km × 16km grid (See also Section 3.4), as illustrated in Fig. 7 (*Van Leeuwen* et al., 1999).

In the so-called 'Pan-European Programme for Intensive Monitoring of Forest Ecosystems' by the EC and ICP Forest, throughfall measurements are being conducted in more than 400 forest stands, distributed over 23 countries in Europe (*de Vries* et al., 1999). Annual throughfall fluxes for the year 1996 could be calculated for 163 plots. A scatter plot of throughfall fluxes and calculated total deposition fluxes (corrected for nitrogen canopy uptake) of N (NH_4 + NO_3) and SO_4 at those plots is given in Figure 8 (*de Vries* et al., 1999).

Total deposition of S and N compounds ranged between 100 and 3000 $mol.ha^{-1}.yr^{-1}$ at approximately 90 % of the plots, but values up to 4000–8000 $mol.ha^{-1}.yr^{-1}$ were also observed. If the uptake of nitrogen through the canopy is calculated correctly, the average N to S ratio varied between 0.5 and 2.7 (*de Vries* et al., 1999). The calculated average total nitrogen deposition thus mostly exceeded that of sulphur. The relative contribution of NH_4 and NO_3 in N deposition varied largely over the plots, but in most countries, especially in Northern and central Europe, NH_4 dom-

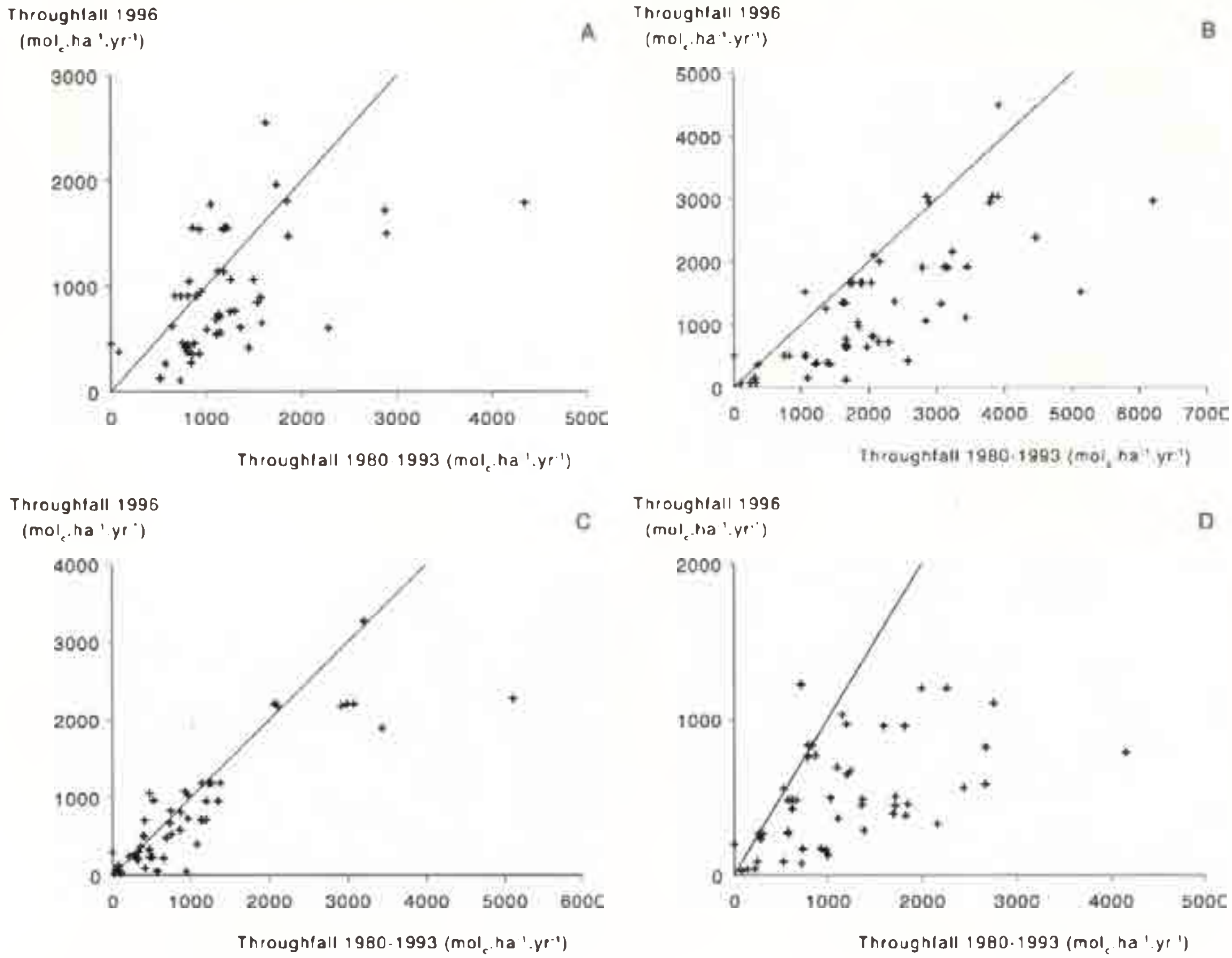

Fig. 6: Comparison of the throughfall of total SO_4 (A), N (B), NH_4 (C) and NO_3 (D) measured at plots located within 10 km in the eighties (80–93) and the nineties (1996).

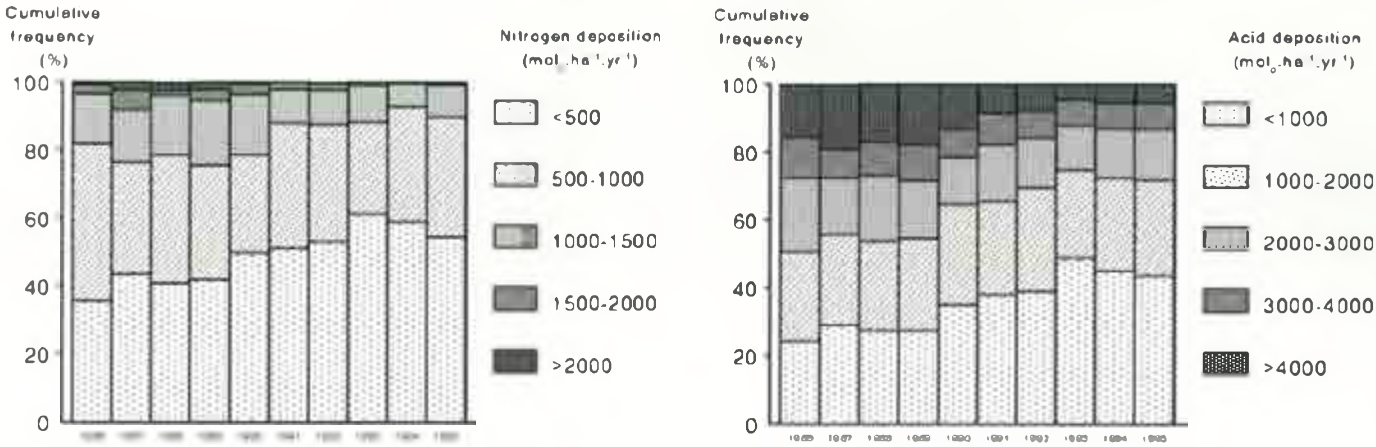

Fig. 7: Temporal variation in annual average deposition of total nitrogen (A) and potential acid (B) calculated on forested plots in a 16 × 16km grid over Europe in the period 1986–1995.

inated N deposition. In Western Europe, N deposition exceeded the sulphur inputs, whereas the reverse was observed at plots in Central Europe. Approximately 50 % of the plots received N inputs above 1000 mol.ha⁻¹.yr⁻¹, being a deposition level at which species diversity of the ground vegetation may be at risk. Below this deposition level tree growth may be inhibited. The total input of (potential) acidity, defined as the total input of N and S minus the base cation deposition corrected for Cl, ranged mostly between 200 and 4000 mol.ha⁻¹.yr⁻¹. Adverse impacts by soil acidification and Al release are likely at very high deposition levels (>3000 molc.ha⁻¹.yr⁻¹), that do occur at approximately 15 % of the plots.

It is foreseen that atmospheric deposition will ultimately be measured at approximately 500 plots in the Pan-European Intensive Monitoring Programme, spread throughout most of Europe (*De Vries* et al., 1999). An extrapolation of those deposition measurements to forested plots at a 16 km × 16 km grid is foreseen in the future, using (a combination of) process based models and statistical relationships. Results of a preliminary application of the inferential EDACS model for those plots are presented in Figure 9. It shows the geographic variation of modelled N deposition on forested plots in Europe, where crown condition monitoring takes place. The estimates are averages over the period 1985–1995. The figure illustrates that elevated N deposition occurs in large parts of Europe (especially in Western and Central Europe), particularly when one considers that the N deposition is likely to be an underestimate in source areas (*Van Leeuwen* et al., 1999).

3.4 Input – output balances

Input – output balances are relevant because they give information about the nitrogen status of the forest (Section 3.1). *Abrahamsen* (1980) and *Grennfelt & Hultberg* (1986) first related increased nitrate leaching from forest ecosystems to N deposition in input-output diagrams. The diagrams showed that elevated nitrate leaching was found in some forest ecosystems at inputs above approximately 10 kg N.ha⁻¹.yr⁻¹. These findings raised concern about the potential acidifying effects of N saturation from increased N deposition.

An analysis of input-output data from 65 forest ecosystems studies (plots

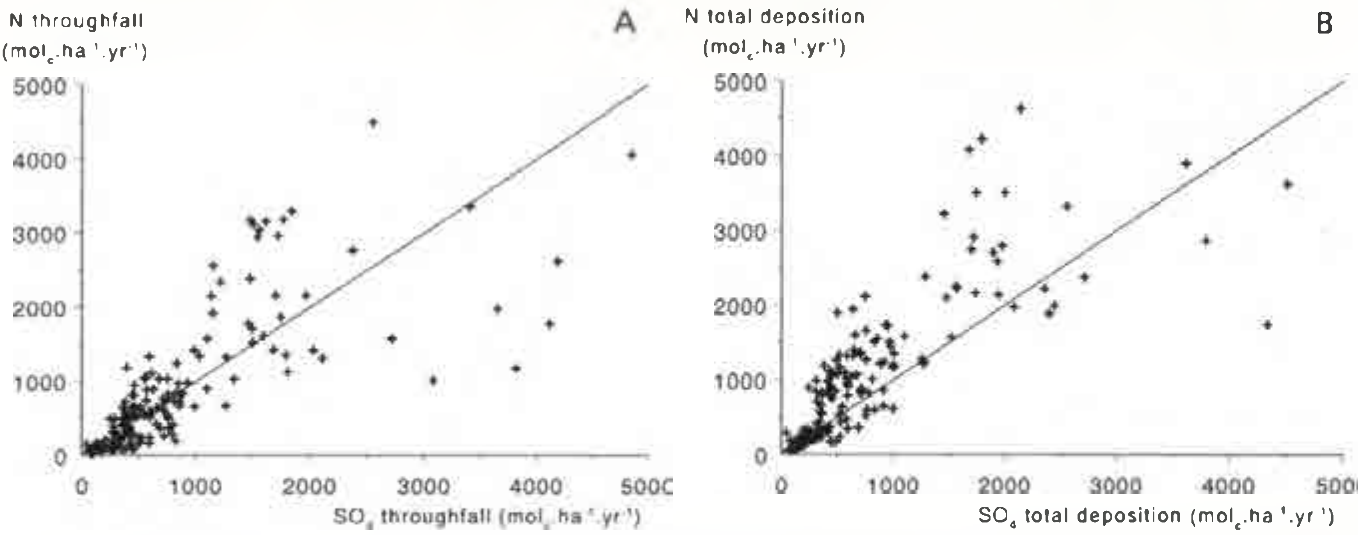

Fig. 8: Relationships between the annual fluxes of N and S in throughfall (A; 163 plots) and total deposition (B; 144 plots). The solid line represents the 1:1 line.

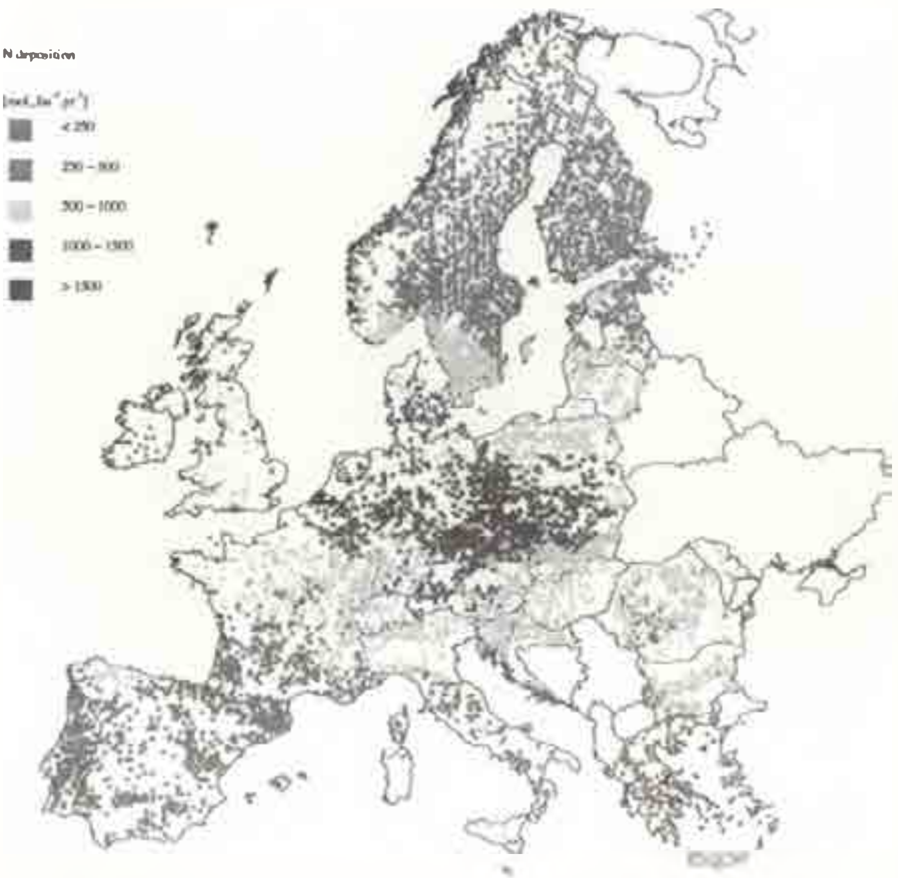

Fig. 9: The calculated 10 years average N deposition (1985–1995) at forest monitoring plots at a systematic 16 km × 16 km grid.

and catchments) across Europe (primarily from the mid-1980s) showed that nitrate leaching was close to zero at inputs below 10 kg N.ha^{-1}.yr^{-1}, whereas a considerable part of the input (10–35 kg N.ha^{-1}.yr^{-1}) was leached in all systems with input above 25 kg N.ha^{-1}.yr^{-1} (*Dise & Wright*, 1995). Nitrogen input with throughfall was the best predictor of nitrate leaching among the 41 soil and ecosystem variables tested. Results suggest a high risk at C/N ratios below 25 and an elevated risk at C/N ratios between 25 and 30 in the humus layer at plots with an N deposition above 10 kg.ha^{-1}.yr^{-1} (*Gundersen* et al, 1998). This would imply that a combination of information on N deposition and soil characteristics gives information about the so-called N saturation of the forest ecosystem. In this context an N saturated ecosystem is defined as 'an ecosystem in which availability of inorganic nitrogen is in excess of total plant and microbial nutritional demand' (*Aber* et al., 1989). A recent compilation of N inputs by throughfall and outputs by soil leaching by *Dise* et al (1998) also suggests that soil characteristics such as C/N ratio and pH are relevant but also the composition of the N species in the input. N retention seems to increase when the fraction of NH_4 in the input increases.

A regional survey of throughfall deposition and nitrate concentrations in soil water on 60 forest sites in southern Sweden showed a similar pattern as for the European scale. Nitrate concentrations in soil water were close to zero at inputs below 15 kg N.ha^{-1}.yr^{-1} and elevated at inputs above 22 kg N.ha^{-1}.yr^{-1} (*Westling*, 1991). Figure 10 shows a compilation of German data from the eighties (*Block*, 1994), Dutch data from 150 plots (*de Vries* et. a., 1994) and the NITREX data measured mainly between 1990 and 1994 (*Bredemeier* et al. 1998). Again, elevated nitrate leaching appeared at inputs above 10–12 kg N.ha^{-1}.yr^{-1}. Some sites, mainly young stands, retained all inputs up to 30 kg N.ha^{-1}.yr^{-1}. Six sites leached more than the input. It must be emphasised that the input represents throughfall data, which generally underestimate the total atmospheric input (see section 2.2). First results at approximately 50 plots of the 'Pan-European Intensive Monitoring Programme' confirmed the input threshold at ca. 10–15 kg N.ha^{-1}.yr^{-1} where nitrate leaching started to increase (*de Vries* et al., 1999).

The difference between the input and output fluxes is plotted against the ratio of NO_3 and NH_4 in throughfall (input) in Figure 11. The sites with the highest degree of saturation (the difference between input and output approaching or exceeding zero) show a decreasing ratio of NO_3 over NH_4. This means that when the input of NH_4 becomes more important leaching of nitrate increases.

4. Effects of nitrogen inputs on forest ecosystems

4.1 Indicators for effects

Before answering the question on what the observed effects are, we need to define what we mean by effects and what

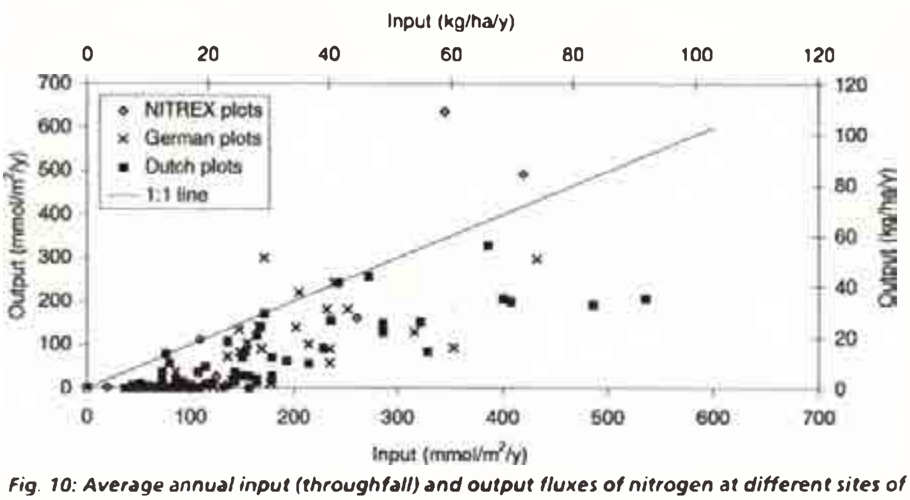

Fig. 10: Average annual input (throughfall) and output fluxes of nitrogen at different sites of Europe.

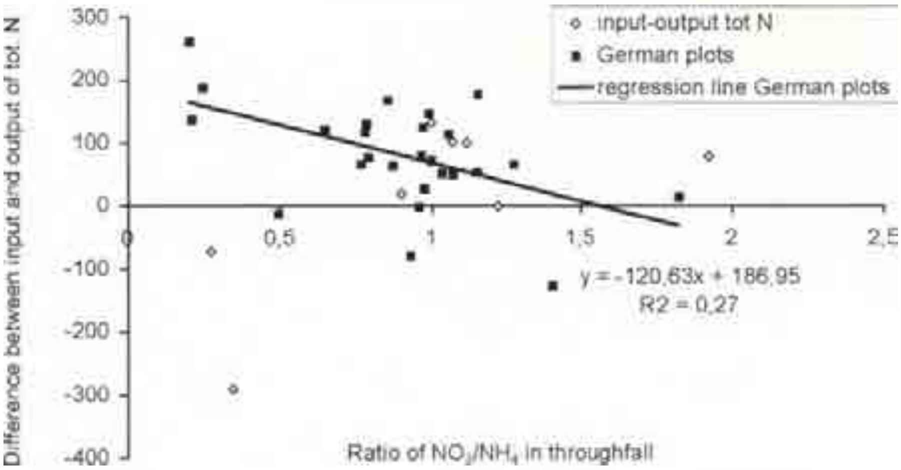

Fig. 11: The difference between input and output (mmol.ha⁻¹.yr⁻¹) versus the ratio of NO_3 over NH_4 in throughfall (input).

kind of effect parameters is taken into account. Effects are defined as systematic changes of biotic components of the forest ecosystem because of environmental impacts/stress. In general, direct and indirect effects are distinguished. Direct effects are the result of exposure to air pollutants, whereas indirect effects are the result of chemical changes in the soil environment. Direct and indirect effects are sometimes also distinguished according to the time lag between cause and occurrence of effects (i.e. effects on photosynthesis versus effects on growth).

In practice, the health (vitality of trees and of entire forest ecosystems defines the capacity to cope with stress, resulting from the occurrence of air pollution and natural stresses caused by changes in environmental conditions, such as drought, frost, windthrow, pests and diseases. Usually, it is difficult to derive mono-causal relations from the multiple stress to which forests are exposed. An overview of possible effects on forests as a result of increased atmospheric acid and nitrogen deposition and/or exposure to air pollutants is presented in Table 1. The increased atmospheric acid and nitrogen loads and air pollutant concentrations lead to changes in the effect parameters and/or changes in sensitivity and thus increase the risk of damage due to, for example, to plagues, diseases, storms, drought and frost sensitivity.

Table 1: Possible effects of increased atmospheric N loading and exposure to NO_x and NH_3 on forest ecosystems.

Ecosystem compartment	Effects	
	Chemistry	Ecosystem
Trees (including foliage and roots)	- NH_3 exposure	- enhanced transpiration and drought sensitivity by elevated stomatal control
	- elevated N contents in foliage	- increased biomass production - increased water demand - increased ratio of foliage to roots (risk of drought and nutrient deficiency) - increased frost sensitivity - increased parasite injury (insects, fungi, virus)
	- elevated arginine concentration nutrient deficiency absolute or relative (to N)	- growth reduction - discoloration (defoliation)
Soil (solution)	- elevated N contents in soil	- increase in nitrophilous species - decrease in biodiversity - NO_3 leaching - No_x and N_2O emission
	- elevated ratios of NH_4^+ and Al^{3+} to base cations	- inhibition of uptake (nutrient imbalances/deficiency) - root damage - mycorrhiza decline

4.2 Nitrogen status

The impact of N on the ecosystem is ambiguous as N is a nutrient that may be both in a situation of shortage or of excess. At low N status, the elevated input of N will increase forest growth. Observations of increased tree growth of European forests (*Spiecker* et al., 1997) may be considered the effect of increased N inputs, although this is one of several reasons that may explain this response. Further exposure to nitrogen, or increase of the N loads may lead to changes in metabolism and in the end to decrease in vitality, as shown in Figure 12 (according to *Gundersen*, 1992). Figure 12 identifies three classes with respect to the nitrogen status of the forest, being an important indicator for the different processes and expected effects: 1. N limitation, where input exceeds output of nitrogen; 2. Saturation, where input about equals output and

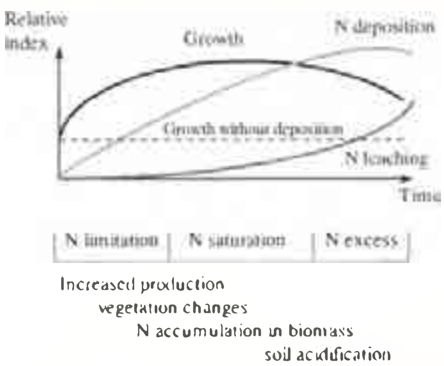

Fig. 12: Hypothesis for the responses of temperate forest ecosystems to increased nitrogen deposition. The time scale (x-axis) for these changes may differ widely between ecosystems and regions (After Gundersen, 1992).

3. Excess, where the output exceeds the input of nitrogen. The phases might be identified by the input – output balances of the forest ecosystem.

The figure shows the development of a forest ecosystem from N limitation to N excess induced by atmospheric deposition, indicating that until a certain optimum level the ecosystem can deal with additional inputs and above that, production decreases. Below the optimum level, however, also changes in the ecosystem are observed, especially the forest floor vegetation may gradually change towards more nitrophilic species (*Ellenberg*, 1985; *Bobbink* et al., 1995; *Bobbink* et al., 1998). Increased N availability from deposition reduces retranslocation of N from old to new tissue and thus increases the N content of litter (reduced C/N ratio). Lower C/N ratios in litter stimulates decomposition and mineralization, which then again increases N availability. The suppression of the nitrification process at low N availability, may be relieved by the increased N input and nitrate may be formed even at very low pH in the soil (*Gundersen* & *Rasmussen*, 1990).

At forested plots with a continuous high N input, essential resources other than N may at least periodically limit the primary production, especially when the canopy will reach its maximum size and the N utilisation efficiency will decrease. The ecosystem then approaches a condition often referred to as "nitrogen saturation" where "inorganic N is in excess of total combined plant and microbial nutritional demand" (*Aber* et al., 1989). By this definition a forest ecosystem leaching nitrate (or ammonium) is saturated, but may still respond to N additions and accumulate a considerable amount of N in the biomass. Increases of nitrate leaching should be considered in comparison with the low background levels from unaffected areas. At the stage of 'N saturation' or 'N excess', the ecosystem may be destabilised by the interaction of a number of factors such as (*NIVA*, 1996; see also the hypotheses in chapter 2): i) an increased potential for water stress by increased canopy size, increased shoot/root ratio, and loss of mycorrhizal infection; ii) root damage due to acidification caused by climatically controlled pulses of nitrification (*Matzner*, 1988); iii) absolute or relative nutrient deficiencies may develop (*Nihlgard*, 1988; *Roelofs* et al., 1985; *Schulze*, 1989), which may even be aggravated by a loss of mycorrhiza or root damage (*Schulze*, 1989) and iv) accumulation of N in foliage (e.g. as amino acids), which may affect frost hardiness (*Aronsson*, 1980) and the intensity and frequency of insect and pathogenic pests (*Popp* et al., 1986; *Roelofs* et al., 1985). This destabilisation phase, may gradually change into decay at a certain accumulation of N in the system caused by a continuing elevated level of nitrogen deposition. Experiments with decreased N deposition at N saturated sites in the nitrogen saturation experiment (NITREX), however, showed an immediate decrease in nitrate leaching after building a roof construction to remove the N input (*Boxman* et al., 1995; *Bredemeier* et al., 1995; *Wright* et al., 1995; *Wright* and *Rasmussen*, 1998). This shows that N saturation is a reversible process in chemical terms. In ecological terms, an improvement is to be expected as well.

4.3 Field evidence for impacts of elevated N deposition

In this section we provide field evidence for impacts of elevated N deposition. Since the Netherlands, is a country experiencing the highest N loads, most examples are taken from this country.

Table 2: Average nitrogen content and ratios between K^{+}, Mg^{2+} and N concentrations in half year old needles in 1956 and 1988 (Van den Burg and Kiewit, 1988).

Tree species	N content (% dry weight)		Nutrient ratio×100 ($g\ g^{-1}$)			
			K/N		Mg/N	
	1956	1988	1956	1988	1956	1988
Scots pine	1.5	2.3	34	27	3.0	2.7
Corsican pine	1.2	1.7	58	35	4.0	3.8
Douglas fir	1.4	2.2	68	24	6.1	5.0

Elevated N-content in leaves and in soil

Comparison of conifer ecosystems over a pollution gradient in Europe confirmed that N content in soil and vegetation pools increase with N deposition (*Tietema* and *Beier*, 1995). Strong linear correlations were found between N flux in both precipitation and throughfall and N content in new needles, needle litter, and organic topsoil. Such relationships were also found in the United States but over a pollution gradient 10 times lower than in Europe (*McNulty* et al., 1991). Experiments in Scandinavia (*Sikstrom* et al., 1998) and new England (*McNulty* et al., 1996) indicate a threshold for the growth response of conifers of 1.4 to 1.6 % N in needles. At this threshold, increased N leaching (N saturation) is also observed in various sites over Europe (*De Vries* et al., 1999). *Flückiger* and *Braun* (1998) showed a linear relation between N in needles and the nitrogen deposition. *Van den Burg* and *Kiewit* (1988) showed that the N content in needles strongly increased between 1956 and 1988, whereas the nutrient ratios of K and Mg over N decreased significantly (see Table 2). In relation to optimal nutrient ratios, a shift has taken place from nitrogen shortage to excess. *Van Dijk* et al. (1992) showed a positive relationship between high nitrogen contents in needles and the occurrence of diseases and plagues, such as the damage of needles by Sphearopsis sapinea.

Nutrient imbalances

An important impact of high N contents in foliage is the occurrence of to nutritional imbalances, i.e. absolute deficiencies or deficiencies relative to N in needles of the macro nutrients K, P, Mg and Ca, and possibly of micro nutrients like B, Mn and Mo. Increased growth rate and elevated N concentrations in foliage may dilute the pool of other nutrients in absolute and/or relative terms. The problem of nutrient imbalances induced by nitrogen can be aggravated by the acidifying impact of both N and S compounds. In soils with a low base saturation (most sandy forest soils in Europe) an elevated input of acidity by S and N compounds, will cause the release of toxic Al that may reduce the availability of nutrients by affecting both root

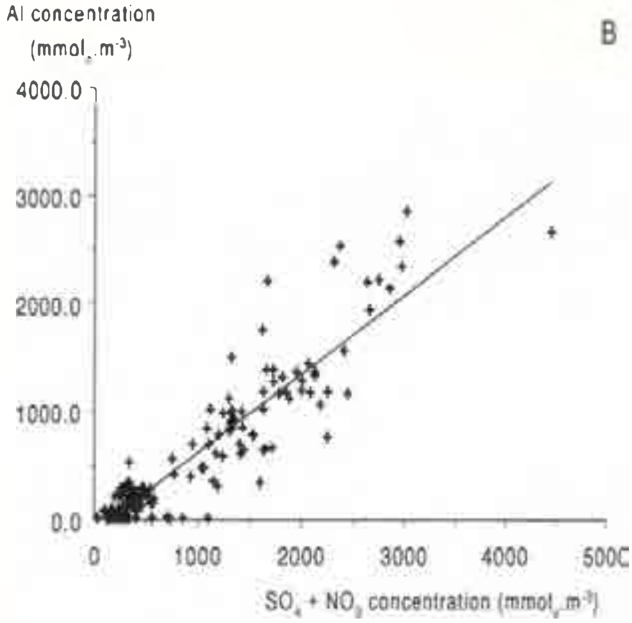

Fig. 13: Relationship between the concentration of Al and the SO_4+NO_3 concentration in the subsoil (159 measurements) of Intensive Monitoring plots with a pH < 4.5. The solid line represents a regression line.

growth and root uptake (e.g. *Sverdrup* and *Warfvinge*, 1993). The release of Al in response to elevated concentrations is illustrated in Figure 13 with results from the Intensive Monitoring Programme of Forest Ecosystems. In soils with a low pH (below 4.5) or base saturation (below 25 %), more than 80 % of the variation in Al concentration could be explained by a variation in SO_4 and NO_3 concentration, which in turn was strongly related to the deposition of S and N respectively. Even though SO_4 is also important in releasing Al, results showed that NO_3 concentrations were mostly higher, reflecting the increasing role of N in soil acidification. Elevated ratios of Al and NH_4 to base cations such as Mg and Ca may cause (relative) base cation deficiencies.

Nutrient deficiencies, especially of Mg, are considered an important factor in the "new type of forest damage" in Germany and central Europe (*Huttl*, 1989; 1990), which could be related to soil acidification from atmospheric deposition (e.g. *Ulrich & Pankrath*, 1983). The effect of increased N inputs in combination with soil acidification has been emphasised in several cases (*Schulze*, 1989; *Schulze* et al., 1989; *Huttl*, 1990). Nitrogen may stimulate tree growth and increase the demand of, for example, Mg, which has to be taken up (a) from a decreasing soil pool, (b) by a root system which may be damaged by Al toxicity or less effective due to a decline of mycorrhiza, and (c) possibly in competition with ammonium in elevated concentration (*Schulze*, 1989). From several of the N saturated sites, deficiencies of elements such as Mg (*Roelofs* et al., 1988; *Hauhs*, 1989; *Schulze*, 1989; *Horn* et al., 1989; *Feger* et al., 1990; *Kazda*, 1990; *Probst* et al., 1990) and K (*Roelofs* et al., 1988; *Gundersen* 1992 a) are observed. These deficiencies may limit the capacity of the vegetation and the soil to retain N inputs hereby causing nitrate leaching.

Roelofs et al. (1985) showed a relation between the vitality of Corsican pine and the nutrient ratios in the soil (see Fig. 14). At increasing ratios of ammonium over both potassium and magnesium, a decrease in vitality was observed. The relation was less obvious with the Al/Ca ratio in the soil.

Root-shoot ratio

Elevated N inputs may decrease both roots length and the root-shoot ratio of forests. A reduction in the specific root length can endanger the uptake of nutrients and water. *De Visser* (1994) used seedlings of Douglas fir (*Pseudotsuga menziesii*) in a pot experiment to study the effect of fertilising with 100 kg N.ha^{-1}.yr^{-1} on the biomass production and in particular on the specific root length (length/weight). Total biomass production was enhanced by the fertilisation treatment, but the specific root length was reduced. Furthermore, the negative effect on the root length was reduced if the same dose of nitrogen was applied but split equally between NH_4 and NO_3 instead of all in the form of NH_4. In another pot experiment with young Douglas fir trees the root growth and drought resistance declined after an application of 120 kg NH_4_N.$^{-1}$.yr^{-1} compared with one of 30 kg N.$^{-1}$.yr^{-1}. The results of these experiments indicate that applying nitrogen can lead to an increase in the shoot/root ratio and can also cause damage to the root system (probably via soil acidification and Al toxicity). It also appears that the response depends not only on the amount of nitrogen supplied to the plant but also on the form in which it is offered. The NH_4_N/NO_3_N ratio is determined by

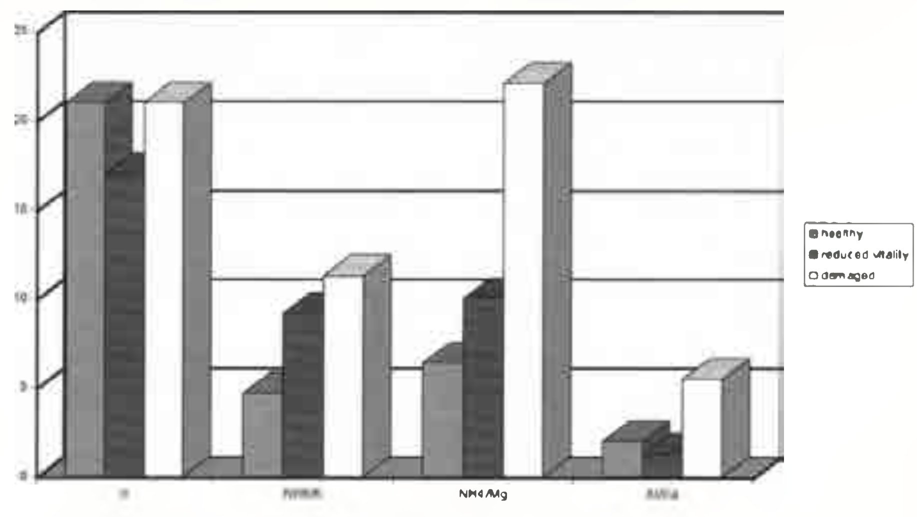

Fig. 14: Relation between the vitality of the Corsican pine and the nutrient ratios in the soil (Roelofs et al., 1985).

Table 3. Chemical soil parameters, root and shoot characteristics of Douglas-fir seedlings grown for eight months in sand at different NH_4 supply levels (Olsthoorn et al., 1991).

NH_4 supply (mmol)	Concentrations (mg kg^{-1} dry soil)		Ratios (mol mol^{-1}) length		Total root length (m/plant)	Specific ratio (m g^{-1})	Shoot/root
	NH4	Al	NH_4/Ca	Al/Ca			
1.5	0.7	25.0	0.12	2.4	41	14	0.8
7.5	0.2	27.9	0.05	3.3	38	10	0.9
49.5	6.3	33.4	1.6	5.0	35	12	1.0
121.5	33.4	33.1	8.6	5.0	20	8	1.3

soil properties, but the composition of the deposition (NH_x/NO_y) can also play a role (*De Visser*, 1994).

Olsthoorn et al. (1991) concluded from container experiments with Douglas-fir seedlings grown on sand during 8 months with different NH_4 supply to the soil, that high doses of NH_4 negatively affected root length and root length per unit of dry matter (see Table 3). Shoot growth was stimulated by high availability of nitrogen. Therefore, the shoot/root ratio increased with higher doses of NH_4..

Growth response and carbon sequestration

Increased wood production in forests during recent decades is documented for different parts of Europe (*Kenk* and *Fisher*, 1988; *Andersen*, 1984; *Eriksson* and *Johansson*, 1993; *Kauppi* et al., 1995). Increased N deposition is a possible explanation for these observations, but management changes, increased CO_2, and climate changes may also be involved. There are, however, observations from fertiliser experiments that N additions alone do not increase growth (*Dralle* and *Larsen*, 1995). Furthermore, simulations of increased N deposition on forest plots within the nitrogen saturation experiment (NITREX) did not result in growth changes during the first three years of treatment (*Wright* et al., 1995). At very high N inputs (most likely above 3000 molc.ha^{-1}.yr^{-1}) a growth decline can be expected. Destabilisation, decline or breakdown of forest ecosystems from high N input has been shown near local sources of NH_3 such as large animal farms (*Kühne*, 1966, *Nihlgird*, 1985; 1988; *Ferm* et al., 1990) and in high deposition areas (*Roelofs* et al., 1985; 1988; *Mohren* et al., 1986).

If nitrogen fertilisation is accompanied by extra carbon sequestration, this effect might be compensated by emissions of N_2O and/or the reduction of the soil uptake of CH_4, both also greenhouse gases with higher greenhouse potentials per molecule than CO_2. Fluxes of N_2O and CH_4 were measured by *Butterbach-Bal* et al. (1998) in a low N input forest in Ireland and a high N input forest in Germany. A strong correlation between increased N_2O fluxes and decreased CH_4 oxidation rates were observed with nitrogen, and especially ammonium inputs. The increased emissions of N_2O and the decreased uptake of CH_4 compensates the additional carbon sequestration in terms of global warming potential. There is not enough knowledge to determine the net effect of nitrogen and carbon fertilisation on the greenhouse gas budgets.

Species diversity

Circumstantial evidence is available for large changes in forest understory in the Netherlands over the period 1950–1990. These changes entail: (i) a decline of terrestrial lichens ('reindeer lichens') and of ectomycorrhiza mushrooms; (ii) an increase of grasses, notably *Deschampsia flexuosa* and (iii) a general increase of mosses and vascular plants that typically occur on nitrogen-rich soils. However, detailed information at site level is scarce. A pilot study carried out by *De Vries* (1983), in an area of pine forests on dry, sandy soil, where vegetation maps from 1957 were available, showed a complete changeover in understorey vegetation, from a moss- and lichen-dominated type to a grass-dominated type. Scattered information on other sites shows that the changes observed at this site are probably typical for most Dutch pine forests on poor soils.

Changes in the Dutch mushroom flora have been studied by comparing old (circa 1950–1970) excursion reports with recent inventories. Extensive studies of this type, carried out by *Arnolds* (1991) and others, showed a strong decline of fruitbodies of ectomycorrhizal fungi, and an increase of fruitbodies of wood-inhabiting saprotrophic and parasitic fungi. Among the soil-inhabiting saprotrophic species those of nutrient-rich soils had increased, while those of nutrient-poor soils had decreased. Changes in the understory of Dutch pine forests in a more recent period were studied by comparing vegetation descriptions made in 177 permanent plots in 1984 and in 1993 (*Van Dobben* et al. 1994). This study showed a significant decrease in the cover of *Erica tetralix* and *Calluna vulgaris* and a strong increase of many nitrophilous species. As a consequence, a highly significant increase in Ellenberg N-indicator value was observed.

Studies comparing vegetation development in untreated and fertilised pine forests in areas with a low background deposition of nitrogen can be used to estimate the effects of nitrogen on forest vegetation. Such studies have shown that the changes in Dutch pine forests can be rather well simulated by the addition of nitrogen fertiliser at rates comparable to the rate of atmospheric ni-

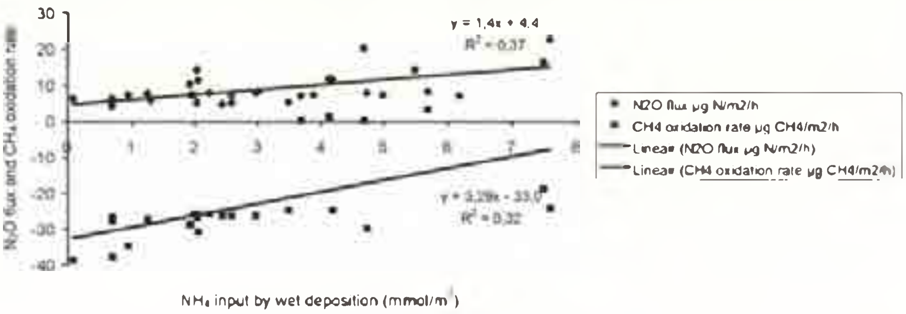

Fig. 15: Correlation between NH_4 input and N_2O flux/CH_4 oxidation rate.

trogen deposition (*Van Dobben* 1993). Species changes in the ground vegetation of forests towards nitrophilic species have also been recorded in other parts of Europe. In a recent review, *Bobbink* et al. (1995; 1998) concluded that these changes occurred at N loads above 10–20 kg $N.ha^{-1}.yr^{-1}$.

5. Discussion and conclusions

The impact of N on the ecosystem is ambiguous as N is a nutrient that may be both in a situation of shortage or of excess. At low N status the elevated input of N will increase forest growth. Observations of increased tree growth of European forests may be considered the effect of increased N inputs, although this is one of several reasons that may explain this response. The question is which forests presently still respond to nitrogen. Above a deposition threshold of approximately 10–15 $kg.ha^{-1}.yr^{-1}$, increased N leaching (N saturation) is observed in various sites over Europe, but the N leaching varies strongly over the sites. Above such a threshold, adverse impacts of elevated N input may occur, such as a decrease in the biodiversity of the ground vegetation by an increase of few nitrophilous species. Furthermore, the growth response to increased N inputs will decrease. At very high N loads, the nitrate concentrations may even exceed the target value for drinking water quality. Furthermore, a continuous high input of N causes an increased risk of water stress (by favouring growth of canopy biomass, whereas root growth is relatively unaffected) and an increased sensitivity to frost and pest and diseases. The problem of nutrient imbalances induced by nitrogen, can be aggravated by the acidifying impact of both N and S compounds, causing the release of potentially toxic Al in soils with a low base saturation (most sandy forest soils in Europe). This may reduce the availability of nutrients by affecting both root growth and root uptake.

In summary, impacts of elevated N inputs on forests are reduction of species diversity, root damage and nutrient imbalances, increased risk for natural stress factors, such as drought and frost and ground water pollution. On the other hand, low inputs may cause reduced forest growth due to N deficiencies. Those impacts may be reduced by management options and reduced N inputs by atmospheric deposition, whereas the situation may be aggravated by changes in land use and climate (e.g. elevated N leaching).

In order to evaluate the effects of management options and environmental changes (changes in atmospheric deposition, land use and climate) on the above mentioned nitrogen impacts, it is relevant to make use of relatively simple risk or impact indicators, such as NO_3 concentrations in leaching water or critical nitrogen loads or even more simple state indicators, such as N contents in foliage and C/N ratio's in the soil (humus layer). At present, there is quite some information on the relationship between those indicators and the real impacts. A key for understanding the impacts of nitrogen on forests is thus to gain insight in the N retention, which governs the N availability and related impacts at a given N input, in relation to the N status of the ecosystem in terms of the N content of the foliage and the C/N ratio of the soil.

Despite the knowledge gained in the past decades there is still a lack of information on:

- The possible role of above ground canopy uptake on N nutrition (N contents in foliage). Experiments with N input removal by roofing the forest below the canopy in high N deposition sites suggest that effects mainly occur through the soil, since the nutritional balance was improved within a few years of treatment (*Boxman* et al., 1998). In low N deposition areas, however, where most N might be retained in the soil, the possible role of direct canopy uptake may be more important.
- The relation between N leaching (N retention) and the N status of forest ecosystems, on a European scale. Even though there is already a lot of information on N retention in forest ecosystems, it is not yet possible to extrapolate the results of detailed studies to the European scale because (i) the data sets are still rather limited and (ii) results are such that it is questionable to use them for prediction at sites where no budget calculations can be made (*Dise* et al, 1998). The data on C/N ratios in the humus layer of both Intensive Monitoring plots (*De Vries* et al., 1998) and level 1 plots (*Vanmechelen* et al., 1997), do indicate a high risk for N leaching (C/N ratio below 25) at nearly 40 % of the plots, according to the relationship between N leaching and C/N ratio developed by Gundersen et al. (1998). An actual assessment of this area on a European scale, however, requires (i) an improvement of the above mentioned relationship based on much more data and (ii) the assessment of atmospheric deposition, and preferably also of precipitation and evapotranspiration at the level I plots. The most up to date overview of the state of knowledge on the site specific estimation of those natural and anthropogenic stress factors on a transnational scale is given in *Müller-Edzards* et al., (1997) and *Klap* et al., (1997). Their studies, however, revealed large uncertainties in the site specific derivation of precipitation, evapotranspiration and atmospheric deposition.
- The relation between simple risk or impact indicators, such as N contents in foliage, C/N ratio's in the soil and NO_3 concentrations in leaching water, and the reduction in species diversity of the forest ground vegetation. Even though there is a lot of circumstantial evidence for impacts of elevated N deposition, more process based research remains to be done in this context.
- The time dependency of critical N loads due to N saturation of the forest ecosystem both on local and a regional (European wide) scale. At present there is empirical and model based information on critical N loads, which is another indicator for N impacts. Critical loads for nitrogen have, however, hardly been assessed from a dynamic perspective. Input-output budgets can be used to assess actual critical deposition levels (loads). Below such loads, stress is avoided at this moment but this may not be the case in the future, because of a decrease in e.g. net N retention rates or base saturation. By using process based models it is also possible to gain insight in the temporal change in actual critical N loads to long-term acceptable values (those used in policy making) due to changes in the net retention of nitrogen over time.
- The impacts of environmental changes (changes in atmospheric deposition, land use and climate) on N leaching from and the N status of forest ecosystems in interaction with the carbon status. In response to the Kyoto protocol, it is relevant to get information on the car-

bon budget on a European wide scale. Carbon sequestration in forests is due to forest growth and C retention in the soil. Insight in C sequestration can be derived by integrated measuring and modelling of net carbon fluxes at the stand scale. Recently, the Euroflux project provided measurements of those fluxes above a range of forests across Europe (*Tenhunen* et al., 1998). Extrapolation of those results to the European scale to gain insight in the overall C budget is however still prone to large uncertainties. Another possibility is the assessment of forest growth and C retention on a European wide scale. Information on forest growth data are available on a European wide scale, but not on C retention. Measurement of C retention would require the reassessment of C pools over a considerably long time period to assess changes. C retention is, however, influenced by N inputs, since there is a close relationship between the C and N dynamics in an ecosystem. A relevant indicator for the sequestration of C (and N) in an ecosystem is therefore the C/N ratio of the soil. Much information has been gained on the impact of N deposition on C and N turnover. Current hypotheses suggest that N deposition affects the rate of C and N accumulation by an increase in litter production and reduced decomposition of organic matter (*Berg* and *Matzner*, 1997). There is, however still a lack of information on C and N sequestration rates on a European wide scale in view of changes in atmospheric deposition, land use (reforestation) and climate.

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Effects of Alkaline Dust versus Acid Deposition on Scots Pine Ecosystems of Eastern Germany

Wolfgang Schaaf, Martina Puhlmann, Michael Weisdorfer and R. F. Hüttl

Abstract

To investigate the effects of high and long-term pollution with SO_2 and alkaline dust, we studied the water and element budgets of three 40- to 60-year-old Scots pine stands along a deposition gradient since 1993. A further objective was to study the reaction of these differently impacted sites to drastic reductions in deposition rates after German unification. With respect to these reductions in emissions the project can be seen as a 'roof experiment without a roof'.

The sites show clear differences in soil chemistry that can be attributed to the deposition history. Especially for Ca and S, large amounts stemming from high atmospheric inputs over decades are stored in the soils at Roesa and to a lower extent at Taura. The two main storage compartments are the organic surface layer and the lower mineral soil horizon (Bw). After the reduction of atmogenic input loads, large amounts of these "historic" stores are released and leached from the soils. The results of our study underline that elevated levels of SO_4^{2-} (and Ca^{2+}) concentrations in the soil solution may persist long after deposition decreases.

Introduction

Over several decades emission rates of both sulfur dioxide (SO_2) and alkaline dust were very much higher in the GDR compared to the FRG and other western countries. Dramatic structural changes since 1989, mainly the discontinuation or modernization of industrial and power plants, lead to severe reductions in these emission rates of about 60 % for SO_2 and >85 % for dust in the new federal states of Germany and corresponding reductions in deposition loads. The implementation of the Federal Clean Air Act in the new federal states by the end of 1995 was expected to further reduce emission rates.

To evaluate the consequences of these drastical changes we studied three Scots pine (*Pinus sylvestris* L.) ecosystems along a gradient of long-term atmospheric deposition impacts in north-eastern Germany since 1993. Main objectives of the project are to characterize the stability and sensibility of these ecosystems, to identify the dominating processes in the soil, and to determine transport and output to the groundwater by means of water and element budgets of the sites in order to evaluate the possibilities and processes of ecosystem recovery from long-term pollution. With respect to the reductions in deposition, these investigations may be considered as a 'roof experiment without roof' (*Schaaf* et al., 1995).

Table 1: Characterization of the three experimental sites.

Name	Roesa	Taura	Neuglobsow
pollution impact	high	medium	background
SO_2 [µg m^{-3}][1]	143 (1988) -> 25 (1995)	37 (1993) -> 19 (1995)	11 (1988) -> 7 (1995)
NO_x [µg m^{-3}][1]	13 (1992) -> 21 (1995)	14 (1994) -> 15 (1995)	12 (1992) -> 10 (1995)
O_3 [µg m^{-3}][1]	61 (1991) -> 51 (1995)	40 (1993) -> 50 (1995)	44 (1988) -> 51 (1995)
location	12°26' E 51°38' N	13°2' E 51°28' N	13°2' E 53°8' N
mean annual precipitation [mm]	566	565	595
mean annual temperature [°C]	8.9	8 9	8 2
vegetation type	Calamagrostio-Cultopinetum sylvestris	Avenello-Cultopinetum sylvestris	Myrtillo-Cultopinetum sylvestris
stand age	61 years	45 years	65 years
trees/ha	935	853	1043
basal area [m² ha^{-1}]	33.90	28.25	36.07
mean height [m]	16.0	18 0	20 1
LAI (leaf area index) [m² m^{-2}]	3.16	2 43	2 87

[1] annual mean air concentrations

Materials and methods

The three sites under investigation are (see Table 1)

- Roesa (high pollution area close to the east of the industrial complex of Bitterfeld),
- Taura (medium pollution area 45 km east of the Halle/Leipzig region), and
- Neuglobsow (located in northern Brandenburg, 'background' area 75 km north of Berlin).

At all experimental sites soil solution is continuously collected using ceramic plates and suction cups with six replicates in four soil depths (0 cm = mineral soil input; 20 cm; 50 cm; 100 cm). Soil tensions are recorded using five pressure-transducer-tensiometers per depth (20 cm; 50 cm; 100 cm; 180 cm). Throughfall is measured by ten bulk samplers and one recording sampler. Climatic parameters like precipitation, temperature, humidity, wind velocity, and global radiation are recorded at a nearby clear-cut at each site. Intensive sampling (usually biweekly) was carried out during the periods 07/93–11/95 and 11/97–04/99. For 1996 and 1997 only a small number of samples could be taken.

For a detailed description of the methods used for laboratory analyses see *Weisdorfer* (1999).

Results and discussion

The sandy soils (typic dystrochrepts derived from glacial outwash) show clear differences in chemical parameters (Table 2), whereas the physical properties are very similar. Base saturation (BS) is very high at Roesa throughout the profile, but especially in the upper part where also the elevated pH values point at the influence of high inputs of base cations by alkaline dust deposition. The lower pH of the Oa layer may be an indication for beginning re-acidification of the profile. The high sulfur (S) contents indicate also high deposition rates of S. The site is characteristic for expositions close to emission sources.

At the site Taura these effects are found only to a less extent, pH and BS in the mineral soil are very low, but S contents are clearly elevated and in the Bw horizon even higher compared to Roesa. Exchangeable Al contents are considerably higher throughout the profile, but especially in the upper part. This situation is typical for more remote sites that received less dust but high S deposition. The soil data at Neuglobsow reflect low influences by atmospheric deposition with low pH and BS and may represent background site conditions.

The differences in historical deposition impact are also reflected in the total S stores of the soils at the three sites (1275, 1160, and 700 kg S ha^{-1} 50 cm^{-1}, respectively). Especially the humus layers at Roesa and Taura show higher S stores (837 and 450 kg S ha^{-1}) compared to Neuglobsow (183 kg S ha^{-1}). These high S amounts are probably mainly stored in organic form.

S retention and release processes in the mineral soil may affect base cation storage or release and may produce negative charge increasing thus the ECEC (*McBride*, 1993). Furthermore, desorption of previously adsorbed SO_4 may prevent the deacidification after reduced SO_4 inputs (*Alewell* and *Matzner*, 1993; *Matzner*, 1989). Thus, the dynamics of SO_4 are important for the development of soil chemical properties and for the ecosystem response to changes in pollutant deposition (*MacDonald* and *Hart*, 1990).

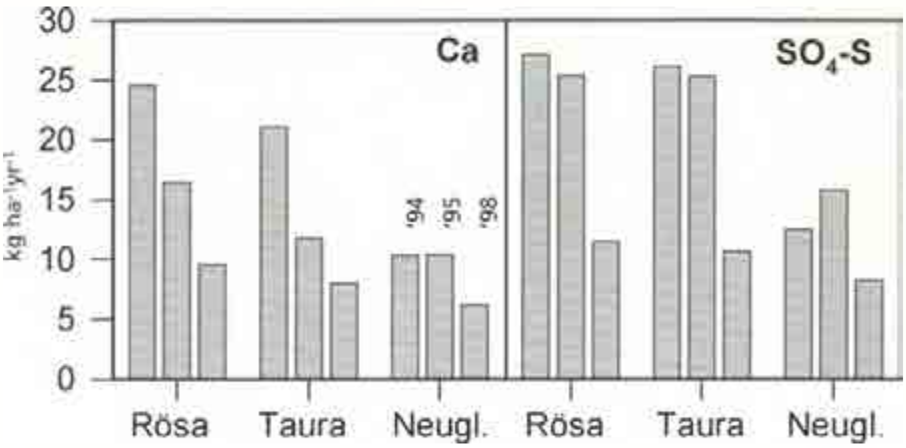

Fig. 1: Ca and SO_4-S inputs with bulk deposition at the three sites for the years 1994, 1995, and 1998.

Table 2: Soil chemical and physical parameters of the soil profiles at the three experimental sites.

Site/ Horizon	Depth (cm)	pH H_2O	pH KCl	ECEC mmol(c)/kg	BS %	Al_{ex} %	C_t %	N_t %	C/N –	S_t mg/kg	clay %	silt %	sand %
Roesa													
Oa	10–4	5,2	4,3	251	67,8	24,6	38,6	1,66	23	2096	n.d.	n.d.	n.d.
Oe	4–0	5,7	4,6	291	92,0	6,2	23,4	1,01	23	2078	n.d.	n.d.	n.d.
E	0–7	5,1	4,1	42	73,8	19,4	0,95	0,04	22	66	3,4	8,6	88,0
Bhs	7–16	5,0	4,2	21	36,1	54,4	0,79	0,05	17	60	4,7	10,4	84,9
Bw	16–50	4,7	4,3	15	25,1	66,9	0,55	0,03	17	73	2,2	10,2	87,6
BC	50–60	4,7	4,3	8	23,6	62,8	0,13	<0,01	–	60	0,9	6,1	92,7
C	60+	5,0	4,3	5	24,0	62,2	0,04	<0,01	–	22	0,8	5,1	94,1
Taura													
Oa	7–2	4,1	3,2	260	66,1	22,5	42,7	1,62	26	2405	n.d.	n.d.	n.d.
Oe	2–0	3,8	3,1	167	43,4	38,8	16,3	0,58	28	993	n.d.	n.d.	n.d.
E	0–6	4,0	3,2	25	24,2	38,8	2,02	0,10	20	143	4,0	12,8	83,2
Bhs	6–13	4,2	3,6	25	11,3	50,2	0,67	0,01	51	49	3,4	11,6	85,0
Bw	13–47	4,4	4,3	15	5,6	84,9	0,55	0,01	41	124	3,6	14,8	81,6
BC	47–63	4,4	4,3	7	6,1	79,6	0,07	<0,01	–	63	2,9	7,2	89,9
C	63+	4,6	4,4	3	6,5	73,5	0,08	<0,01	–	45	0,9	6,4	92,7
Neuglobsow													
Oe	5–0	3,8	2,7	188	48,0	17,6	36,9	1,26	29	1665	n.d.	n.d.	n.d.
E	0–3	3,9	3,1	43	15,5	51,6	3,59	0,13	28	195	2,7	7,8	89,5
AB	3–19	4,5	4,0	30	5,6	81,7	0,81	0,03	26	59	4,2	5,8	90,0
Bw	19–48	4,6	4,3	20	3,9	88,7	0,22	0,01	21	81	0,0	12,1	87,9
BC	48–65	4,5	4,3	15	7,0	83,2	0,04	<0,01	–	42	2,1	5,2	92,7
C	65+	4,9	4,4	13	47,2	44,3	0,01	<0,01	–	34	1,9	5,0	93,1

n.d. = not detected; ECEC = effective cation exchange capacity (0.5 N NH_4Cl extraction); BS = base saturation;
Al_{ex} = exchangeable aluminium in % of ECEC

The bulk deposition values of 1994/95 show a clear gradient. The sites at Roesa and Taura still received more than double the S inputs compared to the background site (Fig. 1). The Ca deposition rates as an indicator for alkaline dust inputs strongly increased in the order Neuglobsow < Taura < Roesa (Fig. 1). These values are already considerably lower than bulk deposition rates of highly polluted areas for the years 1986–1989. *Nagel* et al. (1991) report inputs of up to 190 kg S $ha^{-1}yr^{-1}$ and 320 kg Ca $ha^{-1}yr$-1 for a station at Bitterfeld, only 10 km east of Roesa. At a station 10 km north of Taura the values were 61 kg S $ha^{-1}yr$-1 and 52 kg Ca $ha^{-1}yr^{-1}$, respectively (*Nagel* et al., 1991). In 1998, both input rates at the impacted sites were reduced by more than 50 % compared to 1994 (Fig. 1).

The chemical composition of soil solutions clearly reflects these differences in element inputs of the past and present. The mean sulfate concentrations at

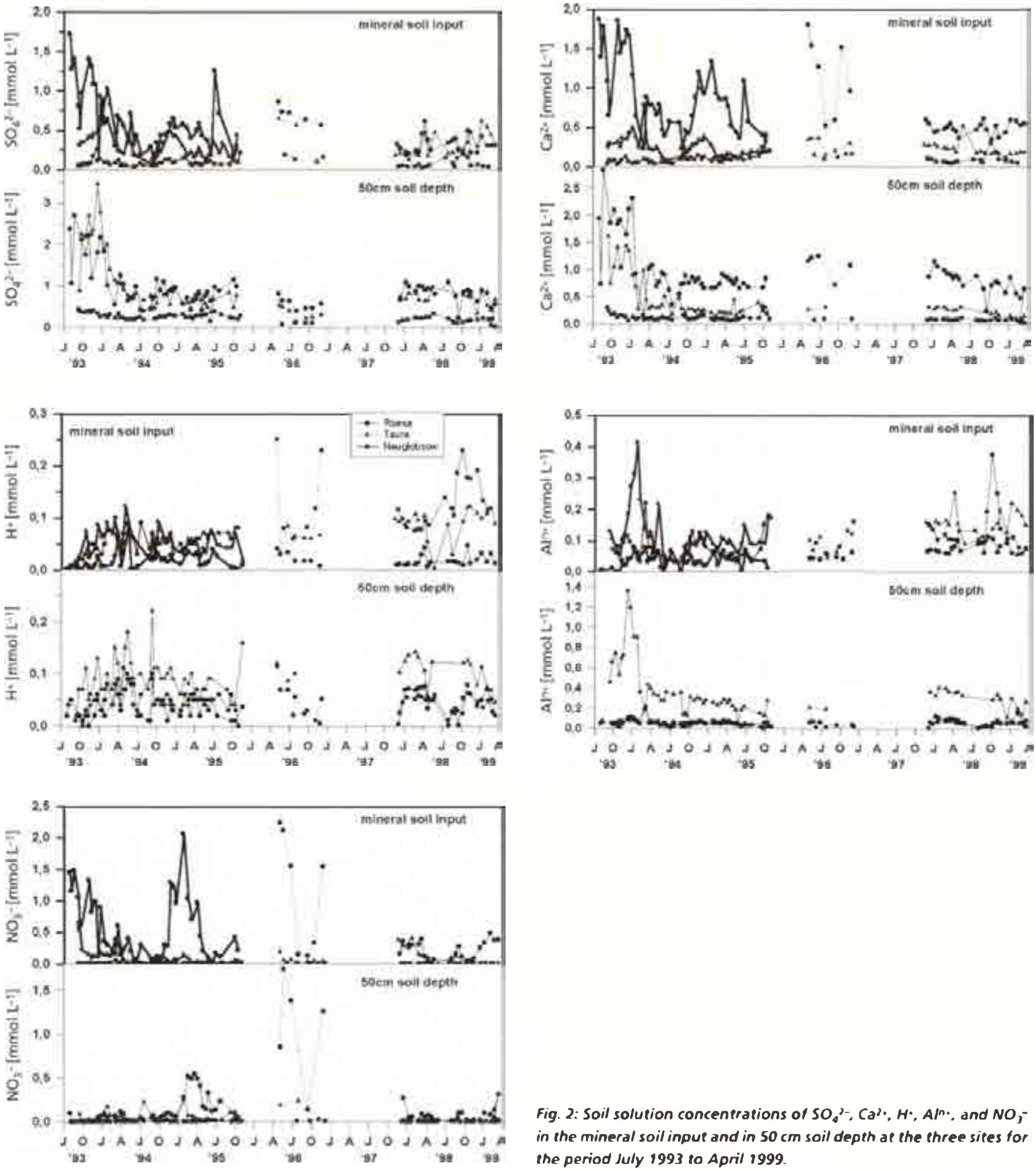

Fig. 2: Soil solution concentrations of SO_4^{2-}, Ca^{2+}, H^+, Al^{n+}, and NO_3^- in the mineral soil input and in 50 cm soil depth at the three sites for the period July 1993 to April 1999.

Roesa and Taura decline over the first six months in all soil depths. After that they remain at considerably high levels (0.5–1.0 mmol SO_4 L^{-1}) in the mineral soil at Roesa and Taura that are manifold increased compared to Neuglobsow (Fig. 2).

Calcium and magnesium (not shown) concentrations increase strongly in the order Neuglobsow < Taura < Roesa (Fig. 2). Proton concentrations in all soil depths are lowest at Roesa and highest in the mineral soil at Taura (Fig. 2). In 1998/99, the mineral soil input at Neuglobsow shows considerably increased H^+ concentrations up to 0.2 mmol L^{-1}. Aluminium concentrations in soil depths >20 cm are significantly increased up to 0.4 mmol Al^{n+} L^{-1} at Taura with peaks of 1.4 mmol L^{-1} (Fig. 2). Whereas at Roesa the high SO_4^{2-} concentrations in all soil depths are paralleled by Ca^{2+}, we find Al^{n+} and in the organic surface layer also H^+ as the companying cations at Taura. Nitrate concentrations are low in the mineral soil at all sites, only at Roesa the organic surface layer and in summer 1996 also the mineral soil shows elevated values (Fig. 2). These peaks are paralleled by Ca concentrations at Roesa indicating mineralization releases from the humus layer.

Conclusions

The atmospheric deposition impacts at our three sites are very different. Deposition of atmogenic pollutants was higher and lasted longer than in many parts of western Europe or North America. Especially at Roesa the accumulation of both sulfur and alkaline dust inputs resulted in quite special site conditions that are very different from most study areas in western Germany.

All chemical parameters of soils and soil solutions clearly reflect the different depositions regimes at the three sites. Especially for Ca and S, large amounts from atmospheric inputs are stored in the soils at Roesa and to a lower extent at Taura. The two main storage compartments are the organic surface layer and the lower mineral soil horizon (Bw). After the reduction of deposition loads, large amounts of these stores are released and leached from the soils (*Schaaf* et al., 1999). SO_4^{2-} concentrations in the soil solutions at the polluted sites remain at elevated levels. With respect to soil and solution chemistry Taura shows the most severe symptoms of soil acidification which is presumably caused by the historical deposition situation at the site with high SO_2 pollution but lower dust impact due to the larger distance to emission sources. Although presently all three ecosystems act as a sink for nitrogen despite high N soil stores, mineralization and nitrification pulses at the alkalinized site Roesa indicate a considerable risk for NO_3^- leaching from the mineral soil. Mineralization processes at the polluted sites also result in the release of SO_4 and an internal proton production 3 to 8 fold higher than the actual deposition load (*Schaaf* et al., 1999). The amounts of alkaline dust deposition and storage have strong influence on the buffering processes in the mineral soils and on the resulting soil solution composition.

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Natural Forest Development – Pattern of Forest Management?

Michael Rode

Abstract

Forest ecosystems are characterised by long-time growth and development. As a consequence, forest management and planning have to be aimed for decades or centuries. Above all, reforestation of degraded forest locations takes long times. Forest management and development on degenerated soils requires information not only about the actual site conditions and the behaviour of the planted tree species but also about changes of site conditions caused by the forest growth itself.

Secondary succession from heathland to forest in combination with reforestation of heathland soils in the Atlantic region of middle Europe is one of the most expanded reforestation in Europe during the last centuries. In an interdisciplinary study fluxes and availability of nutrients as one of the decisive driving factors on forest succession on poor soil were investigated over the course of a 300-yr-long secondary succession from heathland to broad-leaved forest in NW-Germany in relation to other plant resources. The results gives insight into the mechanisms of forest succession and forest ecosystem recovery on lixiviated soil. Beyond that, they are followed by the questions to be discussed here: 1. Does the understanding of succession mechanisms give advises to forest development on nutrient poor and highly acidified soils?, and if it is so 2. What are the consequences for forest management?

During the succession from heathland to forest an increasing nutrient availability due to an increasing nutrient input into pine dominated forests and woodlands, an increasing nutrient turnover within the developing ecosystem, and increasing nutrient pools within the organic layer as well as increasing water availability by the enrichment of organic material mitigates the negative influence of the nutrient poor sandy soil on the growth of oak and beech. They facilitate the conversion of pine dominated woodlands and forests into forests and woodlands dominated by broad-leaved species. This knowledge about the mechanisms of forest succession on heathland soils point out to natural forest management on former heathland soils. Depending on nutrient availability of the mineral soil two ways of conversion of pine dominated forests into beech (or oak) dominated forests are conceivable: A) on less poor soils with higher loam content the direct conversion from Scots pine to beech dominated forests and B) on very nutrient poor soils at first oak have good conditions for planting below an open pine canopy layer followed by planting of beech in a second step as than beech is able to replace oak on these soils.

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Workshop Forests after the Kyoto Protocol

Accuracy of Long-Term Forest Resource Projections of the European Forests

A validation of the EFISCEN model based on historical Finnish forest inventory data

G. J. Nabuurs and M. J. Schelhaas

Abstract

Large scale forest scenario models are intensively used to make projections of forest areas of up to hundred millions of hectares. Within Europe, this has mainly been done at the individual national scale. These models have been developed in the sixties and seventies to assess long-term felling potentials. Now they are increasingly being used to balance various functions of the forest or to incorporate effects of environmental changes. However, the validity of these models as a whole has never been tested.

The aim of this study is to analyse the accuracy with which the European Forest Information SCENario model (EFISCEN) is able to predict the development of forest resources. In order to carry out this validation the model was tested by running it for the Finnish forest resources from 1923 to 1993. The first National Forest Inventory (NFI) of Finland of 1921–1924 was used as input. The results of the next 7 NFI's were used to validate the development as simulated by the model. The results showed that EFISCEN is performing satisfactorily for making large scale projections of forest resources for periods up to 50–60 years. Results regarding increment after 50 years, age class distribution and mean volume per age class should be interpreted with caution.

Introduction

Due to the long rotations in forestry, the long-term impact of management measures, and the variety of actors and (economic) goals in forestry, planning and decision making have always been at the core of forestry research (*Davis* and *Johnson* 1987, *Von Gadow* 1992). This field of research was once the domain of foresters who attempted to regulate forests to maximise the value of the timber extracted from the forest. The tools they used covered a wide range of methods and varied in applicability in space and time. The first 'tools' were very simple classifying the existing forest into groups as 'plenty of wood' or 'shortage of fuelwood', thus gaining insight in medium term possibilities. During the 1950's, as inventory results became available for most European countries, allowable cut was estimated by integrating cutting possibilities per age class of a forest area. These assessments can be seen as static and were carried out by manual calculation.

After the introduction of computers, it became possible to use ever smaller calculation units (even individual trees) for larger and larger areas. It became possible to let the computer propose harvesting and thinning, based on goals and (non-timber) constraints set by the user; i.e. optimisation of an objective function given a specific set of constraints (*Valsta* 1993, *Pukkala* and *Kangas* 1993). The tools thus became more and more sophisticated and sometimes developed into GIS based, spatially explicit models for large areas. An example is the SNAP developed by Sessions (1995) or the MONSU developed by *Pukkala* & *Kangas* (1993). Now that environmental, biodiversity and recreational concerns have become equally or even more important than timber production, the planning problem has become more complicated and interesting as well. The planning tools have developed accordingly taking into account other values of the forest as well (*Lohmander* 1987, *Holland* et al. 1994, *Kangas* et al. 1996, *Szaro* et al. 1996, *Arthaud* and *Rose* 1996, *Naesset* 1997, *Riitters* et al. 1997, *Martell* et al. 1998, *Nabuurs* et al. 1998b). However, since the tools developed very fast, the accompanying data requirements increased just as fast, making the tools often applicable to intensively monitored, experimental forests only. Another conclusion is that despite massive forest inventories and a fast development of computer models, the controversy over future forest development only seems to have increased, see e.g. *Nilsson* et al. for the USA (1999).

Especially the intensive use of Europe's forests [they cover about 4 % of the world's forests but provide 13 % of current global harvest of wood products (*Pajuoja* 1995)] initiated the development of such planning tools (*Nilsson* et al. 1992, *Pajuoja* 1995). Apart from wood production, Europe's forests are a refuge for nature and are of high importance as a recreational area for the urbanised European population (*Konijnendijk* 1999). At the global level, it can be concluded that an increasing variety of forest products have to be produced from a decreasing forest area (*Palo* and *Uusivuori* 1999). This puts a higher pressure on that remaining forest resource and possibly on European forests as well where forest management is becoming more nature oriented. Given this importance of European forests, the multitude of functions, generates a need for long-term projections. Furthermore, European forests are scattered over 30 countries of which only 11 (Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Ireland, The Netherlands, Norway, and Sweden) have a national forest scenario model (Nabuurs and Päivinen 1996). To make European scale projections therefore requires harmonised projection methods.

Aim

In order to use EFISCEN for a European scale projection, it is important to know the accuracy of the predictions. Before adding new features to the model such as incorporating the effects of climate change and incorporating the effects of nature oriented management, a validation is needed.

In this paper we validate the European Forest Information SCENario Model (EFISCEN) which is in use at the European Forest Institute to make such harmonised European forest resource analyses. EFISCEN is based on a Swedish model, developed by *Sallnäs* (1990). In the past, this model has also been used to study the development of the forest resources in Europe under pollution scenario's (*Nilsson* et al 1992).

The aim was to validate the complete model with all its scenario possibilities and not just its growth functions as was done by *Sallnäs* (1990). Another type of validation in which EFISCEN projections were compared against projections made in the European Timber Trend Studies V (*Pajuoja* 1995) had already been carried out by *Nabuurs* et al. (1998a).

Methods

Approach

The validation of the EFISCEN model is carried out using historical forest inventory data of Finland. The First National Forest Inventory (NFI I) was carried out in the years 1921–1924 (*Ilvesssalo* 1927). The results of this inventory are used as input for the model.

When analysing the results of the different inventories, it appeared that after NFI IV (1960–1963) a transient change in the growth rate of trees is reported. Because it was anticipated that EFISCEN could not deal with this transient change in increment in a satisfying way, it was decided to run the model in two steps. First the model was run for the period 1923 until 1963. In this period the increment change was only moderate and other changes in e.g. forest area could be dealt with rather easily. The second run covers the period 1923 until 1993. Because of the changes after 1963 this series gives more uncertainties. For both runs the outcomes of the model are compared with the results of the seven following NFI's.

The EFISCEN model

EFISCEN is an area-based matrix model. The following text is largely based on the explanation by *Nilsson* et al. (1992). The model is especially suitable for the rather large scale, e.g. for a region or a country. The minimum area unit is 100 ha. Per country, forest types can be distinguished, by region, owner class, site class, and tree species, depending on how detailed the input data are. Per forest type the following variables should be known for each age class: area (ha), mean standing volume (m^3 ha^{-1}), and net annual increment (m^3 ha^{-1} yr^{-1}). Furthermore, data are needed about the management regime, like thinning and average final cutting ages.

The forest state is depicted as an area distribution over age and volume classes in a matrix. For each forest type that can be distinguished, a separate matrix is set up. This matrix consists of age-classes and volume classes (10 intervals for the volume dimension and 6–15 intervals for the age dimension). The number and width of the age classes depends on the input data. The width of the volume classes is set by a parameter depicting the natural variance in the volumes per age class in the field.

To calculate the volume distribution, three variables are used: (a) the mean volume per hectare, (b) the coefficient of variation in volume per hectare, and (c) the correlation between volume per hectare and age or transformations of age. The calculation is performed in four steps.

1. Calculate the variance in volume per hectare, using mean volume per hectare and the coefficient of variation:

$$S_v^2 = (\bar{V} c_v \bar{V})^2$$

were cv is the coefficient of variation, $\bar{V}$ is the mean volume per hectare, and S_v^2 is the variance in volume per hectare.

2. Calculate the conditional variance given mean age:

$$S^2_{v(T)} = (1 - r^2) S^2_v$$

where $S^2_{v(T)}$ is the variance in volume per hectare given mean age and r^2 is the coefficient of correlation between age and volume per hectare.

3. Calculate the ratio of variance to mean age ($\bar{T}$), and use this ratio to calculate the variance in each age class:

$$k = S^2_{v(\bar{T})} / \bar{T}$$

The variance in age class i is then

$$s^2_{Ti} = k\bar{T}i$$

The class limits for the volume classes are calculated using the largest volume per hectare plus three times the largest standard deviation as the class limit for the largest volume class. This range is then divided into a sequence of volume classes. The distribution of area over the volume classes is calculated using the mean deviation and the standard deviation of volume in each age class and a modified normal distribution.

The growth dynamics are incorporated as five-year net increment as a percentage of the standing volume. The real volume increment percent per age class is calculated from the input data on volume increment and standing volume. The negative exponential growth models are depicted by the following function:

$$I_{vf} = a_0 + \frac{a1}{T} + \frac{a2}{(T)^2}$$

where I_{vf} is the five-year volume increment in percent of the standing volume, T is the stand age in years, and a_0, a_1, a_2 are coefficients. The functions are estimated from data on age and percent volume increment. From the combination of growth function with volume series the transition probabilities for each matrix cell are calculated.

The mean volume in an age-volume cell will deviate from the mean volume series. Accordingly, the percent volume increment will also deviate from the value given by the function, which means that some correction must be made. The correction is made according to

$$I_v^a = I_v^f \left(\frac{Vm}{Va}\right)^\beta$$

where I_v^a is the five-year percent volume increment for actual standing volume, I_v^f is the five-year percent volume increment given by the function, V_a is the actual standing volume (cubic meters per hectare), and V_m is the standing volume (cubic meters per hectare) from the mean volume series. The relationship between the relative standing volume and the relative volume increment is described by the parameter β.

Management is controlled in two levels in the model. First a basic management per forest type, like thinning and final felling regime are incorporated. These are the theoretical management regimes, which are applied according to handbooks for forest management in the region or country to be studied. These theoretical regimes must be seen as constraints of what might be felled. Second, a total required volume of harvest from thinnings and final felling are specified for the country as a whole per species group for each time period. Based on the theoretical management regimes, the model finds, depending on the state of the forest, the required volumes. At the national scale forest area expansion can be specified per tree species and simulation period.

Thinnings are expressed as a percentage of growth in each period. The area that is thinned is moved to one volume class lower in the matrix. Final felling is expressed as a probability, depending on the stand age and/or volume. These probabilities are converted to a proportion of the area in each cell that can be felled. A felled area is moved to a bare-forest-land class. Regeneration is regarded as the movement of area from the bare-forest-land class to the first volume and age class. The parameter controlling this is the percentage of area in the bare-forest-land class that will move to the first volume and age class during one time step. The model works with time steps of 5 years.

The output consists of e.g. growing stock per hectare, increment per hectare, age class distribution, amount of wood harvested by final felling and by thinning, area affected by final cuttings and by thinnings. Some of these parameters are given for the total area and some also per tree species and/or region.

Data

Data sources

As input data for the model the results of the National Forest Inventory (NFI I) of Finland are used (*Ilvessalo* 1927). The results of the seven following NFI's are used to validate the model projections. These forest inventory results are obtained from *Ilvessalo* (1943) for NFI II, *Tiihonen* (1968) for NFI III & IV and the Finnish Statistical Yearbook (*Sevola* 1997) for NFI V to VIII. The Finnish Forest Research Institute (METLA) provided harvest data for the period of the simulation. They also provided the detailed forest inventory data of NFI VIII (*Tomppo* and *Tuomainen* pers. comm.)

Results

Finnish forests from 1923 to 1993

The Finnish forests have changed considerably since the 1920's. Especially management has evolved from a selective cutting regime (resulting in understocked, over-mature forests) into clear fellings type of management. Drainage and fertilisation during the 1960's has had a tremendous effect on the increment level. The general development of the Finnish forest resource from 1923 to 1993 is characterised by some real decline in area and growing stock from 1923 till around 1960. Afterwards the trends are an expansion of area, and considerable build-up of growing stock due to both an increase in increment and undercutting of this increment.

One of the complicating matters when validating EFISCEN was that the definition of forest land has changed in the course of the 8 National Forest Inventories. Due to these definition changes, the forest area fluctuates stronger than in reality. For instance, the area of productive forest land in the years 1960–1963 was 16.9 Mha and in the years 1964–1970, when the new concept was being used, the area of forest land was 18.6 Mha (*Uusitalo* 1989). Part of this increase can be ascribed to the concept's change and part to a real expansion of forest area, due to draining and afforestation. It is unclear how large the contribution of each of these two to the total is.

The growing stock development is rather stable till 1963, but as of the next NFI the average growing stock is increasing because of an increase in increment and a harvest level that stays behind. The average increment per hectare is overall increasing, except from a slight decrease in the NFI IV of 1962 (Fig. 1). Especially after 1967 the increase is rather fast. The relative increment (increment per standing volume) is increasing as well, so this increase is not caused by an increase in volume per hectare. *Mielikainen* and *Sennov* (1996) and *Mielikainen* and *Timonen* (1996) conclude that it is very likely that the increase in production can be explained by changes in stand structure and silvicultural practices.

In the species distribution the area of forest dominated by birch has decreased in the course of the last 70 years, in favour of pine-dominated stands. The age class distribution has mainly shifted in the first and last age classes (Fig. 2). In NFI I, there was a relatively large share of old forest (older than 160 years).

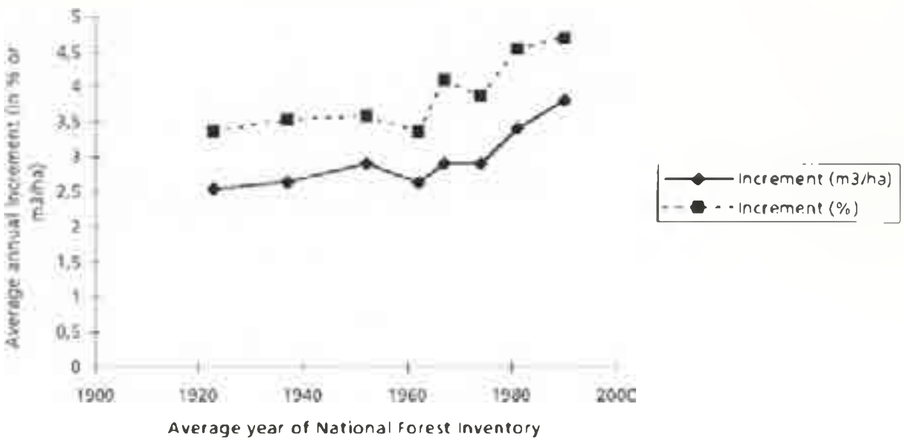

***Fig. 1:** Development of average annual increment per hectare in Finland from 1923 to 1990 on productive forest land (Ilvessalo, 1927, 1940, 1953, Tiihonen 1968, Uusitalo 1989, Sevola 1997).*

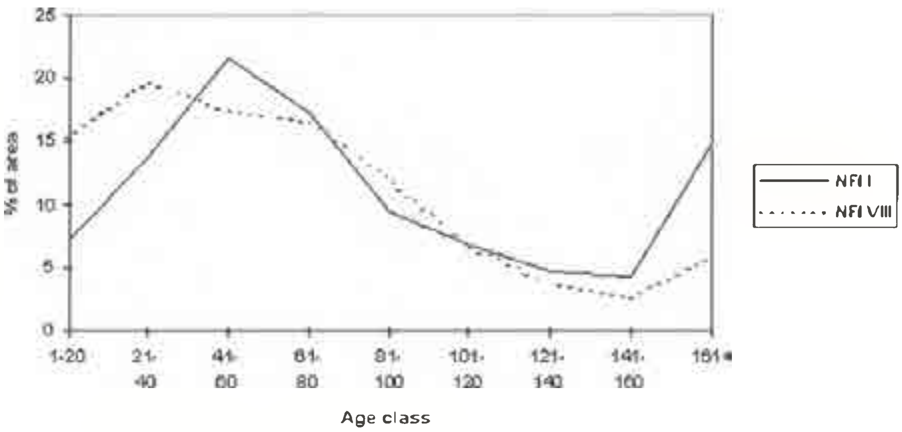

***Fig. 2:** Age class distribution in NFI I and NFI VIII (Ilvessalo 1927, Sevola 1997).*

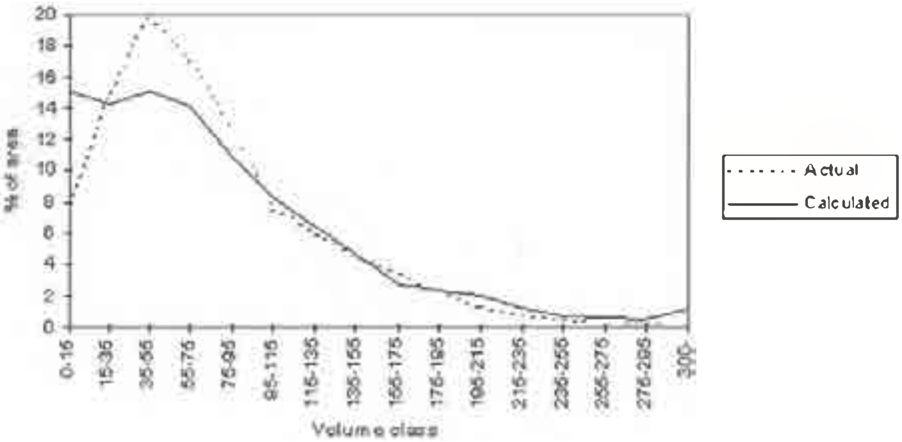

***Fig. 3:** Actual and calculated distribution of total national area over volume classes in the initial situation, for all forest types.*

Results of the simulation until 1963

From the initial matrices the distribution of the area per age class over the volume classes was recalculated (Fig. 3). The area as initialised by the model in the first volume class (0–15 m^3 ha^{-1}) is too large and in the two volume classes (35–55 and 55–75 m^3 ha^{-1}) it is too small. In the higher volume classes the distribution fits well with the actual data.

The large area in the first volume class is caused by assigning a too large area to land that is in regeneration. The area in the class 'clear area' in the inventory is 262,000 ha. In the model the area in the bare-forest-land class is 892,000 ha. The large area in the bare-land class is a consequence of the relatively high value of the top of the first volume class. The larger this value, the larger the amount of area in the bareforest-land class has to be to obtain a realistic average standing volume again.

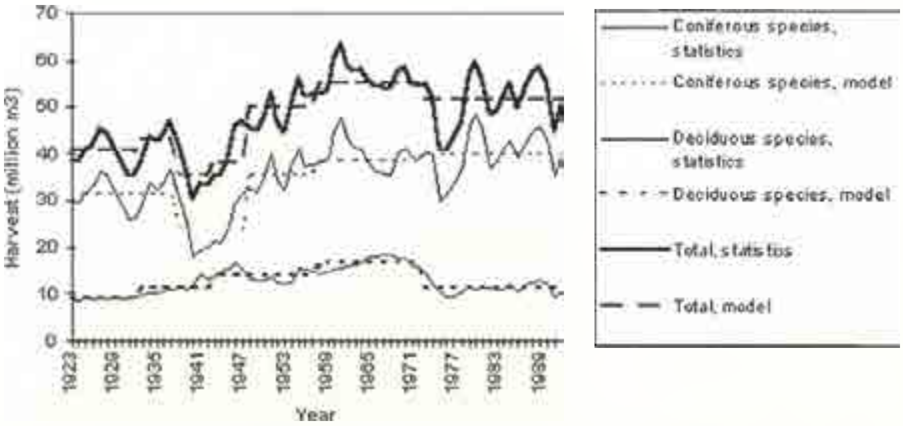

Fig. 4: Fellings from 1923 to 1993 in the statistics and as defined in the model. The harvest levels before 1944 are decreased with 12.8 % to compensate for the area change in the war (Ilvessalo, 1927, 1940, 1953, Tiihonen 1968, Uusitalo 1989, Sevola 1997).

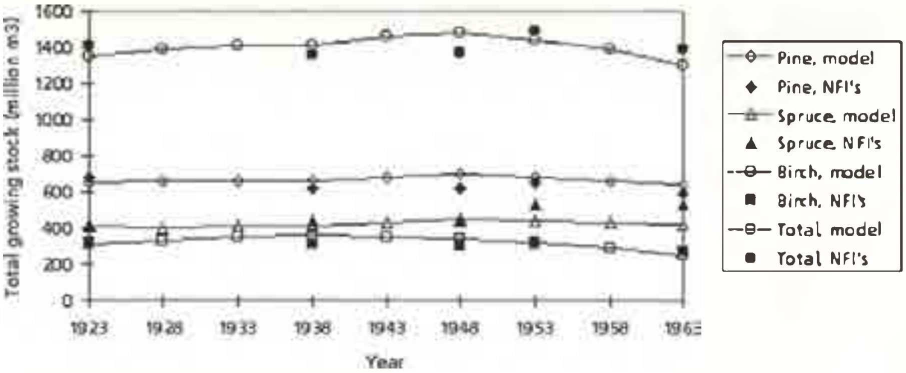

Fig. 5: Development of total growing stock of pine, spruce, birch and all tree species in the model and in the NFI's (Schelhaas et al. 1999).

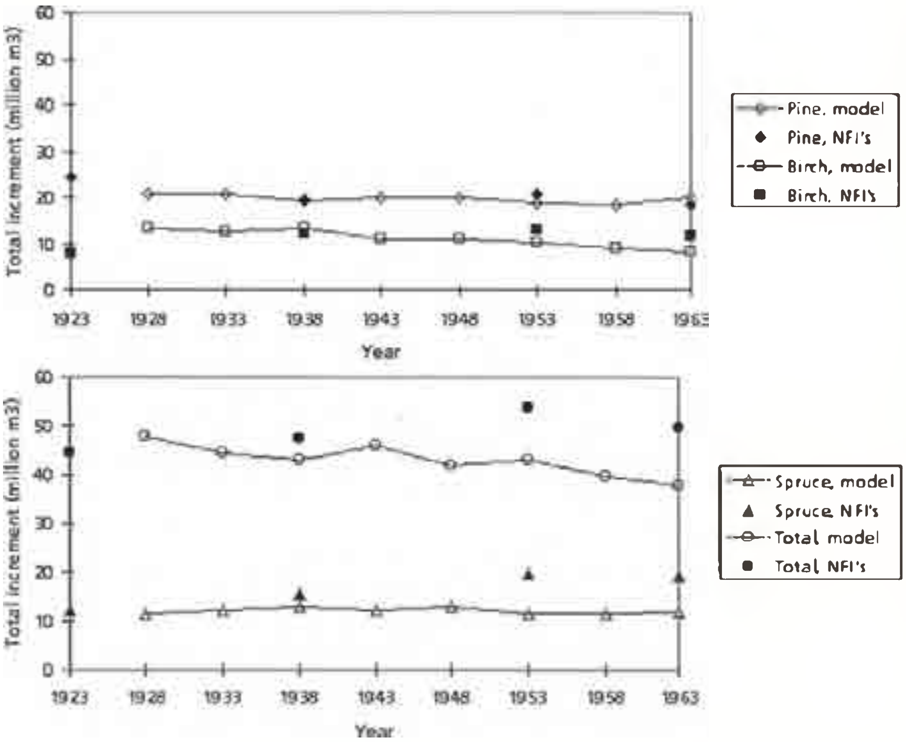

Fig. 6a and 6b: Development of total increment of pine and birch (a) and spruce and all tree species (b) in the model and in the NFI's. The NFI-values are for productive and poorly productive forest land, the model values only for productive forest land (Schelhaas et al. 1999).

The harvest in the model (Fig. 4) for the coniferous species is divided between pine and spruce according to the area covered by these species, the available volume per age class and the final felling regimes. The disadvantage of this was that the increasing share of spruce in the fellings in reality were not followed by the model.

In the simulation the development of total standing volume of pine is close to reality. After 1948, the total volume of spruce in the NFI's is increasing, which is not followed by the model. The increase in total volume of spruce is due to an increase in the increment, which is not simulated. The total volume of birch starts to increase relatively fast in the beginning of the simulation, in 1938 is the total volume in the model 355 million m^3, compared with 305 million m^3 according to NFI II. After 1948 the total volume is decreasing again and at the end the total volume of birch is quite close to the value of NFI IV. The total volume of all tree species is close to reality. After 1953 the simulated total volume tends to decrease. This is caused by the decreasing increment in the model overall (see below) and the transient change in the increment of spruce which was not simulated.

The initial increment as simulated by the model is 2.52 $m^3\,ha^{-1}\,yr^{-1}$. Calculated from the raw forest inventory input file, the average annual increment was also 2.52 $m^3\,ha^{-1}\,yr^{-1}$. For pine the simulated increments fit well with the inventory values (Fig. 6a). The increment of spruce is quite stable during the whole simulation, but after 1938 the increment level in the NFI's starts to increase, which was not simulated (Fig. 6b). This is the reason that the trend in total volume cannot be followed by the model. Birch has in the beginning an increment level that is far higher than in reality. This may be a consequence of the relatively high value for the top of the first volume class used in this simulation.

It is observed in other studies with EFISCEN that the increment level tends to decrease over time (*Nabuurs* et al. 1998a). In the model the increment is calculated as a percentage of the growing stock. After a thinning the volume of a certain 'stand' has decreased and this stand will thus obtain an absolute increment that is lower than before. In reality individual trees will react to the decrease in competition and will grow faster (*Jonsson* et al. 1993). Another explanation of a decrease in total national increment can be the development of the age class distribution. When the age class distribution deviates from reality, also the increment can deviate (see also Fig. 8).

According to the NFI results, the average growing stock in each age class has increased since 1920, especially in the medium aged forests (Fig. 7). E.g. the average volume in 81–100 year old forest has increased from 90 m^3 ha^{-1} to almost 160 m^3 ha^{-1}. So, forests of the same age, now contain far more volume. The results of the model for 1963 show a different picture. First in 1923 the model doesn't show the decline in growing stock in older age classes. This is caused by the way the input data are incorporated, i.e. with non-declining volumes.

In 1963, the average growing stock has risen above the values of NFI VIII of the first two age classes. In the middle age classes the average growing stock is lower than the values in NFI I and VIII. With increasing age the average growing stock is hardly increasing. Then, in the higher age classes, the volume is increasing again. This development is also a consequence of the decreased growth after thinning. The thinning in the model takes place in the age classes 21–40 years to 121–140 years. The difference between age classes with thinning (21–140 years) and without thinning (< 20 years and > 140 years) is clearly visible.

Partly due to the previously mentioned deviations in volume distribution, the age class distribution starts to show deviations as well (Fig. 8). The area in the bare-land class as simulated is too high. The area in the age classes 1–20 and 21–40 years is too high, the area in the age classes 41–60 and 61–80 years is too low. In the higher age classes the area in the model is about the same as in the NFI's.

The percentage of the area that is treated with regeneration fellings is shown in Figure 9. The percentages tend to deviate from the values in NFI II and IV. The percentage for Southern Finland is in the beginning too low and at the end too high. For Northern Finland the percentage is in the beginning much too high, but at the end it is close to the real value. For whole Finland the beginning is quite close, but in the end the value is exceeding the estimation of NFI IV. The area which is clear felled in the last period is too high. This can indicate that the average volume in final fellings is too low in the model. The model is final felling the high age classes, irrespective of the volume classes. So the low volume classes have the same chance to get harvested as the high volume classes. In reality the forests with a high average volume are more attractive to harvest and will thus have a higher chance.

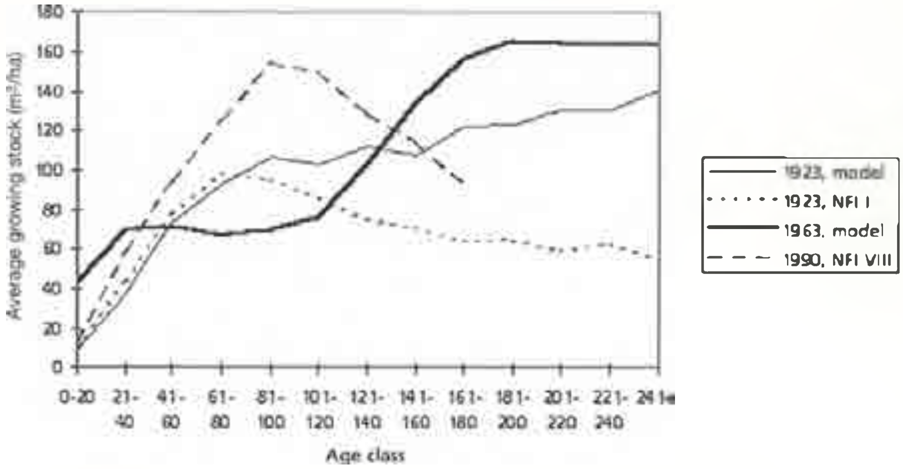

Fig. 7: Comparison of the average growing stock per age class at different moments.

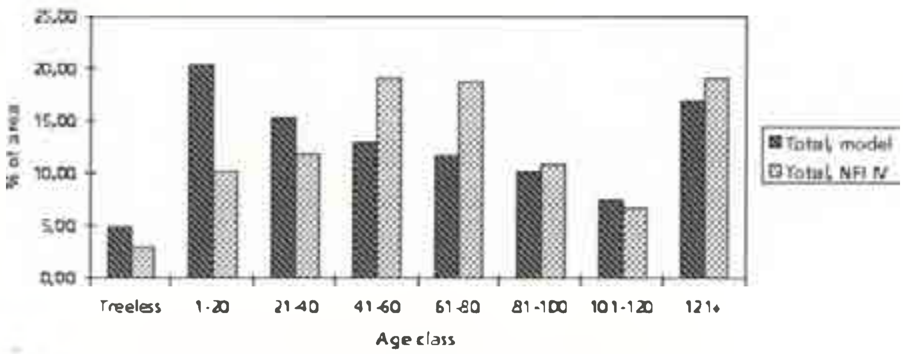

Fig. 8: Distribution of area over age classes in 1963, in the model and in NFI IV, for all tree species.

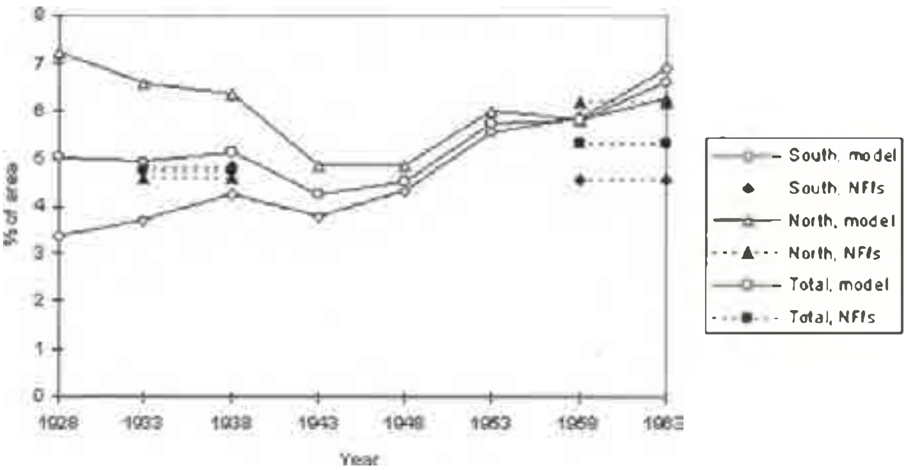

Fig. 9: Areas treated with regeneration fellings in the model and in the NFI's in 5-year periods.

Results of the simulation until 1993

In Figure 10 the development of the total increment during the simulation till

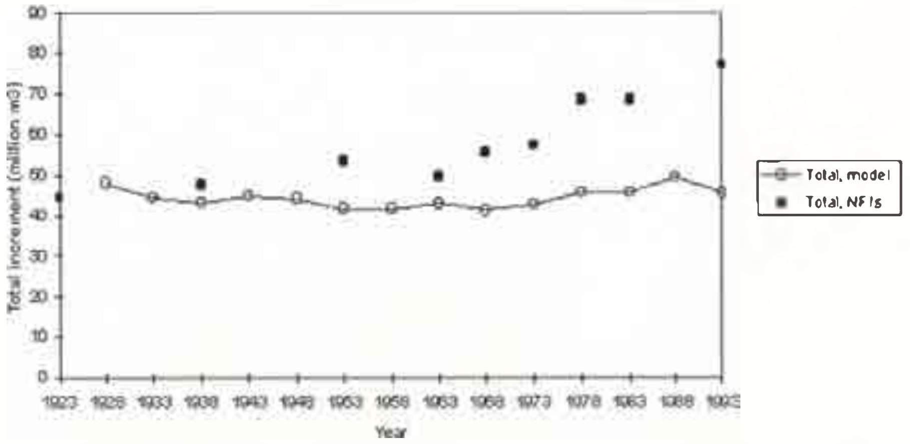

Fig. 10: ***Development of total increment of spruce and all tree species from 1923 to 1993, in the model and in the NFI's.***

1993 and in the NFI's is shown. Since the growth functions were based on the 1920's increment and do not take into account any transient change of growth, the model is not capable to simulate the transient increasing increment level. The figure gives the national total, but especially for spruce and birch the model simulations stayed behind.

Discussion

Attempts to validate forest projection models in order to gain insight in the accuracy of the assessments can be carried out through various approaches. These are:

1. Validating the growth functions against other growth functions or data sets,
2. comparing the projections against other projections carried out for the same forests,
3. running the model on historic data and comparing the output to present day forest state, and
4. propagation of variance assessments (e.g. Monte Carlo simulation) to gain insight in accuracy.

Re 1. Approach 1 has been applied to the previous version of EFISCEN by *Sallnäs* (1990). He compared the growth as assessed in the area matrix approach of EFISCEN with the growth function of the EKÖ model at the forest type level. The growth in the EKÖ model showed some differences with the growth in the EFISCEN model, but these were explained from the fact that the site classes of the EKÖ model represented often extremes within these site classes. Moreover, the increment in the input data of EFISCEN included some 'poor' years with increment values below average. The conclusion was that the overall growth level of the model is acceptable.

Re 2. Approach 2 has been applied by *Nilsson* et al. (1992) for European forests, by *Päivinen* et al (1998) for Leningrad Region forests and by *Nabuurs* et al. (1998a) for a selected number of European countries. *Nabuurs* et al (1998a) compared the output of EFISCEN with the European Timber Trend Studies V scenario results for seven European countries for 1990–2040. EFISCEN was able to reproduce the ETTS scenarios and seemed to yield more satisfying results. Where differences in output occurred they were explained from differences in input data or by the fact that a more dynamic approach was incorporated in EFISCEN.

Re 3 & 4. Approach 3 that can be seen as a way of validating the whole model with all its module interactions had never been tried for EFISCEN and in general for very few other forest projection models. The only exceptions are *Manley* (1998) for New Zealand projections of supply and by *Clawson* (1979) for US forests' net increment. *Clawson* concluded that the projections have consistently underestimated actual growth. *Manley* concluded that most projections were realistic till about 1990, but thereafter consistently underestimated the actual harvest. He states that the projections are not predictions, but merely scenarios of what could happen under specific assumptions.

Errors in predictions have three main sources (*Kangas* 1997):

a. stochastic character of the estimated model coefficients (growth variation and management irregularity is not incorporated);

b. measurement errors in the data used for model construction;

c. goodness of fit of the utilised models.

Re A. From the run until 1993 it becomes clear that the EFISCEN is not able to predict the situation of the forests in 1993 with the data from 1923. The reason for this is the transient increase in increment after the 60's. The current model was never built to take such changes into account and we have assumed stable environmental and management conditions (i.e. stationarity assumption). The transient increase is comparable to what *Kangas* (1997) mentions as uncertainty in growth projections due to annual variation of growth. She states that the uncertainty of stand volume growth considering annual variation was about 5–6 %. In addition, uncertainty is caused by residual errors, estimated model coefficients and future stand treatment.

We can determine to what degree the declining increment over time is caused by the development of the age class distribution. Figure 11 shows the average annual increment as simulated by the model and the expected increment level for pine, spruce and birch. The expected increment level is calculated by multiplying the relative age class distribution as simulated for that time period with the average growth per age class as given in input data of NFI I. Figure 11 shows that the increment as calculated by the model stays behind with the expected increment level for Scots pine. Most likely this is caused by a too limited regrowth after thinning. For birch the simulated and expected increment fit very well. This is due to the fact that in birch the proportion of fellings from thinnings was small (*Schelhaas* et al. 1999).

Furthermore, the transient change in increment caused problems in trying to set up a realistic scenario. This transient change in increment level can most likely be subscribed to silvicultural measures (*Mielikäinen* and *Sennov* 1996, *Mielikäinen* and *Timonen* 1996).

Re B. In the present study there are two types of uncertainties which resulted in problems in data preparation and in setting up an accurate scenario:

■ the reliability of the individual inventory results; The latest forest inventory in Finland is very accurate: standard errors of some characteristics at the country level are: forest land area 0.4 %, growing stock 0.7 %, and total increment 1.1 % (*Tomppo* 1996). *Ilvessalo* (1927) also reports very accurate results of the first NFI. The result for mean volume was: 64.3 ± 0.96 m^3 ha^{-1} (s.e. 1.49 %) and for mean growth was 1.77 ± 0.029 m^3 ha^{-1} yr^{-1} (s.e. 1.64 %). This is however only the uncertainty in initial data quality. *Mowrer* and *Frayer* (1986) project the coefficient of variation as a result of input measurement and regression errors. They state that when the input CV is 5 to 10 %, the maximum projection period would be 20 years when desiring an output CV of less than 20 %. Also *Kangas* (1998) states that when the data set contains measurement errors, the coefficients will contain a bias that cannot be ignored.

■ the limited comparability between the different inventories because of the use of different definitions. *Uusitalo* (1989) reports that when using a new method to determine the volume in NFI VI, that resulted in 3 % higher volumes for all previous inventories. Also the definitions on e.g. forest land in the different NFI's have changed.

Re C. Figure 11 showed that the increment levels tend to decrease after some periods. The reason for this decrease is probably the decreased growth after thinning. In the model, growth is expressed as a percentage of the volume. After a thinning the volume will be less and consequently the growth will be less than before. In reality the growth of a stand will decrease after a thinning only for a short period and will then increase. This increase in growth is not dealt with in the model. From the present study it appears that this thinning effect becomes visible in the increment after 30 till 40 years. This limited regrowth after thinnings also results in the areas in the matrix to diverge, i.e. the areas in high volume classes grow increasingly fast, the areas in low volume classes increasingly slow.

Another problem that is caused by thinnings is the mean volume per age class. As can be seen in Figure 7 the mean volume per age class is hardly increasing in the age classes were thinning is applied. This is not according to reality. In order to solve these problems, the growth of recently thinned stands should be higher in the model than unthinned stands. The average volume in thinnings is 65 m^3/ha, which is reasonable. The average volume in final fellings is around 96 m^3/ha, which is too small. The area that is treated with final fellings is already too high in the model in the 50's, with implications for the development of the age class distribution and thus again on the increment. When the proportion of thinnings from fellings is decreased, as stated above, more final fellings should be made. In order to prevent the clearcut area then to increase, the average volume in final fellings should be much higher. This would also give a picture that is more according to reality. The average volume in final fellings should probably be around 250 to 300 m^3/ha. This can be done by making felling chances dependent on the volume class.

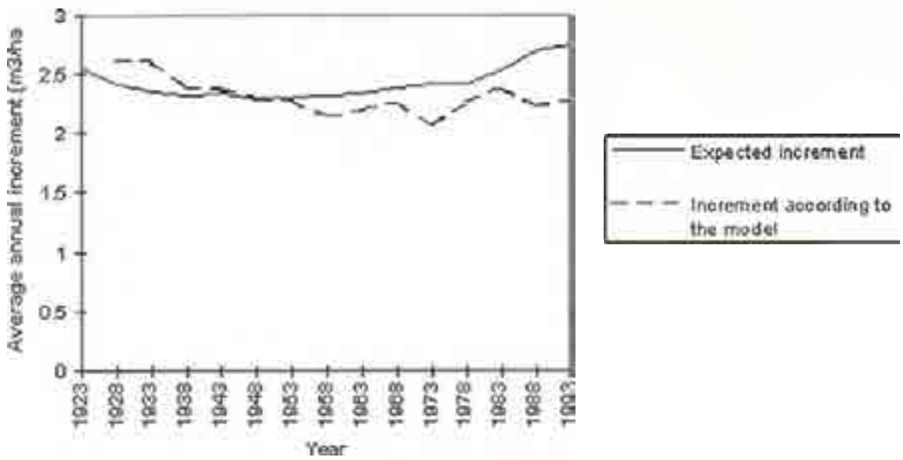

Fig. 11: Average annual increment of pine as calculated by the model and as could be expected by the age class distribution as simulated by the model. The expected increment is calculated with the current increment per age class in NFI I and the age class distribution as simulated by the model (Schelhaas et al. 1999).

Conclusion

Due to the dynamics in the model, many variables have a feedback on each other. The underestimated growth after thinning causes the total increment to be too small. This resulted in a volume class distribution which is not very realistic and thus in too large clearcut areas (also because the final felling regimes were defined according to age only, not according to volume class) with implications for the development of age class distribution. The area in the bare land class stayed relatively large because the young forest coefficients were estimated too low in the parametrisation. This will also influence the age class distribution. Deviations in the age class distributions will affect again the total increment level.

For the period 1923–1963 EFISCEN is able to reproduce the historic forest development in terms of increment, growing stock, average thinning level and total harvest level. However, the increment level tends to be underestimated at simulation periods longer than 50 years because of the decreased growth after thinning.

The age class distribution as calculated by the model for 1963 deviates from NFI IV. Partly this can be explained by the unevenagedness of the forests and the selection fellings which are carried out. A small young forest coefficient, too much area in the bare-land class in the initial situation and the fact that actual harvest regimes will deviate from the theoretical regimes also have influence on this deviating age class distribution.

The simulated mean volume per age class in 1963 is not comparable to the actual situation. Already in the initial situation the mean volume per age class deviates, because of the non-declining volumes in the model. Because of the decreased growth after thinning the deviation gets worse.

The management regimes as entered in the model are derived from yield tables and handbooks and thus reflect a theoretical regime. In reality forests are not managed according to these theoretical regimes, so simulations will always show deviations.

With the present state of the model it is impossible to simulate the development of the forest resources of Finland from 1923 to 1993, using NFI I as input. The main reason for this is the increase in actual increment after 1960, which the model cannot handle.

From the results the conclusion can be drawn that EFISCEN is performing good enough to make projections of forest resources for periods up to 40 to 50 years. Results should be interpreted with care, especially regarding increment at the end of the simulation period, age class distribution and mean volume per age class.

Given the fact that comparable data as were used in this study are available for most European countries, we can conclude that EFISCEN can be used for European scale forestry scenario studies, even though every country will give its own specific problems like we have seen in the present validation.

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Emission Reduction via Forest Conservation, Forest Management and Afforestation – A Case Study from Argentina –

Klaus Böswald

Abstract

At present the so called Clean Development Mechanism (CDM) described in Art. 12 of the Kyoto Protocol remains largely undefined. This is particularly true for the forestry sector, as it is not clear which specific options are accepted or neglected as eligible for pursuit under the CDM.

Most of the questions still open in the context of the CDM may be analyzed scientifically. However, there are issues such as (1) acceptability, (2) participation and information, (3) sustainable forest management, (4) externality, (5) capacity, (6) risk and uncertainty and (7) additionality where a scientific approach may be improved via professional judgement based on practical experience.

To contribute to these issues, the paper presents some findings of a large scale forest conservation, forest management and afforestation project in Patagonia, Argentina. The interdisciplinary approach of the project provides procedures to operationalize questions currently discussed in the scientific debate.

Introduction

Art. 12 of the Kyoto Protocol defines a so called Clean Development Mechanism (CDM) to assist Parties not included in Annex I in achieving sustainable development and contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their Quantified Emission Limitation and Reduction Commitments (QUELRCs).

At present CDM remains largely undefined. This is particularly true for the forestry sector, as it is not clear which specific options are accepted or neglected as eligible for pursuit under the CDM. While some assume that Art. 12 includes forest conservation projects (e.g. projects that result in reduced emissions) the text seems to exclude reforestation- or afforestation-projects initiated to sequester carbon. Some Articles of the Protocol offer possibilities for interpretation as they foster the need for sustainable forest management (Art. 2) and integrate afforestation, reforestation and deforestation in the evaluation of Annex I Parties compliance of commitment (Art. 3).

The German non-profit organisation PRIMA KLIMA – weltweit – e.V.[1], Duesseldorf, Germany, together with the Center for Investigation and Extension of the Forestry Sector in the Andino-Patagonian Region, Esquel, Argentina (CIEFAP, Centro de Investigación y Extension Forestal Andino Patagónico), is currently implementing a large scale forest conservation, forest management and afforestation project in Patagonia, Argentina. The project is comprehensively investigated by a group of scientists working under the auspices of PRIMA KLIMA[2]. The combination of practical and scientific analysation during project-planning and -implementation allows for the operationalization of queries currently discussed in the international debate.

Historic development of Patagonia

The management/misuse of the natural resources of Patagonia commenced with the immigration at the end of the last century. The dominating branch of industry was sheep breeding and wool production. The patagonian land resources appeared to be unlimited, which encouraged the farmers to intensify the production of wool. If necessary, forests were burnt to gain new pasture lands and animals have been foddered in the forests. Besides, non-sustainable timber utilization and destructive forest management practices were used in the Patagonian region. All activities resulted in a degradation of the ecosystems. Today inappropriate management schemes have impoverished many pastures, forests and soils with all negative implications for the global carbon budget (*Defossé*, 1999).

Project area: position, size and socio-economic situation

The project area corresponds to the water catchment area of lakes La Plata/Fontana situated in the southern part of Argentina about 2000 km southwest of Buenos Aires in the Department of Rio Senguer, Province of Chubut, Patagonia. It is a wide open, horseshoe-shaped valley between 45 degree southern latitude and 70 to 72 degree western length.

The project area is bordered by Chile in the northern, western and southern part. The eastern border of the project area is a fictitious north-south tangent cutting the eastern edge of lake Fontana. The so defined project area amounts to about 120,000 ha (1,200 km^2). 50,400 ha of which are forests, 55,000 ha are pastures and high mountain regions. The surface of the lakes covers about 15,000 ha.

The precipitation in the project area changes significantly from 4,000 mm/(m^2*a) in the western part of the project area to 500 mm/(m^2*a) in the eastern part.

The water catchment area of the lakes comprises a unified socio-economic and ecological region within the Department Alto Rio Senguer. The municipality of Rio Senguer which is situated 70 km east of lake Fontana has about 2,000 inhabitants. At the height of the season there are about 100–200 permanent residents in the catchment area of the lakes. They earn their income in two small saw-mills, on three Estanzias, in tourism, in a stone factory, and as frontier guards and foresters.

[1] PRIMA KLIMA is financing and promoting afforestation-, forest management-, and forest conservation-projects in cooperation with nationally and internationally approved organisations to prevent global climate change.

[2] PRIMA KLIMA ist greatful to the European Union and the German Ministry of Environment for financing the project "Forestry Options for Carbon Sequestration", which serves to analyse the La Plata/Fontana Project scientifically.

200–300 people are living on 5 large and 10 small Estanzias with seasonal variations. Besides, some hundred tourists fill the area during summer. The main reasons for the touristic activities are the beauty of the landscape and to an increasing degree fishing and hunting activities. All the indications are that the touristic activities will expand in the future.

The area in the western part of the project area as well as the usufructs in this part belong to the Province of Chubut. The land in the eastern part of the project area belongs to the property of 5 large Estanzias.

Many inhabitants are seasonal workers for sheep shearing, with no employment in the rest of the year. Currently, there are about 10 workers per Estanzia with seasonal fluctuations. That is half the number of employees the Estanzias had 20 years ago. The mean income of people in the project area is hardly to determine. A manager of an Estanzia might earn approximately 1,000 US $ per months, a worker may have 500 US $ per months to his disposal. The returns of the Estanzias have been reduced in the last decades due to falling market prices for wool and an overgrazing of the pastures. Currently, to cover the living costs of a family of four an Estanzia of about 20,000 ha is necessary.

The forests in the project area

The dominating tree species in the project area are Nothofagus pumilio (spanish: Lenga) on about 35,000 ha and *Nothofagus antarctica* (spanish: Ñire) on about 11,000 ha.

Pristine Lenga-forests with a standing volume larger than 600 m³ per hectare are dominating the landscape on about 21,000 ha in the western part of the project area. The ecosystems are by and large in the state of a primeval forest. Some isolated groups of *Nothofagus dombeyi* (spanish: Coihue) can be found in sheltered, wet areas. Managed forests cover approximately 14,000 ha. The standing cubic volume is about one half of that in pristine forests. Stands are uneven-aged and the current practice of silviculture leaves large amounts of dead wood on the forest floor. Lenga produces a beautiful reddish-grained wood which is comparable to that one of Cherry (*Prunus avium*). It is well suited for furniture construction. Impoverished Lenga-forests form open stands on about 4,400 ha with low cubic volume. The bole form is mainly insufficient, stems are short and a second canopy is just as often missing as an understory. There is less herbage and the humus layer is reduced by wind erosion.

If the growing conditions for Lenga are unfavourable (Lenga demands medium soils and temperatures, humus for regeneration and is not able to stand frost), Ñire-forests conquer the landscape (about 11,000 ha in the project area). Ñire (*Nothofagus antarctica*) also grows on sites if impoverished Lenga-forests break down or if they are heavily damaged by fire.

Objectives of the project

Forests in Patagonia suffer of large-scale impoverishment and destruction. The reasons are man-made fires, unsustainable forest management and forest pastures of cattle and sheep. The project aims to facilitate sustainable development in the water-catchment area of lakes La Plata/Fontana, Province of Chubut. The objectives in implementing the project are the following:

(1) introduction of forest conservation areas,
(2) establishment of sustainable forest management practices in parts of the project area,
(3) introduction of a understory in impoverished forests, and
(4) afforestation of pasture land.

Given that the goals of the project will be attained, ongoing CO_2-emissions will be reduced and additional carbon will be sequestered.

Project performance

To sustain the project results in the long term, it is necessary to maintain and enhance the ecological situation in the project area. It is also important to improve the economic situation of the project areas inhabitants. Therefore, a bunch of activities has been developed to provide both, ecological and eco-

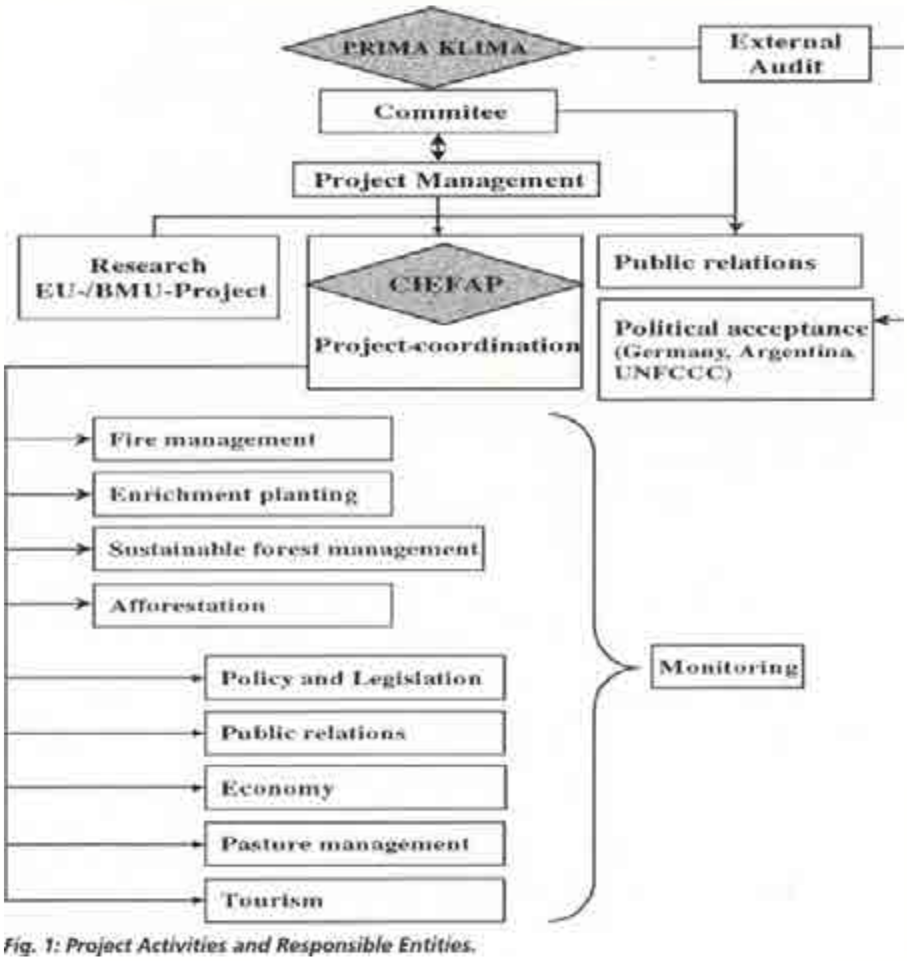

Fig. 1: Project Activities and Responsible Entities.

nomic project benefits. Figure 1 provides an overview of the project performance and the responsibilities of the participating entities.

The overall responsibility of the project is with PRIMA KLIMA. PRIMA KLIMA makes use of the money of a German donor. PRIMA KLIMA tries to consider – if possible – relevant outcomes of the international climate debate. Several scientists are currently working to provide an operational system for JI-/CDM-projects in the forestry sector. The implementation and analyses of a "real world"-project shall help to improve theoretical knowledge. The research project is financed jointly by the European Union and the German Ministry for Environment.

CIEFAP is the operational entity in Argentina. CIEFAP is responsible for the coordination of the project activities and for the integration and participation of interest groups and stakeholders. CIEFAP provides monitoring data for the controlling of the project and informs the inhabitants of the project area as well as visitors about the projects targets and activities. The different activities are gathered in the following modules: Fire management, enrichment planting, sustainable forest management, afforestation, policy and legislation, public relations, economy, pasture management and tourism (see Fig. 1). All activities are integrated in a project cycle management.

The implementation is reviewed by an external environmental verifier against the PRIMA KLIMA "Catalogue of Criteria" (GERLING Cert Environmental Verifiers, Cologne).

Evaluation of the project in the CDM frame

In the following, it is discussed, whether the La Plata/Fontana project performance is in line with the provisions of Art. 12 of the Kyoto Protocol. This discussion is based on anticipated necessities for CDM projects as the international climate debate up to now did not provide operational procedures for forestry projects. The following topics have been investigated: (1) Acceptability, (2) Participation and information, (3) Sustainable forest management, (4) Externality, (5) Capacity, (6) Risk and uncertainty, as well as (7) Additionality.

1 Acceptability

It is indispensable, that participating countries and the project itself are conform with international agreements and national forest and climate policies and laws. In addition, consistency with national and regional environmental programs is important to ensure that project activities are supported.

Therefore the Argentinian Ministry for Environmental Affairs and the Ministry of Environment in Germany have been informed about the project and its intention. There is a written statement of the Argentinian Ministry for Environmental Affairs, that the project in its present form assists the host country in achieving sustainable development taking into account its own priorities and needs. An approval of the project by the national CDM-body in both the host country and in the donor country will be important to participate in the carbon market.

Up to October 1999 neither Argentina nor Germany ratified the Kyoto Protocol. Nevertheless, PRIMA KLIMA and CIEFAP decided to implement the project, as the protection of sensible landscapes shall not depend on the pending negotiations in the follow up of Kyoto. We did not apply for acceptance under the AIJ pilot phase, as AIJ projects will not for sure result in tradable offsets. However, a market of carbon credits may alter significantly the expected revenues and thus the business plan of the project. To avoid problems we put emphasis on a judicial examination of the contracts.

2 Participation

The Kyoto Protocol explicitly asks for a participation and full information of decision makers and NGOs at all steps of the project performance. We therefore identified and consulted all relevant stakeholders to inform them about the project goals and activities. The demand driven design and adapted extension tools are expected to encourage participation and support of the project.

3 Sustainable Development

On the one hand the project initiates or enhances sustainable development due to the

(1) introduction of forest conservation areas to protect impressing remnants of Lenga forests in the western part of the project area;
(2) establishment of sustainable forest management practices in parts of the project area to convert formerly destructive forest management practices;
(3) introduction of a understory in impoverished forests to restore formerly productive Lenga stands;
(4) afforestation of pasture land and introduction of new pasture regimes to convert degraded in productive sites (forests and pastures).

On the other hand, inhabitants and visitors area are informed about the value of the landscape in the project area to foster an environmentally careful behaviour in the La Plata/Fontana region.

4 Externality

There are environmental benefits that occur with the implementation of the project: The protection of the forests in the project area maintains their relevance for soil protection and avoids erosion, which will probably arise if the standing stock in forests is to be reduced. The project activities serve to avoid floods as the water storage capacity is perpetuated. The town Comodoro Rivadavia will draw excellent drinking water from the project area in the future (Comodore Rivadavia a town with 127,000 inhabitants, is situated at the Atlantic coast, some hundred kilometres east of the project area). Finally, the project area is an important reservoir for biodiversity and species conservation.

The financial input of PRIMA KLIMA (about 1.2 Mio US$) and the co-financing of official entities in Argentina (about 1.0 Mio US) results in an improvement of the infrastructure, income and employment for at least 50 families during 5 years in timber industry, tourism, silvi- and agriculture. This is a valuable contribution to an integral regional development in an area with 2,000 to 2,500 inhabitants.

5 Capacity

The project reaches its goals of project implementation and formal evaluation of results with the given equipment.

Table 1: Assumed baseline scenarios and development of the project area with project implementation.

Forest type	Baseline		Project Scenario
	best case	worst case	
Impoverished Lenga-forest	Biomass reduced to zero within a 50-year interval	Biomass reduced to zero within a 50-year interval	Planting of a second layer under the canopy to gain a mean volume of 100 m³ per hectare within 50 years
	50 % of the lost Lenga-forests are followed by Ñire-stands	50 % of the lost Lenga-forests are followed by Ñire-stands	Old Lenga-forests will break down within the next 50 years
Managed Lenga-forest	Unsustainable timber utilization results in a 10 % decline of the standing volume	Unsustainable timber utilization results in a 50% decline of standing volume	Sustainable practice of silviculture results in a 15 % enlargement of the standing volume
	5 % of the managed Lenga-stands are disturbed by fire (50 % of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)	10% of the managed Lenga-stands are disturbed by fire (50% of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)	2.5 % of the managed Lenga-stands are disturbed by fire (50 % of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)
Pristine Lenga-forest	No management, 1,000 ha are disturbed by fire (50 % of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)	No management, 2,000 ha are disturbed by fire (50 % of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)	No management, 750 ha are disturbed by fire (50 % of the damaged stands are followed by Ñire-stands, 50 % without considerable stocks)
Ñire-forests	5 % enrichment of standing stocks as a gas pipeline reduces the necessity to use wood for energy purposes	10 % reduction of standing stocks due to unsustainable production of wood for energy purposes	5 % enrichment of standing stocks as a gas pipeline reduces the necessity to use wood for energy purposes
Afforestation	–	–	300 ha poplars along irrigation ditches

CIEFAP is highly capable for all project goals. Satellite images are a basis for project monitoring, controlling and evaluation. Both PRIMA KLIMA and CIEFAP try to improve consequently their skills concerning the C-issue.

6 Risk and uncertainties

The project has a tolerable level of risk and uncertainties and guarantees a certain reduction in carbon emissions. The project management is able to guarantee the durability of the project. From the current point of view, the political situation in Argentina will be stable in the next years.

7 Additionality

Baseline and Project Scenario

One of the core issues still unresolved in the international climate debate is additionality. A project shall only be accepted, if it is in line with the interpretation of additionality in terms of the programme intent, in terms of emission reductions and in financial terms. CDM emission reductions and their costs can only be calculated by comparing a reference case, the so called baseline, and the project scenario. Both baseline and project scenario have to provide an accurate description of the path of net emissions and to cover all relevant sources, sinks and reservoirs of greenhouse gases. It also has to be considered, if emissions elsewhere are caused by the project implementation ("leakage"). By definition, a baseline is what would have happened in the absence of the project. It can therefore neither be observed nor be proved to be correct, thus the baseline is a "counterfactual construct".

The baseline issue has been discussed in a two days workshop in Esquel, Patagonia. A worst case and a best case scenario have been developed. Table 1 describes the baseline and a predicted project scenario.

C-reservoirs in the forests of the project area

The following algorithms have been used to estimate the size of the C-reservoirs in forests:

$$[CT] = [C_{LT}] + [C_{DW}] + [C_S] \quad (1)$$

where

$$[C_{LT}] = SW_{>10\,cm} * ExpFac * RedFac * D * C_{cont} \quad (2)$$

C_T = carbon in trees, C_{LT} = carbon in living trees, $SW_{>10\,cm}$ = volume of standing wood larger than 10cm diameter (*Bava*, 1997; *Lencinas*, 1999), ExpFac = estimation of the volume of branches and roots, calculated as percentage of stand-

[3] To calculate the C-reservoirs in pristine Lenga forests in the water catchment area of lakes La Plata/Fontana volume figures of *Lencinas* (1999) have been used. Expansion- and reduction factors have been investigated by *Weber* (1999).

ing wood larger than 10cm diameter (*Weber*, 1999), RedFac = estimation of the content of wooden debris, calculated as percentage of standing wood larger than 10cm diameter (*Weber*, 1999), D = wood density (*Weber*, 1999) and Ccont = carbon content of biomass (*Burschel* et al., 1993), and

$$[C_{DW}] = DW_{>10\,cm} * RedFac * D * C_{cont} \quad (3)$$

where

C_{DW} = carbon in dead wood, $DW_{>10\,cm}$ = volume of dead wood larger than 10 cm diameter (*Bava*, 1997; *Weber*, 1999), RedFac = estimation of the content of wooden debris, calculated as percentage of dead wood larger than 10 cm diameter (*Weber*, 1999), D = wood density (*Weber*, 1999) and Ccont = carbon content of biomass (*Burschel* et al., 1993), and

$$[CS] = C_H + C_{MS} \quad (4)$$

where

C_S = carbon in soils, C_H = carbon in humus layer, C_{MS} = carbon in mineral soils.

Table 2 provides an example for managed Lenga forests (*Nothofagus pumilio*) in the project area. Please note, that the carbon in dead wood and soils has been estimated as the results of the investigations were not available, yet.

To estimate the total C-reservoir in forests in the project area, the forests were devided in pristine Lenga- (*Nothofagus pumilio*), managed Lenga-, impoverished Lenga- and Ñire-forests (*Nothofagus antarctica*). The results of the calculations are presented in Table 3.

The total C in forests in the project area amounts to 12.6 Mio t. As there are no volume data for the unmanaged Lenga-forests in the project area it has been assumed that the mean volume is comparable to that investigated in the south of Patagonia (see Table 1). Pristine Lenga-forests in the project area contribute about 63 % to the total C-reservoir, managed Lenga-stands 25 %, impoverished Lenga-stands 4 % and Ñire-stands approximately 7 %.

In February 1999 about 2,500 ha have been destroyed by fire in the northern part of lake Fontana. If one assumes, that the mean C-reservoir in the burned area has been about 50 t C in the living dendromass, the total C presented in Table 3 would have to be reduced by at least 0.1 Mio. t C.

Table 2: Carbon reservoirs in managed Lenga forests (Nothofagus pumilio) in the project area and basic calculation parameters (volume data by LENCINAS, 1999).

	Unit	Managed Lenga-forests in the project area
Volume	m³/ha > 10 cm Ø	307
Stemvolume	m³/ha	254
Basal area	m²	33.5
Wood density	t/m³	0.52
C content of dry weight		0,50
Expansion-factor		1.45
Reduction-factor		0.90
C in living trees	t C/ha	104
C in dead wood	t C/ha	25
C in soils	t C/ha	100
C in forests	t C/ha	229

Table 3: Estimated C-content in forests in the project area.

	Unit	Lenga impoverished	Nire	Lenga pristine	Lenga managed	Total/ Mean
Area	ha	4,376	10,897	20,925	14,234	50,432
Volume	m³/ha >10 cm Ø	150	100	711	307	414
Wood density	t/m³	0.52	0.55	0.52	0.52	0.5
Expansion-factor		1.45	1.45	1.45	1.45	1.45
Reduction-factor		0.90	0.90	0.90	0.90	0.9
C content of biomass		0.5	0.5	0,5	0.5	0.5
C in living trees	t C/ha	50.9	32.3	241.2	104.2	140.9
C in dead wood	t C/ha	5.0	1.0	37.0	25.0	23.1
C in soils	t C/ha	50.0	50.0	100.0	100.0	84.9
C	t/ha	105.9	83.3	378.2	229.2	248.8
Total C in living trees	t C	222,717	391,066	5,047,995	1,482,686	7,144,464
C in forests	t C	463,397	946,813	7,914,720	3,261,936	12,586,866

Implication of the different activities on the global carbon budget

In the following some examples are given for the carbon implications of different activities, which are planned during the implementation of the La Plata/ Fontana project.

– Underplanting of impoverished Lenga-forest (4,376 ha)

Increment rates are relatively low. The biomass accumulation in a second layer under a canopy may result in additional 34 t C / ha after 50 years.

– Managed Lenga-forest (14,234 ha)

The current unsustainable management of forests in Patagonia, the so called "Floreo", leaves large amounts of non merchantable timber on the area. This is due to the fact, that elder stems are mainly decayed. The decay rate may be reduced significantly, if the mean diameter of harvested trees is reduced from about 80 cm to 40–50 cm breast height (see Bava, 1997). This allows to expand the amount timber harvested and – as the quality of the timber will be better as well – to expand the C reservoir in long-lived wood products. However, a conversion of formerly unsustainably managed Lenga forests into sustainably managed forests results first of all in a reduction of the standing stock and thus in a reduction of the carbon reservoirs in forests. A change in the management regime is therefore only favourable for the global carbon budget if a long-term strategy is taken into account (Figs. 2 to 4). The break-even point will be reached after about 30 years if an accumulation of carbon in products is considered (Fig. 2). 50 years are necessary if only the carbon accumulation in the standing biomass is considered. Another positive element for the carbon budget should be mentioned. The project activities also intend to avoid cattle grazing. This will result in a second canopy of which the carbon effects are comparable to an underplanting of stands.

– Afforestation (300 ha)

Due to increment rates in poplar plantations a high accumulation of C in the biomass is expected. If one assumes a mean volume of about 400 m³ per hectare after 50 years 120 t C/ha will be sequestered.

Fig. 2: Comparison between baseline and project scenario (GORCAM calculation, Schlamadinger 1999).

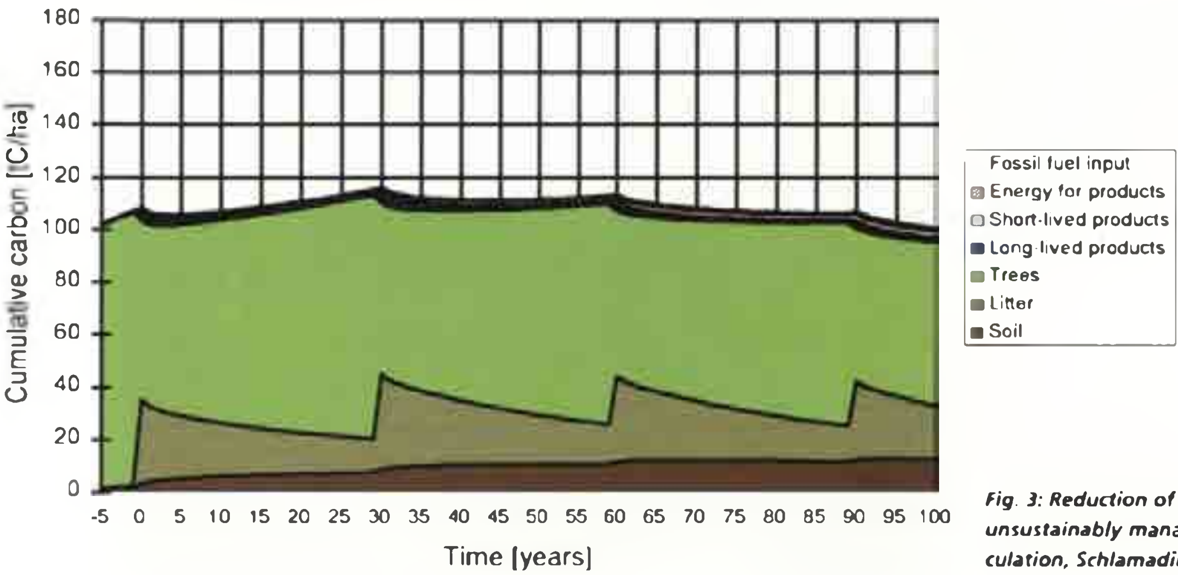

Fig. 3: Reduction of C (t C/ha) in forests unsustainably managed (GORCAM calculation, Schlamadinger 1999).

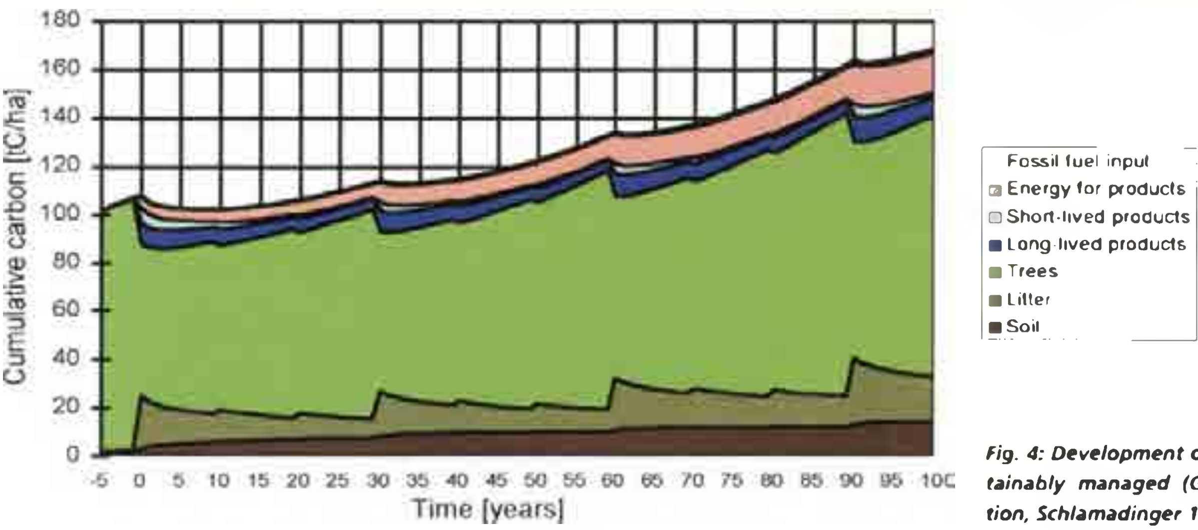

Fig. 4: Development of C in forest sustainably managed (GORCAM calculation, Schlamadinger 1999).

Implication of the project on the global carbon budget

The implication of the project for the global carbon budget are estimated to a CO_2-emission reduction and/or C-sequestration between 64,000 t CO_2 per year (comparison project scenario and baseline – best case) and 116,000 t CO_2 per year (comparison project scenario and baseline – worst case).

Outlook

The development of a forest project in the CDM frame is currently a decision in uncertainty. The Kyoto Protocol asks Annex I Parties to assist Parties not included in Annex I in achieving sustainable development. Sustainable development, however, is a vague phrase. Several standards and definitions try to define sustainable development. Another unresolved issue concerns the so called "additionality" and in particular baseline determination. Last but not least, it is still undecided if forestry projects will be accepted under Art. 12 of the Kyoto Protocol.

Nevertheless, action is necessary to reduce the negative human influence on the global carbon budget. PRIMA KLIMA therefore decided to promote a land-use project developed to avoid CO_2-emissions and to sequester carbon in the andino-patagonian region, Argentina. The La Plata/Fontana project with its comprehensive performance has the prerequisites to form an example towards a sustainable development and to reduce the negative impact of ecosystems on the global carbon budget. As we tried to anticipate future needs for CDM projects, we suppose the project to be in line with the provisions of Art. 12 of the Kyoto Protocol.

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Creating an Efficient Certification and Verification Framework

G. Jones

Synopsis

The articles in the Kyoto Protocol defining the flexible mechanisms refer inter alia to monitoring, verification, certification and independent auditing. The objective of these activities is to ensure that rules, modalities and guidelines, to be decided upon by the Conference of the Parties, are consistently applied, and that the process is transparent, efficient and accountable.

Certification and verification of greenhouse gas emissions trading could be achieved by using a system of accreditation and certification, similar to that currently used for quality and environmental management Systems certification, i.e. ISO 9000 and ISO 14000 respectively. Considerable experience exists throughout the world in operating these systems, and there are lessons that can be learned from that experience.

This paper discusses the role of accreditation and certification and suggests different arrangements that could be adopted to ensure the transparency, efficiency and accountability required by the Kyoto Protocol.

It concludes with a review of the verification and certification that will be necessary to ensure that the flexible mechanisms defined in the Kyoto Protocol are applied in a consistent manner. This is necessary to maintain the credibility and integrity of a greenhouse gas emissions trading scheme and to ensure the implementation of the Protocol has a beneficial effect on climate change.

1. Introduction

The articles in the Kyoto Protocol defining the flexible mechanisms refer inter alia to monitoring, verification, certification and independent auditing. The objective of these activities is to ensure that rules, modalities and guidelines, to be decided upon by the Conference of the Parties, are consistently applied, and that the process is transparent, efficient and accountable.

Certification and verification of greenhouse gas emissions trading could be achieved by using a system of accreditation and certification, similar to that currently used for quality and environmental management systems certification, i.e. ISO 9000 and ISO 14000 respectively. Considerable experience exists throughout the world in operating these systems, and there are lessons that can be learned from that experience.

Throughout this paper, the following definitions are used.

Accreditation: The recognition, by a responsible authority, that an impartial body is competent to undertake defined activities.

Certification: The authoritative act by which an independent accredited body documents that a process or procedure is compliant with pre-set standards or criteria.

Verification: Confirmation, by examination and provision of objective evidence, that results have been achieved or that specific requirements have been fulfilled.

Monitoring: The systematic surveillance and measurement of defined parameters.

It has been assumed that the Conference of the Parties will delegate responsibility for the day to day operations of the trading scheme to a subsidiary body, perhaps the United Nations Framework Convention on Climate Change (UNFCCC), and that the subsidiary body will, in turn, use experienced certifying authorities for certification and verification activities.

For management system certification, there are almost 50 accreditation bodies throughout the world. It is clear to those involved in this process that there are significant differences in the interpretation of international standards and accreditation criteria by the various bodies.

With regard to certifying authorities, over 500 have been granted accreditation throughout the world, and this number is growing rapidly. Despite satisfying accreditation criteria, there can be a significant variation in the implementation of certification, not only between certifying authorities in different countries, but between certifying authorities within a country.

This experience from the quality and environmental management system certification process leads to the conclusion that, for greenhouse gas emissions trading, the subsidiary body should be supported by an international accreditation body. Alternative schemes are considered in this paper.

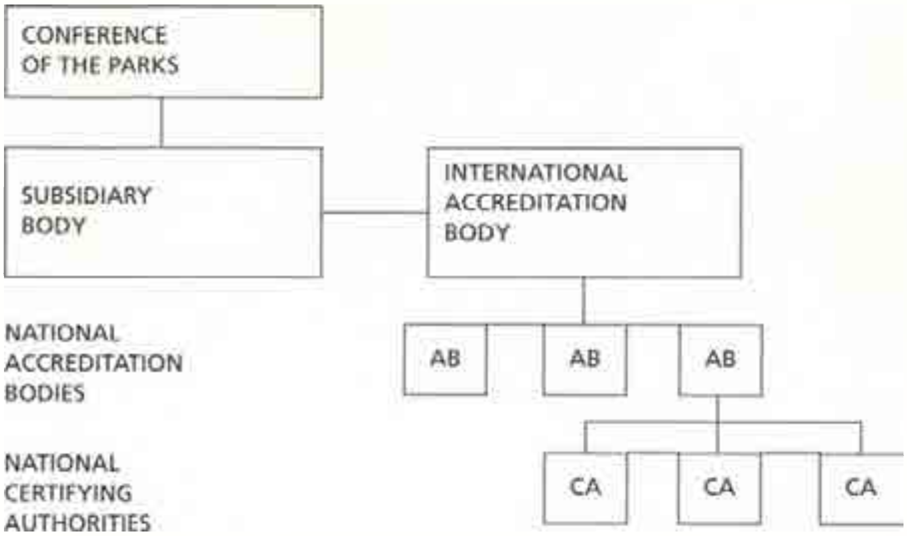

Fig. 1: Typical Structure for Accreditation and Certification.

2. Accreditation and Certification

The following are seen as the principle objectives of the accreditation and certification process for emissions trading, although this is by no means exhaustive:

- to provide a service which instils, in all participants, confidence that the trading scheme regulations are being properly and consistently applied to maintain integrity world-wide;
- to ensure that the trading scheme is regulated in such a way that it is equitable and free from anomalies, and that expanding the scheme does not disadvantage either the incumbents or the new entrants;
- to be cost-effective and not a burden which might discourage trading;
- to be independent, auditable, rigorous and transparent.

Very briefly, the role of the accreditation body can be summarised as follows:

- to provide accreditation to suitably qualified certifying authorities;
- to monitor the evaluations undertaken by certifying authorities through approved procedures and systems;
- to ensure evaluations are meaningful and the results of assessments are reliable;
- to annually audit each accredited body and evaluate changes to operating systems;
- to withdraw accreditation from certifying authorities who fail to maintain the necessary level of integrity.

For emissions trading the role of the certifying authority can be summarised as follows:

- to audit emission records of entities participating, or wishing to participate, in emission trading;
- to validate, through the certification process, the permits participants wish to trade;
- to provide other certification services as required by domestic arrangements.

Other tasks may be added to these for both the accreditation body and the certifying authority when the rules, modalities and guidelines for emissions trading have been agreed by the Conference of the Parties. Individual countries may also wish to extend these activities to suit national requirements.

The structure of the accreditation and certification scheme is a very important factor in ensuring the integrity of emissions trading. It is in the interests of all parties to ensure that trading and compliance is properly applied in a consistent manner. The concept of an International Accreditation Body (IAB) provides the best opportunity to ensure consistent certification standards throughout the world, but this may be perceived by some governments as an infringement of their sovereignty. At this stage, I do not intend to discuss in detail the structure of the IAB, but clearly there are several alternatives which could operate successfully.

Even with an IAB it is possible that some governments will appoint a national accreditation body, which will be responsible for accrediting certifying authorities within their country. With this arrangement, shown in Figure 1, the IAB would be responsible for ensuring consistent application of the rules by all of the certifying authorities through the national accreditation bodies.

With this system there is some duplication in the accreditation process, therefore, some countries may wish to use the IAB as their national accreditation body.

The IAB would need to have the following credentials:

- international experience in certification processes;
- financially independent and free from commercial pressures;
- must have, under direct management control, experienced high calibre assessors and analysts;
- must be prepared to set and maintain high accreditation standards and be prepared to apply sanctions against certifying authorities when necessary.

3. The flexible mechanisms defined in the Kyoto Protocol

With the envisaged emissions trading scheme there are two types of allowances, allocated and created. Firstly, there is an allocated entitlement or Assigned Amount based on parties' agreed emissions limit. And, secondly, there are created credits. These are credits from Joint Implementation (JI) projects, including carbon sequestration projects, and Clean Development Mechanism (CDM) projects. These credits are referred to in the Protocol as Emission Reduction Units (ERU) and Certified Emission Reductions (CER), respectively.

In fact, ERUs are not strictly created as they result in part of one party's Assigned Amount being transferred to another party, unlike CERs which are additional to Assigned Amounts.

By using these flexible mechanisms, a party will be in compliance if their emissions are equal to or less than their Assigned Amount plus any created entitlements plus the net value of units traded, which, of course, could be negative.

Baselines

Emission reductions in both joint implementation and clean development mechanism projects must be additional to any reductions that would have occurred in the absence of the project. Also, Article 12, paragraph 5(b) requires CDM projects to provide real, measurable and long term benefits to the host country. Therefore, there is a need for baselines to be set for each project. This includes sequestration projects.

There has been much debate regarding the setting of baselines, matched by the concern that baselines can be manipulated to exaggerate the reductions being achieved. Alternative approaches to setting the baseline include a national baseline incorporating emissions from all sectors, a sectoral baseline appropriate to the project, and project specific baselines. In my view, the last of these options, i.e. project specific baselines, is consistent with the language and intent of the Protocol and is the approach which should be adopted.

The cost of each approach has been an important issue in the debate. One view is that the project specific baseline will be the most expensive to implement. This is unlikely to be the case, as an investor would naturally be interested in the credits likely to be created, as these would form part of his return and, therefore, he would include this aspect in any feasibility study. Also, this approach to baselines can be made transparent and, therefore, the risk of inflated credits being certified is reduced.

No approach is perfect, but some are obviously less perfect than others. In the case of clean development mechanism projects, the approval of the baseline can form part of the project approval process and, hence, could be part of the supervisory remit of the executive board of the clean development mechanism. However, it is not clear from the Protocol as to who would have similar responsibilities for joint implementation project baselines or for sequestration project baselines under Article 3, paragraph 3.

Given their importance, it would seem appropriate that baselines should be certified, perhaps for a fixed period, with reviews at appropriate intervals. The need for transparency is very important, as the CERs created through the CDM should be fungible with assigned amounts.

Joint Implementation Projects

Article 6 of the Kyoto Protocol allows an Annex I Party to acquire from another Annex I Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals of greenhouse gases by sinks. There are two important conditions to be met. Firstly, the emissions reduction must be additional to any that would otherwise occur (Article 6, paragraph 1 b), and, secondly, the acquisition of emission reduction units shall be supplemental to domestic actions taken by the recipient Party for the purposes of meeting commitments under Article 3 of the Protocol (Article 6, paragraph 1 d).

Certification and verification of the emission reduction units created will be of interest to all participants in the emissions trading scheme. Although joint implementation (JI) projects which reduce emissions by sources do not effect the aggregate emissions of the two parties involved, there is a need for certification and verification to ensure the transfer meets the requirements of Article 6. More detailed certification and verification may be required for projects involving greenhouse gas sinks.

As discussed earlier, the issue of additionality requires the determination of a baseline for the project. This is true for both emission reduction projects and sequestration projects. Once the baseline has been set, it will be necessary to verify that real emission reductions have been achieved. This could be done annually, and, once the reductions have been verified, permits of equivalent emissions transferred from the host party to the investing parties. However, the value and use of these certified permits may be affected by the need to satisfy Article 6, Paragraph 4, of the Kyoto Protocol.

Clean Development Mechanisms

In the Kyoto Protocol, it was envisaged that CDM projects would be sponsored by Annex I Parties for the benefit of the non-Annex I host developing country and the creation of certified emission reductions for the investing Party. However, there is nothing in the Protocol which precludes non-Annex I Parties from investing in internal projects which create certified emission reductions. At this stage, there is no explicit provision for carbon sequestration projects under Article 12 and, again, there is a body of opinion within the Conference of the Parties which takes the view that sequestration projects should be excluded from the CDM.

Article 12 of the Protocol defines the CDM, referring to both certified emission reductions and certified project activities. Certification is normally seen as an ex-post activity and the action of "certifying" a project at the concept stage runs contrary to this. However, it is clear that a project must meet certain conditions and, once these have been demonstrated, the project can be "certified". It is assumed that the approval mechanism will be through the executive board of the CDM and that they will keep a register of approved CDM projects.

Once the project is operational, periodic auditing of emission records will be required to determine the emission reductions that have been achieved against the agreed, and certified, baseline. This process should be undertaken by a certifying body independent of the project. This will include verifying that accepted IPCC guidelines on measuring emissions have been followed. Having verified the emissions, the certifying authority can recommend to the executive board of the CDM that GER permits of an appropriate value can be issued. These permits should then be fungible with allocated entitlements.

Certified permits, created through CDM projects, may be perceived to have greater value than certified permits from JI projects, as the issue of host country compliance does not arise. However, this difference could be eliminated if, as has been assumed, a strong compliance enforcement procedure is in force.

Because CDM projects result in an increase in Annex I emissions compared with the limits agreed in the Kyoto Protocol, it can be argued that more stringent certification and verification procedures are required for these created entitlements. This should be addressed to a large extent by the modalities and procedures to ensure transparency, efficiency and accountability through independent auditing and verification of project activities (Article 12, paragraph 7) and the guidance and decisions of the executive board of the clean development mechanism.

Emissions Trading

The trading of allocated entitlements in the US sulphur dioxide allowance trading programme does not require certification. Provided the trading units of allocated entitlements are uniquely identified, this should also apply to greenhouse gas emissions trading. However, it is easy to envisage verification being required. The extent of the verification process will vary depending upon whether it is a government with responsibility for national compliance who is trading or a private entity. It will also be affected by whether liability rests with the seller, or the buyer, or is shared. This last issue is far from being resolved.

Rules, guidelines and modalities are to be decided upon by the Conference of the Parties, in particular for verification, reporting and accountability for emissions trading. However, the need for additional verification associated with each transaction may be specified by the buyer, particularly where a buyer or shared liability is in force.

4. Certification and verification of sequestration projects

The basic certification and verification framework described earlier can be applied to all projects, including sequestration projects. Obviously monitoring procedures will be different, but here again the same principles can apply to all projects. However, certifying the carbon credits created through sequestration does present some unique factors which must be considered. In my view, the most important of these is accounting for the carbon emissions when the forest is harvested or reduced by fire or disease.

Investors will naturally want to see returns on investment as early as possible and this would best be achieved through issuing certified credits annually based on the verified amount of carbon sequestered. To allow for uncertainty in this measurement, the credits may be limited to a fraction of the carbon sequestered. Obviously, the measurement can account for losses caused by fire and disease, which may result in negative credits.

However, concern for the environment requires the carbon emissions to be accounted for when the forest is harvested. This may prove to be a complex task, as the emissions will depend upon the purpose for which the forestry products are used and the emissions may occur over an extended period of time. This process is likely to be expensive. In addition, the beneficiary of the forestry products should need to match these emissions with the equivalent value of carbon permits.

Costa and *Wilson* [1] have suggested carbon credits being created using an equivalence factor. In effect, the credits are equivalent to the atmospheric benefit of delaying the release of greenhouse gases to the atmosphere for a specific period. This approach has a number of advantages in that it does not require long-term guarantees or the need to submit carbon permits on harvesting. However, it is recognised that further research into residence time and decay profiles of greenhouse gases in the atmosphere is required to reduce the uncertainty of the equivalence factors used. For example, for carbon dioxide Costa and Wilson suggest an equivalence factor of 0.0182 whereas CSIRO Australia[2], in research undertaken for the Greenhouse Challenge Office in Australia, suggests an equivalence factor of 0.007.

Whatever the difficulties, this approach would seem to be consistent with the objectives of the Framework Convention and the Kyoto Protocol. It may not meet with the approval of investors looking for a quick return on investment, however, it should reinforce the integrity of sequestration projects, especially with those who have doubts with regard to their role in the stabilisation of greenhouse gas concentrations in the atmosphere.

5. Verification and certification of the flexible mechanisms

The process of certification for the flexible mechanisms can be split into three general activities. These are project assessment, annual audit and compliance. The first two do not apply to Article 17. The requirements for each activity will depend upon the Rules, Modalities and Guidelines to be developed by the Conference of the Parties, and the activities shown in Tables 1, 2 and 3 are typical and not necessarily authoritative.

Project Assessment will include, as far as certification and verification is concerned, the approval of the parties involved, the determination of a baseline with respect to additionality , and, for a CDM project, registration with the executive board of the CDM and that it

Table 1: Project Assessment.

	Article 6	Article 12	Article 17
Approval of Parties	V	V	–
Sustainable Development	–	V	–
Baseline (Additionality)	C	C	–
Project Registration	–	V	–

Table 2: Periodic Audit.

	Article 6	Article 12	Article 17
Validity of Baseline	V	V	–
Cert. of Actual Emissions (Monitoring)	C	C	–
ERUs Created	V	–	–
Certification of CERs	–	C	–
Certification of Carbon Sequestered	C	C?	–

Table 3: Compliance.

	Article 6	Article 12	Article 17
Article 5	V	V	V
Article 7	V	V	V
Article 8	V	V	V
Supplementarity	V	V	V
Additionality	V	V	–
Sustainable Development	–	V	–
IPCC Methodologies	V	V	V
Government Approval (Seller)	–	–	V
Validity of Permits	–	–	V

meets the developing country's definition of sustainable development. This is mainly a verification phase, although Article 12 does refer to certified project activities, so project registration could be, in fact, project certification.

There is potentially a greater degree of certification during the annual or other periodic audit. This is particularly appropriate for actual emissions and for the credits created through CDM and sequestration projects.

It is generally recognised that the validity of a project baseline may have a finite life. It is therefore important to verify, at each audit, the validity of the baseline against which achieved emission reductions are to be measured. Once the emissions have been verified the reductions should be certified.

At this point, it may be appropriate to differentiate between joint implementation projects and clean development mechanism projects. In the former, the ERUs created are, in fact, part of the host country's assigned amount. Therefore, for reduced emissions, verification of reductions may be considered appropriate. In the latter case, certified emission reductions allow Annex I parties to emit more greenhouse gas than their agreed limit. In this case the emission reductions should be certified.

Compliance is seen as a verification exercise, although the end result may be the issuance of a certificate confirming that a party has complied with its emission limit.

To be in compliance, a country must demonstrate it has met the conditions of Articles 5, 7 and 8, which deal with methodological issues, communication of information, and the review of information, respectively. This will include conformance with any guidelines provided, and methodologies recommended, by the Intergovernmental Panel on Climate Change.

Parties will need to demonstrate that rules and guidelines on supplementarity and additionality have been met, and, for clean development mechanisms, that the project has met sustainable development criteria. This last point may prove difficult to quantify, and the use of sustainable development indicators is still under consideration.

Finally, before permits are traded, it would be wise to verify their validity, and that when the seller is an operating company, they have the approval of their government to proceed with the sale.

It must be stressed that the requirements at each phase are dependent upon the relevant rules, modalities and guidelines, which are yet to be decided upon by the Conference of the Parties.

6. Conclusions

If emissions trading is to play a successful part in the stabilisation of greenhouse gas concentrations in the atmosphere, participants must have confidence in the integrity of the system. The Kyoto Protocol recognises this by requiring certification, verification and independent auditing of the flexible mechanisms available to Annex I parties, to assist them in complying with their commitments under the Protocol.

The application of the rules covering the flexible mechanisms must be consistently and rigorously applied to ensure equity and fungibility between allocated and created entitlements. It is in the creation of entitlements, through both JI and CDM projects, that the greatest risk of inequitable implementation exists. Firstly, there is a need to establish an acceptable baseline for the project, and, secondly, the additional emission reductions must be verified and certified to enable the credits to be used to assist a party to achieve compliance. Ensuring a consistent application of the rules covering these aspects of the scheme is imperative if the scheme is to operate fairly and successfully.

Although still requiring further research, certifying carbon credits for forestry sequestration projects using the equivalence factor method would have advantages with regard to accounting for credits and subsequent emissions, lower verification costs and perhaps wider acceptance by participants, environmental institutions and the general public.

A possible method of monitoring the system, based on accreditation and certification, has been proposed. Whichever method of monitoring is adopted, it must be auditable, transparent and accountable. There must also be the commitment by all parties to accept the rigorous application of the rules governing each provision of the Protocol and the acceptance by the parties of penalties associated with non-compliance.

Through adapting existing accreditation and certification practices, the bureaucracy associated with monitoring, verification and certification will be kept to a minimum and implemented in a cost-effective manner. However, whatever the cost, for the system to be transparent, efficient and accountable, through independent audit and verification, a credible certification system must be in place, complimented by a realistic compliance procedure and fully supported by the Conference of the Parties.

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Forestry-based Greenhouse Gas Mitigation: A Short Story of Market Evolution[1]

Pedro Moura-Costa & Marc D. Stuart

Summary

Concern about rising atmospheric concentrations of greenhouse gases has prompted the search for methods for reducing greenhouse gas emissions or ways of sequestering carbon in plant biomass. For reasons of cost effectiveness, high potential rates of carbon uptake, and associated environmental and social benefits, much attention has focused on promoting forestry as a means of offsetting carbon emissions. During the last ten years, forestry-based carbon offsets have evolved from a theoretical idea towards being a market-based instrument for accomplishing global environmental objectives. This paper provides an overview of the evolution of the market and transaction mechanism for carbon offsets and greenhouse gas emission reduction projects. Although many of the concepts and ideas presented here are generic and applicable to any type of greenhouse gas mitigation option, the paper emphasises issues related to forestry-based carbon offsets.

Keywords: carbon sequestration, carbon offset projects, carbon offset costs, Joint Implementation, emission reduction markets, flexibility instruments, clean development mechanism.

1. Introduction

The notion of compensating for rising atmospheric carbon dioxide (CO_2) concentrations through global scale afforestation was first put forward in the late 1970's (*Dyson* 1977). During the last ten years, forestry-based carbon offsets have evolved from a theoretical idea towards being a market-based instrument for accomplishing the global environmental objectives of the United Nations Framework Convention on Climate Change (FCCC), signed in Rio in 1992 during the United Nations Conference on Environment and Development (UNCED). While we are still a long way from an organised market with prices defined according to supply and demand forces, the initial voluntary schemes and bartering transactions common in the early 90's have already given way to more sophisticated market mechanisms. If this trend continues, it seems very likely that forestry offsets will play a part in accomplishing the legally-binding emission reduction commitments agreed in 1997 in the Kyoto Protocol of the FCCC. It is estimated that, once fully operational, the international market for carbon projects, credits and allowances will reach tens of billions of dollars each year (*World Bank* 1997), a sizeable proportion of which could flow to developing countries if the trading regime is properly structured.

For countries rich in forest resources, altering non-sustainable land-use patterns is likely to be a prized greenhouse gas mitigation opportunity. Forestry carbon offsets encompass a range of project-level interventions, including direct preservation of existing forests, reforestation, and reduction of the negative impacts of forest management and harvesting (*Moura-Costa* 1996a, *Brown* et al. 1996). There is also the possibility of increasing the production efficiency of swidden agricultural systems or the end-use efficiency of fuelwood resources, both of which help take pressure off of standing forests, with accompanying GHG benefits.

Considering the wider perspective, forestry carbon offset projects can provide support for the other convention signed at UNCED – the Convention on Biodiversity. While a variety of financial mechanisms are being explored to support biodiversity conservation, initiatives like trust funds and pharmaceutical prospecting rights have yet to demonstrate that they are fully accepted by either policy-makers or the marketplace. Forestry-based carbon offsets – whether they promote direct preservation, sustainable forestry practices or reforestation – all have the potential to positively support the goals of the Biodiversity Convention.

[1] Commonwealth Forestry Review, September 1998.

2. Forestry and calculation of the costs of greenhouse gas sequestration

Carbon sequestration through forestry is based on two premises. First, carbon dioxide is an atmospheric gas that circulates globally and, consequently, efforts to remove greenhouse gases from the atmosphere will be equally effective whether they are based next to the source or on the other side of the globe. Second, green plants remove carbon dioxide from the atmosphere in the process of photosynthesis, using it to make sugars and other organic compounds used for growth and metabolism. Long-lived woody plants store carbon in wood and other tissues until they die and decompose, from which time the carbon in their wood may be released to the atmosphere as carbon dioxide, carbon monoxide, or methane, or it may be incorporated into the soil as organic matter.

Plant tissues vary in their carbon content. Stems and fruits have more carbon per gram dry weight than do leaves, but because plants generally have some carbon-rich tissues and some carbon-poor tissues, an average content of 45–50 % carbon is generally accepted (*Chan* 1982, *IPCC* 1996). Therefore, the amount of carbon stored in trees in a forest can be calculated if the amount of biomass or living plant tissue in the forest is known and a conversion factor is applied.

Forestry-based carbon offset projects[2] can be based on two different approaches: 1) active absorption[3] in new vegetation, and, 2) avoided emissions[4] from existing vegetation (i.e., from decomposition). The first approach includes any activity that involves planting of new trees (afforestation, reforestation, agroforestry, etc.) or increasing growth rates of existing forest stands (e.g., silvicultural practices). The second approach can be accomplished through prevention or reduction of deforestation and land use change (e.g. through conservation projects), reduction in damage to existing forests (e.g., through uncontrolled logging, fire), etc. All methods have similar results in that they reduce the accumulation of GHG's in the atmosphere, but will require different analytical tools for the evaluation of their merits as carbon offsets (i.e. whether they differ from an ongoing baseline) and for the calculation of their offset potential.

Different methods have been used for evaluating the carbon sequestration achievements of a project during its life time (*Matthews* 1996). Most projects and authors (e.g., *Verweij* 1997, *Tipper* et al. 1997, *Pinard* and *Putz* 1997, *Nabuurs* and *Mohren* 1993, *Faeth* et al. 1994, *Swisher* 1991) report the amount of carbon stored in a site at a given point in time after the beginning of the project. This approach has the drawback that it ignores the carbon flow dynamics that occur over the lifetime of a project. Furthermore, the time chosen for this "evaluation" varies from project to project, hindering comparison between projects. Other authors (*Richards* and *Stokes* 1994, *Trexler* and *Schmidt* 1997) suggested discounting techniques to calculate a "net present value" of the carbon flows of the project, but the subjective choice of a discount rate would affect the comparison of projects with carbon benefits at different times (*Price* and *Willis* 1993). Another method proposed is to calculate a project's "average storage capacity", by summing the storage on a yearly basis and dividing it by the number of years in a project's life time (*Dixon* et al. 1991, 1994). This approach takes into account the fluctuations in carbon storage during a project's life, and avoids the time preference issues of discounting. It does not, however, take into consideration the amount of time carbon is stored, giving, for instance, similar values for a plantation that is kept for one rotation or many. A method that takes into account both the dynamics and the time dimension of carbon storage is that of carbon leasing, which uses tonnes of carbon/year as a mensuration unit, as opposed to tonnes of carbon (*Moura-Costa* 1996b).

Calculation of the costs of carbon sequestration, consequently, has reflected the inconsistencies of using a range of carbon offset quantification methods. Usually, the amount of capital spent in a project is divided by the amount of carbon offset, which is done in a variety of manners. In this paper, we divided the amount spent in a project by the amount of carbon offset provided in the existing literature about this project, but these sources often do not mention the method used for calculation of offsets. These figures, consequently, are bound to contain inaccuracies due to the variety of methods which may have been used. Our analysis attempted to include all existing forestry-based carbon offsets, but, since this is a fast changing field, some projects may have been inadvertently excluded.

3. Early days: voluntary projects

The earliest forestry-based carbon offset project bear little resemblance to the market transaction systems that are evolving in several quarters today. The first company to express interest in compensating for its GHG emissions through the planting of trees was the American electricity company AES (Applied Energy Services). In the late 1980's AES contracted the World Resources Institute (WRI), an environmental policy think tank and lobbying group, to look for alternative project possibilities to offset CO_2 emissions. While energy options were not excluded from the proposal call, there was substantially greater emphasis placed on forestry options, due to the perception that forestry could be a substantially more cost-effective mechanism. After receiving nearly 100 proposals, WRI developed a framework for evaluation of forestry projects, based on a Land Use and Carbon Sequestration (LUCS) model (*Faeth* et al. 1994).

At the outset, AES intended to "link" particular offset investments with particular plants, beginning with a coal-fired power plant in Connecticut. For its first investment, AES put US$ 2 million into an existing social agroforestry scheme in Guatemala, managed by CARE (Cooperative for Assistance and Relief Everywhere), an international poverty-relief NGO. The estimated total cost of the project ranges from 6.6 million to $14 million, depending on the value placed on CARE volunteer labour. The original objective of the project was to plant 51 million trees over a 10-year period on a 186,000 ha area (*Trexler* et al. 1989), with a projected additional

[2] also referred to as carbon emissions mitigation projects, carbon sequestration projects, etc.

[3] also referred to as carbon fixation, sink creation, sink enhancement, etc.

[4] also referred to as sink protection, pool protection, emissions reduction, etc.

Table 1: Forestry JI projects initiated to date.

Project name	Date proposed Initiated	Carbon offset (1000 t C)	Area (ha)	Host Country	Investor Country	Project description
AES – Care	1990	10,500	186,000	Guatemala	USA	Agroforestry
Face Malaysia	1992	4,250	25,000	Malaysia	Netherlands	Enrichment planting
Face-Kroknose	1992	3,080	16,000	Czeck R.	Netherlands	Park rehabilitation
Face Netherlands	1992	885	5,000	Netherlands	Netherlands	Urban forestry
ICSB-NEP 1	1992	56	1,400	Malaysia	USA	Reduced Impact Logging
AES – Oxfam – Coica	1992	15,000	1,500,000	S. America	USA	Forest protection
AES – Nature Conservancy	1992	15,380	58,000	Paraguay	USA	Forest protection
Face-Profafor	1993	9,660	75,000	Ecuador	Netherlands	Small farmers plantation forestry
RUSAFOR-SAP	1993	79	450	Russia	USA	Plantation forestry
Face Uganda	1994	6,750	27,000	Uganda	Netherlands	Forest rehabilitation
Rio Bravo	1994	1,300	87,000	Belize	USA	Forest protection and management
Carfix	1994	2,000	91,000	Costa Rica	USA	Forest protection, and management
Ecoland/Tenaska	1995	350	2,500	Costa Rica	USA	Forest conservation
ICSB-NEP 2	1996	39	980	Malaysia	USA	Reduced Impact Logging
Noel Kempff M.	1996	14,000	1,000,000	Bolivia	UK/USA	Forest conservation and management
Klinki forestry	1997	1,600	87,000	Costa Rica	USA	Reforestation with klinki
Burkina Faso	1997	67	300,000	Burkina Faso	Denmark	Fire wood community forestry
Scolel Te	1997	15	13,000	Mexico	UK/France	Community forestry
PAP OCIC	1997	18,000	570,000	Costa Rica	Norway, USA	Forest conservation
Norway-Costa Rica	1997	230	4,000	Costa Rica	Norway	Forest rehabilitation and conservation
Tesco "green petrol"	1998	n.a.	n.a.	Undefined	UK	Forestry
Green fleet initiative	1997	n.a.	n.a.	Australia	Australia	Reforestation
AES - Ilha Bananal	1998	n.a.	n.a.	Brazil	USA	Forest rehabilitation
NSW + Pacific Power + Delta Electricity	1998	69	1,041	Australia	Australia	Reforestation
World Bank Prototype Carbon Fund	1998	n.a.	n.a.	International	International	Renewable energy and forestry
Totals/average	–	103,310	3,970,171	–	–	–

n.a. = not available

carbon storage of 16 million tonnes of carbon. Re-evaluation of the project, in 1994, showed that many initial assumptions were rather optimistic and that under a similar static analysis, at best 10 million tonnes of carbon could be sequestered (*Faeth* et al. 1994).

Applied Energy Services invested another US$ 5 million on two other projects in South America. To offset a 180 MW coal-fired facility on Oahu, Hawaii, AES partially funded the establishment a Nature Conservancy reserve in Paraguay. The primary source of carbon offset is conservation of standing carbon in a 58,000-ha dense tropical forest tract. The total calculated cost of carbon based on the US$5 million cost (of which AES put in US$2 million) yields a calculated cost of avoided carbon release of US$0.33/ton C. The carbon offset price, reflecting AES's agreement to fund $2 million of the project in return for all the carbon credits, is $0.13/ton C.

Lastly, the Oxfam America-AES Amazon Program (which was tied to a power plant in Oklahoma) represented a 10-year, US$3 million project to protect threatened rainforests by helping indigenous Amazonians gain legal title to and manage the resources of 1.5 million ha of their traditional territories. By funding indigenous land-title and resource-management projects in Ecuador, Peru, and Bolivia, the program claims that it will help save 500,000 hectares of pristine rainforest from imminent destruction. The estimated costs for carbon emissions reduction were around US$0.20/ton C.

None of the AES projects underwent any type of government or third party scrutiny after the initial evaluations by the AES/WRI teams. Furthermore, none have been put forth into the emissions reduction registry mechanisms that have emerged since these projects were undertaken. AES claims that it never intended to "use" these offsets officially and that it was simply being a good global corporate citizen. In many ways, this reticence to be peer examined was unfortunate, because it set an example that there was greater value in public relations than scientific certitude. It is notable how many environmental groups continue to be suspicious of forestry-based offsets, as a non-credible window dressing exercise that allows companies to continue GHG pollution without penalty. Much of this scepticism was generated by those early projects. Given the far greater diligence in creating "reasonable" baseline and emission reduction evaluations that future projects have taken, all cost estimates of AES's early efforts should be re-evaluated against current knowledge and practices.

Following on AES, in the early 1990's the Dutch Electricity Board (SEP), a consortium of five electricity companies in the Netherlands, created the Face (Forests Absorbing Carbon-dioxide Emissions) Foundation (*Dijk* et al. 1994). The mandate of the Face Foundation was to promote the planting of enough forests to absorb an amount of CO_2 equivalent to the emissions of a medium-sized coal-fired power plant (400 MW) during its 40-year life time (*Face* 1994, *Verweij* 1997). In this way, SEP would be able to build a new power plant in the Netherlands, with no net emissions to the global atmosphere. A multi-year budget of US$ 180 million was allocated to Face, for the establishment of a portfolio of forestry projects in different parts of the world. The initial investment proved to be a tropical rainforest rehabilitation programme in Sabah, Malaysia (see Box 1; *Moura-Costa* et al. 1996).

These initiatives illustrate the first transactions for CO_2 emission mitigation. They were voluntary in nature, since there were no legislation requirements for polluters to reduce GHG emissions. Projects were established in anticipation of changes in environmental legislation, while capitalising on the public relations value of projects. That said, the industry as a whole continued to oppose any type of emission reduction legislation. In the case of AES, their first projects did not even have any contractual arrangement for carbon credit allocation and transfer, and they were never submitted as Joint Implementation initiatives (see next section). This voluntary aspect was somewhat reflected in the assumed price paid for carbon sequestration, which averaged US$ 0.19/ton C (Table 2), based upon the costs to the investor.

4. From Rio to Berlin (1992–1995): first generation JI projects

In July 1992, representatives from 155 nations gathered in Rio de Janeiro for the United Nations Conference on Environment and Development (UNCED). At Rio, the United Nations Framework Convention on Climate Change (FCCC) was signed. This included a voluntary commitment by Annex 1 countries (industrialised countries) to reduce their emissions to the levels of 1990 by the year 2000 (*Grubb* et al. 1993). Embedded in FCCC was the concept of Joint Implementation (JI). At the initiative of Norway, the Convention approved – in principle – activities between countries to collectively reduce GHG emissions or promote the absorption of atmospheric CO_2. The investing participants in these projects could presumably claim emission reduction "credits" for the activities financed. These credits could then be used to lower GHG-related liabilities (e.g. carbon taxes, emission caps, etc.) in their home countries. The overall rationale of JI is that the marginal costs of emission reduction or CO_2 sequestration can vary dramatically, and that such costs are generally lower in developing nations than industrialised countries.

Although such crediting arrangements were not officially endorsed by the FCCC, this promise of potential transfers through JI led to a small flurry of activities in the forestry sector. One of the first companies to move forward was the American utility company New England Power (NEP). Like AES/WRI, NEP put out a wide-ranging call for proposals. The eventual winner was a Reduced Impact Logging (RIL) project in Sabah, Malaysia (*Putz* and *Pinard* 1994; *Moura-Costa* and *Tay* 1996; see Box 2). The Face Foundation, who had already initiated their activities before UNCED, continued expanding its operations by committing funds to four more projects around the world (*Verweij* 1997). These involved: reforestation of degraded pasture land by small farmers in Ecuador (1992), rehabilitation of an acid-rain degraded park in the Czech Republic (1992), urban forestry in the Netherlands (1993), and rainforest rehabilitation in Uganda (1994). Other emerging forestry projects included the CARFIX project in Costa Rica (a precursor of the PFP project, see Box 3), established by Fundecor (a Costa Rican NGO, developed partially with USAID funding and supported by a group of Norwegian financiers), and the Rio Bravo Conservation and Management Area Carbon Sequestration Pilot Project, which combines land acquisition with a sustainable forestry programme to achieve carbon mitigation, financed by various US electric utilities, namely the Wisconsin Power Company), Cinergy, Detroit Edison, PacifiCorp and the Edison Electric Institute's Utilitree Carbon Company (a single purpose investment vehicle 100 % owned by a consortium of US and Canadian Electric companies, that invested several million dollars into a portfolio of five forestry projects, three of which were domestic to the US).

The model of these transactions consisted of investor companies paying for the full costs of the carbon saving activities, in return for the promise of carbon credits generated as a result of these activities. This differed in part from the AES model, in which AES had a minority participation in the financing of broad environment/development projects, in return for a "claim" on total emission reductions. As such, it is exceedingly difficult to accurately ascertain the actual cost structure of reduced emissions under the AES sponsored projects.

In the post-Rio model, investing companies determined the direct costs of the carbon beneficial components of the project implementation, and directly claimed the resultant emission savings. The amount paid for carbon, therefore, almost invariably corresponded to marginal costs, accounted for through an open book approach that was requested for the competitive bidding process of project selection. While this led to some interesting comparisons of predicted costs, the actual price discovery model remained oblique, resembling a "barter" system. Often, parties would choose to implement projects based on a variety of negotiation points supplementary to actual supply and demand for emission reduction "credits", usually centred on a project's public relations appeal in either the host or buying country. For suppliers, there were few incentives for participation, as the maximum profit was capped by what the buyer would term "allowable" costs (as under the New England Electric contract in Malaysia).

This still remained a long way from characterising CO_2 credits as a commodity, since buying parties were required to invest in the production process. Investment was far from passive – indeed, it required a buyers fairly full engagement to a project, from beginning to end. Consequently, there was virtually no liquidity associated with these investments or their resulting "carbon credits"; each was uniquely valuable to its own investor, and such values were virtually non-transferrable to other parties. Projects that were designed and formulated by consultants, academics and NGOs, who did all the ground work of identifying partners, infrastructure and training needs, and negotiation with host country authorities, as well as quantification and monitoring of carbon savings. Little indigenous capacity for undertaking these types of proposals emerged. Development costs, consequently, were comparatively high, though often supported by a variety of agencies like international aid groups, multilateral organisations, foundations and the like.

The difficulty from the buying side was that there continued to be a great deal of uncertainty regarding carbon sequestration credit transfer arrangements. Given that CO_2 emissions were not penalised (indeed, still are not penalised) companies wanted to be sure that their investments would be recognised under future regulatory regimes. While interim regulatory institutions were being established, they were not given the ability to accept or reject emissions credit aspects of projects, rather they could accept or reject them for inclusion in a national registry system. The first institution given a mandate to input such projects was the US Energy Information Administration, under Section 1605-b of the 1993 Energy Policy Act, and in late 1994 was followed by the United States Initiative on Joint Implementation (USIJI), a highly structured system of US government project evaluation for international projects.

During the post-Rio phase, an average of 3.3 new projects and US$ 50 million were committed yearly during the two years between UNCED and the First Conference of Parties (CoP 1) in 1995 (see Table 2). The average price (usually equating costs) paid for carbon sequestration is estimated to be around US$ 1.97/ton C, a 10-fold increase from the prices paid in the previous phase.

Table 2: Yearly average number of new JI projects, yearly area committed to new JI projects (ha), average investment committed yearly (US$ millions, based on value of contracts signed) and price paid for carbon sequestration (US$/ton C) during 5 phases since 1989. Figures for the Post-Kyoto phase were based on non-official data, and were adjusted to give a proportional idea of a one-year contribution. Some figures were based on press announcements and bound to contain inaccuracies.

	Pre-UNCED	Pre-CoP 1	AIJ PP	Pre-Kyoto	Post-Kyoto
Number new projects per year	0.5	3.3	1.5	4	14
Area of new projects (ha/year)	93,000	628,467	501,740	893,000	2,002,082
Investment committed (US$ millions/year)	1.00	49.25	6.05	4.48	347.00
Carbon price (US$/ton C)	0.19	1.97	0.59	11.07	> 12.00

Pre-UNCED = before 1992; Pre-CoP 1 = phase between UNCED and the 1st Conference of Parties to the FCCC, 1992 to 1995; AIJ PP = Activities Implemented Jointly Pilot Phase, from 1995 to 1996; Pre-Kyoto = 1997; Post-Kyoto = January to June 1998.

Box 1: The Innoprise-Face Foundation Rainforest Rehabilitation Project (INFAPRO) is a cooperative venture between Innoprise Corporation, a semi-government forestry organisation which has the largest forest concession in the state of Sabah, Malaysia, and the Face (Forests Absorbing Carbon-dioxide Emissions) Foundation of the Netherlands, an organisation set up by the Dutch Electricity Generating Board to promote the planting of forests to absorb CO_2 from the atmosphere to partially offset the emissions of their power stations (*Dijk* et al. 1994, *Verweij* 1997). The objective of the project is to rehabilitate 25,000 ha of logged forests by enrichment planting and reclamation of degraded areas using indigenous tree species such as dipterocarps, fast growing pioneers, and forest fruit trees, over a period of 25 years (*Moura-Costa* et al. 1996). The total investment committed by the Face Foundation amounts to US$ 15 million over 25 years.

In the pilot phase (1992–1994), 2,000 ha of logged-over forests were planted as an initial trial of the effectiveness of this system. The planting phase will be extended for 25 years and the forests maintained for 99 years. The long term nature of the project should enable the maintenance and silvicultural treatments required to sustain growth rates during the project life. It is expected that at the end of the first 60-year growth cycle, these forests will be exploited for timber, which will belong exclusively to Innoprise. However, timber harvesting will have to be done in a careful way, so that a healthy residual stand can again regenerate a well-stocked forest in order to maintain a carbon pool for the Face Foundation, which has the exclusive rights to the carbon sequestered through the 99 years of the project. It is expected that the project will fix at least 4.25 million tonnes of carbon (15.6 million tonnes CO_2) during its life-time (Stibbe et al. 1994) at an average cost of US$ 3.52 per ton of carbon (US$ 0.95 per t CO_2).

Its been estimated that the project will also produce over 4 million m^3 of hardwood sawn timber, worth close to US$ 800 million, which belongs to Innoprise Corporation. Given that Innoprise is fully owned by the Sabah Foundation, a semi-government organisation with the mandate of improving people's welfare in the state of Sabah, it is expected that the project will generate considerable social spill-offs. Additionally, during its initial 25-year planting phase, the project will directly generate 230 jobs-year, for various activities such as field planting, silviculture, nursery work, mapping and GIS (geographical information systems), computing, financial control, and research. It is important to note that 90 % of the project's budget is spent on personnel.

Box 2 – The ICSB-NEP Reduced Impact Logging (RIL) Project is a cooperative venture between Innoprise Corporation Sdn. Bhd. (ICSB), a semi-government organisation which has the largest forest concession in the state of Sabah, Malaysia, and the New England Power (NEP) Company, an American utility trying to address the challenge of reducing its net CO_2 emissions. The objective of the project is to introduce the use of reduced impact logging (RIL) techniques in order to lower the level of damage caused by selective harvesting operations, reducing the release of CO_2 from decomposing vegetation and soil loss.

In an initial phase, 1,400 ha of forests were logged using reduced impact logging techniques, from 1992 to 1994. The project managed to reduce logging damage by 50%, thus saving approximately 40 tonnes of carbon per ha and a total of 58,000 tonnes of carbon (212,860 t CO_2, *Pinard* and *Putz* 1995). Given the project cost of US$ 450,000, the cost of carbon saved was US$ 7.60 per tonne C (US$ 2.00 per ton CO_2) at 2 years after logging (*Moura-Costa* and *Tay* 1996). Higher savings are expected in the longer term. All the incremental costs of training and implementation of the project were paid by NEP, who has full rights to the carbon savings. ICSB benefits from improved management of its forests, and a better residual stand after logging.

The first phase of the ICSB-NEP RIL project has created a positive momentum in the direction of achieving sustainable logging practices. The contract has been renewed and a second phase was initiated early 1996, which will consist of 9000 ha of RIL during a 3-year period. In 1996, NEP placed the project into the Edison Electric Institute Utilitree consortium, which will pay for 1000 hectares of RIL.

The Innoprise RIL CO_2 offset offerings are based on an explicitly commercial contract for services between two huge private sector entities. While there has been some modest assistance from third parties in developing the quantification methodologies, this project is comparatively unleveraged, i.e. the cost of the contract truly reflects the cost of the emissions savings. The project was initiated well before the development of the USIJI and other JI programs, and its contractual nature, involving arbitration, defined credit assignment, credit resale clauses, insurance and the like all point to a more business-like carbon offset arrangement. The project is also highly scaleable, given that Innoprise harvests between 10,000 and 20,000 hectares of its own concession holdings each year, and could easily transfer the techniques to other concessions which it is managing (though the costs and carbon estimates would clearly change). This is substantially different to project level investments, which tend to have much more defined parameters and are not necessarily able to expand quickly in case of market demand for the CO_2 offset service.

5. AIJ Pilot Phase: more uncertainty (1995–1996)

Growing dissatisfaction among G77 countries led to more concrete opposition to the JI model (*Stuart* and *Sekhran* 1996, *Stuart* and *Moura-Costa*, in press). Perceived problems included a feeling that JI was little more than a mechanism for industrialised countries to avoid addressing the real issues of reducing emissions at source, maintaining the economic advantage over developing countries. It was also felt that developing countries were in danger of transferring all their inexpensive GHG reduction opportunities to industrialised countries during this initial policy phase in which developing countries had no commitments to GHG emission reductions (and therefore during which such reductions were worthless at home). This brought forth older arguments regarding "terms of trade" which effectively critiques the unfairness of transactions where a commodity is only valuable to purchasing parties. Some developing country observers consistently referred to JI as "eco-colonialism". Moreover, developing countries would find themselves at a strategic disadvantage – if and when they were brought into the Climate Convention emissions limits process – as their most advantageous emission reduction opportunities would have already been exported.

These fears were consistently exacerbated by the announced price of offset projects, in which the calculated volume of credits (to be nominally transferred) was based upon the marginal costs of the intervention, without any rents accruing to the supplier. Often, the total volume of credits was sought, even though the claiming party had supplied, at most, only marginal costs. This overt lack of profit potential provided no commercial incentive for developing countries to supply offsets and reinforced the notion that carbon offsets are "win-win" for industrial countries only. Considering the proposed and discussed carbon taxes suggested at the time, which ranged US$25/ton C and upward (*Barrett* 1991), the nominal prices being paid for emission reductions (less than US$ 3/ton of carbon) at the time seemed a unbeatable bargain.

In the First Conference of Parties (CoP 1) in Berlin, March of 1995, developing country dissatisfaction was voiced as a formal refusal of JI with crediting against objectives set by the Convention. Instead, a compromise was found in the form of a pilot phase, during which projects were called Activities Implemented Jointly (AIJ). During the AIJ Pilot Phase, projects were conducted with the objective to establish protocols and experiences, but without allowing carbon crediting between developed and developing countries. This was meant to simulate the process of JI, giving substantive information to decision-makers in formulating the final system for emission transaction between countries and private entities.

However, the absence of credit transfer substantially dulled the appetite for participation among private sector parties in particular. The direct statement from Berlin – that current JI projects were not eligible for future crediting – meant that these were unrecoverable costs. Because of this lack of real incentives for the private sector (which most observers believe must eventually drive the trading system), the results of the AIJ pilot phase were generally considered poorly representative of the full potential of JI.

In this new environment, where companies were faced with even more uncertainty about the potential value of projects for their respective balance sheets, a great reduction in the level of investment in JI/AIJ-type projects was observed (Table 2). Only three new AIJ forestry projects were initiated during this phase, with an average yearly committed investment of US$ 6 million (down from US$ 50 million). The willingness to pay for carbon also reduced, down to an average of US$ 0.59 per ton C.

While few investments took place during this phase, the supply of "potential projects" continued to increase, as more parties perceived this to be a new source of capital for sustainable environment/development projects. In this context, calls for proposals were organised by various organisations including the World Business Council for Sustainable Development and the USIJI, which gathered dozens of project proposals to be considered for investment in the future. Potential investors included the Edison Electric Institute, and the E-7, a global association of mega-sized electric utilities. More JI/AIJ bodies were formed in many countries, including Canada, Netherlands, France, Germany, Switzerland, Norway, Australia and Japan. Several developing countries, including

Box 3: The Costa Rican system of direct payment for environmental services

Costa Rica is launching three national level innovative carbon sequestration programmes, two in forestry and a third in renewable energy. Commercialisation of CO_2 reduction credits is done through the sale of Certified Tradable Offsets (CTOs), the first security-like instruments backed by carbon offsets, which are issued by the recently created Costa Rican Office on Joint Implementation (OCIC – Executive Decree N. 25066 Minae, 1996). These CTOs are credits of carbon fixation based on the amount of CO_2 fixed in forests or emission reductions derived from their renewable energy plants. The first batch of CTOs (200,000 tons of carbon) was sold to a Norwegian consortium at US$ 10/ton C for a total of US$ 2,000,000.

The Private Forestry Programme (PFP), encourages land owners to opt for forestry-related land uses by providing direct payment for environmental services. Environmental services include CO_2 fixation, water quality, biodiversity, and landscape beauty [Forestry Law N. 7575, April 1996; *La Gaceta* (1996)]. The monetary incentives aim at increasing the attractiveness of forestry compared to higher impact forms of land use. Incentives are paid to land owners over a period of 5 years following the signing of a contract to keep their land under a specified type of utilisation for a minimum period of 20 years. Farmers who receive these incentives assign the rights of to the environmental services of the government, who bundles them for potential sale. The resources for initiating the PFP programme were raised by a domestics 15 % tax on fossil fuels, which is expected to raise US$ 21 million per year (*Franz Tattenbach*, pers. comm). It is hoped that future payments to farmers will be based upon successful sales of resultant CTOs. Due to the promising international market for carbon fisaxtion, this is the area that the government has focused its external marketing efforts.

The value of PFP incentives varies. There are three main areas of interest: conservation of existing forests, selective harvesting for sustainable wood production, and reforestation or natural regeneration of degraded pasture or agricultural land. In the case of private forest conservation, farmers receive U$ 56/ha/year for to a total of US$ 280/ha. They are also waived payment of land tax. Those opting for natural forest management receive US$ 47/ha/year, to a total of US$ 235/ha, in addition to the revenue derived from timber harvesting. In order to enforce compliance with low impact logging guidelines, the law requires that any harvesting operation must be supervised by a trained forester. Farmers who choose to reforest part of their agricultural land receive a series of payments related to the costs of plantation establishment, to a total of US$ 558/ha.

The institution co-ordinating the administration of the private sector incentives is called Fonafifo (Fondo Nacional de Financiamento Forestal – Forestry Financing Fund), an office created by the MINAE (Ministerio del Ambiente y Energia - Ministry of Energy and Environment). Fonafifo has the role of receiving and analysing applications, conducting field verifications, carrying out the payments, and monitoring field implementation of forestry projects.

Costa Rica is also working on a second national level land use project, called Protected Areas Programme (PAP), with the objective of reducing deforestation rates by consolidation of its national parks network. The programme aims at consolidating 570,000 ha within 28 national parks, and claim the carbon savings derived from avoided deforestation, which historically has averaged 3% per year. Costa Rica expects to avoid the release of about 18 million tonnes of carbon (66 m t CO_2) through the implementation of the PAP. These savings will be independently verified by the international certification company SGS Forestry, with the assistance of EcoSecurities, a specialist consultancy firm, and CTOs will be issued accordingly. At a projected price of US$ 10 per tonne of carbon, Costa Rica expects to raise US$ 180 million through the Protected Areas Programme. The sale of CTOs from the PAP will be done with the assistance of the Centre of Financial Products, possibly through Chicago Board of Trade transactions. In conjunction with the Earth Council, who is providing some of the catalytic finance for the PAP, Costa Rica will use a portion of those proceeds to finance construction of the Earth Centre, which is envisioned as a research/demonstration project highlighting various aspects of sustainable development and environmental values.

All of these Costa Rican programmes provide good examples of how could JI be utilised by developing countries to attract international investment into national priorities. The whole programme has been entirely conceived by the Costa Rican government and, consequently, totally conform to national priorities. While Costa Rica managed to secure catalytic funding for the initial phase of the PAP (provided by the Earth Council and the World Bank), all other costs will be borne by Costa Rica itself, who is also responsible for determining the sale price of CTOs. In this way Costa Rica maintains full control of the production costs and profits associated with the commercialisation of CTOs, which will be redirected into priority areas within the country.

Costa Rica, Guatemala and Sri Lanka, developed domestic AIJ offices to regulate projects from the perspective of the host country.

Although few transactions occurred, there was a growing feeling that some form of JI with crediting would inevitably arise, if developed countries were to commit themselves firmly to real targets. This led to a great increase in the level of interest in the subject, which was manifested world-wide in many forms, capturing the imagination of many economists, policy analysts and scientists. Multiple journals and Internet sites devoted to nothing but joint implementation topics. Innumerable papers, monographs and books began being written on the subject during this period. A variety of consulting "experts" now worked with different clients, developing projects, products, positions, strategies and services. Various business enterprises got organised to look for investment opportunities and formulate lobby strategies.

Nonetheless, only three carbon offset forestry projects were established during this phase (extending from 1994 until the end of 1996). These were: the second phase of the Reduced Impact Logging Project of New England Power, now with other co-investors (see Box 2); the EcoLand forest protection project in Costa Rica (a similar concept to the PAP project, see Box 3), developed by a Costa Rican NGO and a US Consultancy, Trexler and Associates, with US$1 million co-finance from Tenaska Inc.; and the Noel Kempff Climate Change Action Project in Bolivia, a forest conservation and management project developed by The Nature Conservancy and Fundacion Amigos de la Naturaleza, a Bolivian NGO, with funding from American Electric Power (in a later stage, this project also attracted funding from PacifiCorp and British Petroleum).

6. The run up to Kyoto (1997)

In the year preceding the Third Conference of Parties of the Climate Convention (CoP 3), to take place in Kyoto, December of 1997, there was great anticipation that some changes were imminent. Discussions during CoP 2, in Geneva in 1996, determined that binding commitments were going to be a central point in CoP 3. The consequences of these commitments were unknown but could be manifested in the form of carbon taxes, quotas, caps, etc., all of which would entail hard costs to industrialised economies.

In this phase of uncertainty, interesting moves have been observed in many sectors previously not involved in this field. Among electricity companies, there has been seen a preference for less carbon intensive energy sources, such as gas. *Manne* and *Richels* (1994) estimated that this business was already imputing a value of US$17 per ton of carbon. Several oil companies started to invest in a diversification of their energy matrix, pushing the flow of capital to the renewable energy industry. This can be illustrated by the rising of the solar energy sector and by specific investments such as British Petroleum's (BP) commitment to 1 billion dollars to the solar industry. Shell created its Shell Renewable International division, in the fifth core component of the organisation, with an initial investment budget of US$500 million for forestry, solar and biomass projects. Large car manufacturers, such as Toyota and Mercedes Benz, demonstrated numerous car models with lower GHG emissions, including fuel cell prototypes (*Greenhouse Issues* 1998). The International Automobile Association, the organisation responsible for Formula 1 competitions, decided to offset the GHG emissions of their events (*Tipper* 1997b, *Greenhouse Issues* 1997). The insurance and re-insurance sectors took climate change into consideration, and formed a group under the auspices of the UNEP.

It became obvious that third-party certification was instrumental in the validation and credibility of these new transactions. The first international certification agency to offer a service of independent verification of carbon offset projects was offered by the Swiss company Société Génerale de Surveillance (*Moura-Costa* et al. 1997), and other auditing firms are already considering offering similar services.

Four new forestry projects were initiated in 1997. These included two large national carbon offset programs in Costa Rica (see Box 3), the Protected Areas Project (PAP) and the Private Forestry Project (PFP), a 13,000 ha community forestry project in Mexico, financed by the International Automobile Association (*Tipper* 1997a); and a community forestry project for fuel-wood production in Burkina Faso, financed by the Government of Norway through the World Bank. While the level of investment remained low (US$ 4.5 million per year), the price paid for carbon raised to an average of US$ 12 per ton C.

7. The Kyoto protocol and after

In December 1997, 170 countries signed the Kyoto Protocol during the CoP 3 of the FCCC. The most important aspect of the Kyoto Protocol is the adoption of binding commitments by 37 developed countries and economies in transition (collectively called the Annex 1 countries) to reduce their GHG emissions in an average of 5.2 % below the year 1990 until the years 2008–2012 (Kyoto Protocol, 1997; web site http://www.unced.de). At the same time, the Protocol approves the use of 3 "flexibility mechanisms" for facilitating the achievement of these GHG emission reduction targets. These are:

1. QUELRO (Quantified Emission Limitation and Reduction Obligations) trading, allowing the international transfer of national allotments of emission rights;
2. joint implementation, the creation of emissions reduction credits undertaken through transnational investment between industrial countries and/or companies of the Annex 1 (note that according to the new terminology, JI includes participation only of Annex 1 countries, which are OECD and the former Soviet block); and,
3. The Clean Development Mechanism (CDM), a new mechanism resembling JI, which allows for the creation of Certified Emission Reduction (CER) credits in developing countries, regulated by a newly formed central authority.

Another important output of the agreement is the recognition of forestry activities as valid options for reducing net concentration of atmospheric GHGs. While the language of the Protocol is somewhat contradictory regarding what types of activities are allowed and by what parties, it is finally clear that forestry sinks will be part of the equation. For a review of these issues, see *Schlamadinger* and *Marland* (1998).

The Kyoto Protocol appears to be a real truly international step in the GHG emissions mitigation arena. Overall, what emerged was what business oriented climate activists have always hoped for; a compromise between substantial emissions reduction targets and a fluid market mechanism under which to achieve those emissions reduction requirements. The protocol opened for signature on March 16, 1998 and will close one year later on March 15, 1999. It becomes legally binding ninety days after the fifty-fifth government ratifies it, assuming that those 55 countries account for at least 55 per cent of the emissions of the developed countries in 1990. As of July 1998, 48 countries have signed it.

The establishment of binding commitments has led to a more substantial demand for offsets. *Sandor* (1997) estimated that, for the US alone, the costs of reduction of GHG emissions to the levels 10 % below 1990 is in the range of US$ 32 billion a year. If these targets were partially accomplished through GHG emissions trading, this would generate an American demand for GHG Emission Reduction Units in the order of US$ 6 billion a year, a huge increase from the voluntary demand of the pre-Kyoto phase. Another change in demand specification regards the quality of offsets. According to the Kyoto Protocol, all ERU generated outside capped Annex 1 countries will have to be independently certified, creating a potentially high demand for this type of service.

Associated with the endorsement of emissions trading concept, there has been an immediate response in the, still incipient, carbon market. In less than 8 months after the Kyoto Protocol, a variety of initiatives were announced. These include: the creation by BP of a voluntary cap on its internal emissions associated with an internal trading system; the investment by BP in forestry-offset projects in Bolivia; the development of a forestry conservation project in Brazil, by AES; the creation of a consumer-based scheme to offset the emissions of petrol usage through forestry activities, promoted by Tesco petrol stations in UK (*Greenhouse Issues* 1997); and Green Fleet, a similar consumer-based initiative to offset car emissions through forestry activities in Australia.

The supply of offsets has begun to get more organised, and offer more sophisticated financial instruments. This is the case of the Costa Rican national programme, the first to produce carbon denominated securities (CTOs – Certified Tradable Offsets; Box 3). This system has been used by New South Wales State Forests, a state organisation which sold the carbon sequestration services of some of its plantations in the form of CTOs to Australian power companies in late June 1998. At the same time, the World Bank announced its intention to launch the first carbon offset investment fund (*JIQ* 1997), which will have initial capitalisation of US$ 150 million.

At the same time that supply and demand is becoming more organised, it becomes apparent that market mechanisms and supporting infrastructure also have to develop to support the expected level of transactions. A number of initiatives aim at supporting this market, such as the GHG tradable permit trading mechanism co-ordinated by the UNCTAD (*UNCTAD* 1992, 1994, 1995); and the GHG emissions trading programme proposed by the International Petroleum Exchange (*IPE* 1998).

These new conditions greatly increased the attractiveness (and reduced the risks) of investment in forestry-based carbon offset projects, resulting in an immediate rise in the level of investment, and in the price paid for carbon credits, which reached up to US$ 20-25/ton, in the case of the World Bank carbon fund.

8. Ways forward for the forestry sector

To date, several million ha of forests world-wide are under forest management regimes related to GHG mitigation funding. According to the IPCC (*Brown* et al. 1996), forestry has the potential of offsetting approximately 15 % of the world's GHG emissions, a partial solution to the overall problem. If this investment trend continues, we may see a huge infusion of new capital into the forestry sector, which will have enormous importance in addressing some of the topical issues of sustainability and conservation of biodiversity.

For this to occur, however, more mature markets have to develop. We are still a long way from a price denominated CO_2 credit market determined by equilibrium of supply and demand. Significant transactions will never occur if the model remains that of emitters putting forth calls for proposals, which are answered haphazardly by a combination of environmental, social development and business interests. The direct linkage between supply and demand must be broken and the commodity must become more homogenous. It can no longer be the case that production of this novel commodity only occurs when a downstream client makes a direct investment in the "factory" creating the good.

For forestry professionals, the next steps in this process require that they begin formally recognising the potential of emission reductions in their planning process. They can then develop verifiable volumes of emissions reduction outputs through the capital allocation process. Forest output optimisation will eventually develop a new production possibility boundary, based on relative values of the main output (forest products) together with the associated carbon sequestration potential (for a discussion, see *Boscolo* and *Buongiorno* 1997). Once a more detailed understanding of the production process comes on line, more sophisticated emissions reduction services will emerge and there will likely be a bloom of structured financial instruments based on this value. For this to occur, however, policies must emerge – sooner, rather than later – that better define the acceptable quality range of the commodity. That said, however, the forestry community would be immediately well served to more actively participate in the current debate, so that the most rational policies from a sustainable forestry perspective do ultimately emerge.

In large part, this futuristic model reflects an expansion of the current mechanisms within the Costa Rican national programme, which provided the first true break between supply and demand, reduced transaction costs and the development of standardised instrumentation regarding carbon flows. However, smaller and private organisations are less likely to be able to dedicate similar internal resources to invent similar products. We expect that a new class of forestry investors may arise, speculating in the environmental performance of new varieties of forestry projects, according to anticipated markets for verifiable GHG commodities. This may well be the next market evolution, where emitter-based or internal financing gives way to venture capital financing, based on perceived future market evolution. Forestry professionals need to prepare to meet this new world, armed with information and with a recognition that they may control a valuable commodity in a greenhouse-gas enhanced world.

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Quantifying Carbon Offsets in FACE Reforestations

Igino Emmer

Abstract

This contribution will deal with the current approach of the Face Foundation to quantify carbon sequestration, utilising the following techniques:

1. Calculation of tree growth using the model CO_2FIX which is parametrised to obtain conservative estimates.

2. Mapping of Face biotic offset projects using Satellite remote sensing.

3. Calculation of carbon offset schedules for individual projects and portfolios.

These 3 topics will be explained with examples from 'the real world'.

In addition, for the reason that the Face Foundation has entered into a certification procedure, the requirements set by the certifier to obtain so called Carbon Offset Verification (approval of the carbon offset schedule) will be outlined.

The contribution will include issues such as cost-effectiveness, baselines and 'CO_2-offset as a product'.

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Afforestation, Reforestation and Deforestation: A Review for EU Countries and Nordic Countries

Timo Karjalainen

Summary

An important step towards meeting the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) was taken in the third conference of the parties of the UNFCCC in December 1997 in Kyoto, Japan. In the so-called Kyoto Protocol, concrete emission limitation and timetabled reduction commitments for the Annex I countries (countries included in the Annex I to the UNFCC) were agreed. The protocol allows the use of some forestry related activities to meet the commitments. According to the Kyoto Protocol, parties can use the balance between greenhouse gas emissions from the sources and removals by the sinks that result from direct human-induced land use change and forestry activities to meet their commitments. These activities are limited to afforestation, reforestation, and deforestation since 1990 (such forests are called here "Kyoto forests").

The possible role of forests in helping to meet commitments of the Kyoto Protocol was studied by European Forest Institute as part of the European Topic Centre Nature Conservation work for the EEA report "Environment in the EU at the turn of the century", as well as in the study for the Nordic Council of Ministers. This presentation shows the main results of the mentioned studies.

The area of forests that can be classified as "Kyoto forests" in many EU countries constitutes only a small proportion of the area of managed forests. Because they are a small and particular sub set of forests, the carbon stock changes in "Kyoto forests" can be very different in magnitude and even of opposite sign to that in the managed forests as a whole. Thus, the total carbon sink of tree biomass in EU countries calculated from forest statistics for 1995 was equal to about 6 % of the EU anthropogenic CO_2 emissions. However, depending which definition of reforestation is applied (IPCC or FAO), the carbon sink of tree biomass in "Kyoto forests" was equal to only 0.1–1 % of these emissions. For some countries "Kyoto forests" showed carbon source, while forest statistics showed there should be a carbon sink. For example in Sweden, Finland and Norway, carbon sink of the tree biomass was equal to 80, 40 and 30 % of the anthropogenic emissions, while "Kyoto forests" were either sink or source depending of the applied definition for reforestation. Nevertheless, whichever approach is used, it is clear that carbon sequestration in forests can only form a small part of the overall EU commitments to reduce greenhouse gas emissions during the first commitment period 2008–2012.

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Cryptic Impoverishment of Amazonian Forests through Logging and Fire

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AMAZON deforestation rates are used to determine human impacts on the global carbon cycle[1–3] and to measure Brazil's progress in curbing forest impoverishment[1, 4–8]. But this widely-used measure of tropical land use tells only part of the story. Here we report that the estimates of annual deforestation for Brazilian Amazonia, where one third of the world's tropical forests are found, capture less than 60 % of the total forest area that is impoverished during years of average rainfall, and even less during years of severe drought. Our field studies of wood mills and forest burning across Brazilian Amazonia show that logging crews and ground fires in standing forests severely damage 10,000 to 15,000 km^2 yr^{-1} of forest that are not included in deforestation mapping programs, rising to >20,000 km^2 in years of severe drought. These "cryptic" forms of impoverishment increase forest vulnerability to future burning 9–11 and release forest carbon stocks to the atmosphere, thereby increasing by at least one sixth previous estimates of net carbon emissions from Amazonian land-use[1]. Forest ground fires can increase dramatically when severe droughts provoke forest leaf-shedding, and greater flammability. Our regional water balance model predicted that ~980,000 km^2 of forest became vulnerable to fire in the 1998 dry season. Both logging and fire increase forest vulnerability to future burning and release forest carbon stocks to the atmosphere, potentially doubling net carbon emissions from Brazilian Amazonian land-use during severe El Niño episodes. There is an urgent need to either restrict logging activities or replace them with low-impact timber harvest techniques, and for more effective strategies to prevent accidental forest fire in Amazonia.

Human uses of tropical forests vary greatly in their intensity. Ranchers and farmers "deforest" land in preparation for cattle pasture and cropland formation by clear-cutting and burning patches of forest. Loggers harvest or damage a subset of the trees in forest tracts, while rubber tappers and other extractivists use the forest at very low intensity through the harvest of animals, fruits, latex and other "non-timber products"[12–15]. Deforestation has a greater impact on forest carbon content, forest hydrology, and the diversity of native plant and animal species than other forest uses[13 19] and has become the main parameter by which human effects on tropical forests are measured. Part of the appeal of this forest vs. non-forest approach to assessing human impacts on tropical forests is its tractability. Forest conversion to agriculture is readily monitored from space using imagery from the Landsat Thematic Mapper satellites, permitting the development of deforestation maps of large regions at a reasonable cost and speed[4–8].

This binary approach to the analysis of human impacts on tropical forests neglects those forest alterations that reduce tree cover, but do not eliminate it, such as logging and surface fires in standing forests. The forest openings created by logging and accidental surface fires are visible in Landsat TM images, but they are camouflaged by the crowns of residual live trees, are often covered over by regrowing vegetation within 1 to 5 years, and are therefore easily misclassified without accompanying field data[20, 21].

Although logging and forest surface fires usually do not kill all trees, they severely damage forests. Logging companies in Amazonia reduce or damage 10 to 40 % of the living biomass of forests through the harvest process[13, 14, 22]. Logging also increases forest flammability by reducing forest leaf canopy coverage 14 to 50 %[11, 13, 14, 22, 23], allowing sunlight to penetrate to the forest floor, where it dries out the organic debris fuels created by the logging. Fires ignited on agricultural lands can penetrate logged forests[11, 23 24], killing 10 to 80 % of the living biomass[9, 10, 23] while greatly increasing the vulnerability of these forests to future burning[9, 10, 25]. Fires from agricultural lands can also penetrate those undisturbed forests that have lost portions of their leaf canopies because of severe seasonal drought[25].

We estimated the area of Brazilian Amazonian forest that is impoverished each year through logging by interviewing 1393 wood mill operators, representing more than half of the mills located in 75 logging centers (Table 1); these logging centers are responsible for >90 % of Amazonian timber production. In each interview, we obtained the mill's harvest records of roundwood (tree boles) for 1996 and 1997 and the harvest rate (m^3 of timber per ha of forest), thereby calculating the forest area required to supply each center's timber production. The accuracy of the roundwood harvest rates reported by mill operators was tested by comparing these interview data with direct measurements of roundwood harvest in ~100-hectare forest plots that had been harvested at low (n = 12)[13, 26], moderate (n = 7, unpublished data, Tropical Forest Foundation) and high (n = 3)[14] harvest intensities. In each comparison, harvest rates measured directly in the forest were within the 95 % confidence interval of the average harvest rates reported by mill operators in the nearest logging center. Mahogany mills were excluded from this study because their impact on the forest is very small compared to other types of logging, and the volume of mahogany extraction is <5 % of total Amazonian production[22].

The area of standing forest subjected to surface fire each year was assessed by

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interviewing 202 landholders in five regions along a 2,200-km transect through the states of Para, Mato Grosso, Rondonia and Acre. The properties had a total area of 9,200 km², and were randomly selected within each of four size class categories. The number of properties within each size class was chosen to reflect the size class distribution of properties in each study region. In each interview, the landholders drew onto satellite images the forest areas on their property that had been deforested and the forest areas that had burned by surface fire (without prior forest felling), for 1994 and 1995. The accuracy of these landholder maps was tested by comparing them, in one study region, with a 1995 Landsat TM image. Forest surface fire scars were identified within the image by analysis of spectral characteristics[21], and areas of deforestation were identified visually. Within the 640 km² test area, all of the forest surface fires and deforestation burns reported by landholders were detected in the Landsat image. However, the landholders underestimated the area of surface fires by 43 % and of deforestation by 48 % ($p < 0.001$, sign test). For the purpose of this study, landholder errors in the reporting of forest surface and deforestation fires were considered equal. We also tested the accuracy of the interview data by visiting one out of every six burned forests reported by landholders.

We estimate that 10,000 to 15,000 km² of undisturbed forest were logged per year in 1996 and 1997 by the 2,533 wood mills operating in the Brazilian Amazon, based on the 95 % confidence interval of the harvest intensities reported by mill operators. Hence, annual logging in these years affected a forest area that was 50 to 80 % as large as the area deforested in 1996[7] (Table 1). Virtually all of the forests of eastern Amazonia lie within the average harvest distance of logging centers in Para and Maranhão states, and are being harvested at high (40 m³ ha⁻¹) and moderate (28 m³ ha⁻¹) intensities (Figure 1a). Logging activity is also vigorous in the southern Amazonian states of Mato Grosso and Rondônia, at moderate and light (19 m³ ha⁻¹) harvest intensities (Figure 1a).

The total area of standing forest on the study properties that experienced surface fire in 1994 and 1995 (310 km²) was 1.5 times greater than the area that was deforested in those years (200 km²), according to landholder interviews. At the regional level, the ratio of forest surface burning to deforestation ranged from zero in Acre, the study region with the mildest dry season and lowest rate of logging, to 4.6 in Santana do Araguia, southern Pará, the study region with the most severe dry season. The other ratios were 1.4, 0.4, and 0.1 in Mato Grosso (Alta Floresta), eastern Para (Paragominas) and Rondônia (Ariquemes), respectively. We made a preliminary estimate of the area of forest experiencing surface fires in the states we studied by multiplying these ratios by the satellite-based estimates of annual deforestation in 1993 through 1995[6]. This calculation suggests that approximately 25,000 km² of forest may have experienced surface fire each year in 1994 and 1995 (Table 1).

Table 1: Estimates of the area of forest affected by logging and forest surface fire for the states of the Brazilian Amazon. Logging information is based on field interviews of more than half of the region's 2,300 wood mills and estimates of the area of surface fire in standing forests is based on 202 interviews of land holders. Logging centers, by our definition, produce at least 100,000 m³ of roundwood each year, and are responsible for >90 % of Brazilian Amazonian roundwood production. At least 43 % of the mills in each logging center were interviewed. Based on this sample, we estimated the percentage of roundwood production in each state that was harvested at low (19 m³ ha⁻¹), moderate (28 m³ ha⁻¹) and high (40 m³ ha⁻¹) intensities.

State	Total logging centers	Total mills	Mills studied (%)	Roundwood production (10⁶ m³)	intensity of logging[1] (% of production) Low	Moderate	High	Logging[2] 1996-97	Fire[3] 1994–95	Deforestation[4] 1993–95	Deforestation[4] 1996	Original forest area[4] (km²)
Acre	1	25	55	0.3	100	0	0	120-210	~0	720	430	152,394
Amapa	2	89	80	0.2	100	0	0	80–140	n.d.	0	0	137,444
Amazonas	3	20	60	0.7	100	0	0	290-500	n.d.	950	1,020	1,531,122
Maranhao	2	52	49	0.7	0	45	55	160-200	n.d.	830	1,060	145,766
Mato Grosso	22	708	48	9.8	100	0	0	4,080-7,000	5,300	7,610	6,540	527,570
Para	24	1,324	43	12.9	11	70	19	3,560–4,910	3,800	5,470	6,130	1,183,571
Rondonia	19	272	55	3.9	35	65	0	1,320-1,920	2,300	3,310	2,430	212,214
Roraima	1	25	52	0.2	100	0	0	80–140	n.d.	230	210	172,425
Tocantins	1	18	53	0.1	100	0	0	40-70	n.d.	490	320	30,325
Total	75	2,533	55	28.8	49	41	10	9,730–15,090	11,400	19,610	18,140	4,092,831

[1] Low intensity logging = 19 (14–24) m³ ha⁻¹; moderate intensity = 28 (24–32) m³ ha⁻¹; high intensity = 40 (35–45) m³ ha⁻¹. Average and 95 % confidence interval.

[2] See text for explanation.

[3] Estimated by multiplying the annual area of deforestation of each state for 1993-95 by (forest surface fire area)/(deforestation area), calculated from landholder interviews. The values for Para' state were calculated with and without the very high ratio of forest surface fire to deforestation (4.6) obtained in the Santana do Araguaia study region.

[4] INPE 1996, 1997

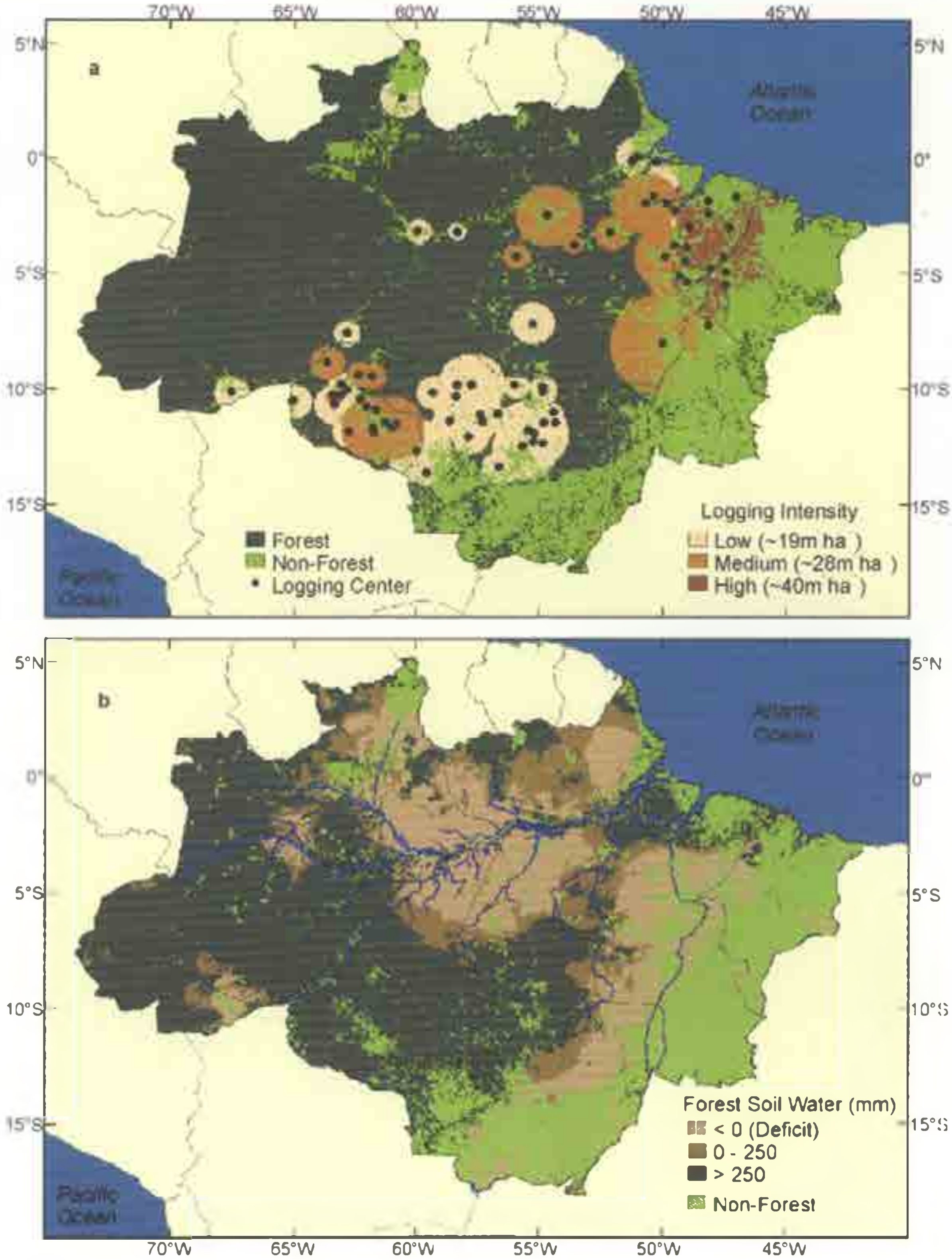

Fig. 1: The geographical patterns of forest logging and severe soil water deficits in Brazilian Amazonia. a. Forest regions in Brazilian Amazonia that lie within the average extraction distances of 75 logging centers which account for >90% of Amazonian timber production. Extraction intensities are "Low" (19 m3 ha^{-1}), "Moderate" (28 m^3 ha^{-1}) and "High" (40 m^3 ha^{-1}). State boundaries of the Brazilian Amazon and national boundaries of neighboring countries are displayed. Paragominas is located near the center of the region of high logging intensity. b. Predicted forest soil water content to ten meters depth, at the end of the 1998 dry season (December 31). Forests with <0 mm (deficit) will have depleted all plant-available water in the upper ten meters of soil and are predicted to be highly vulnerable to fire. Roraima is the northernmost state of Brazilian Amazon.

If we exclude the very high ratio measured in Santana do Araguaia, our estimate drops to 13,000 km² per year. Most of the forests that experienced surface fire had already been logged in Paragominas and Rondônia, but large areas of undisturbed forest burned in Santana do Araguaia and Mato Grosso.

The area of forest surface fires may be much larger during periods of severe drought, such as occurred during the 1997–98 El Niño Southern Oscillation (ENSO) episode when 9,000 km² of standing forest burned in the northern Amazonian state of Roraima alone[28]. We assessed the potential for further large-scale, drought-induced Amazonian forest burning as a result of this ENSO episode using a regional water balance model, in which water stored in the soil is depleted by forest evapotranspiration and replenished by rain, and forests become flammable when soil water is exhausted. The model tracks soil water beginning on May 1, 1997, the onset of the 1997 dry season, when we assume that the soil was fully charged with water. Amazon forests can tap the water stored in deep soil layers to maintain evapotranspiration during periods of low rainfall[17,29]. We estimate that forests become flammable only when soil moisture is depleted to ten meters depth, based on field studies of soil moisture, leaf shedding[17], fine fuel moisture, and the propagation of experimental fires (*M. Cochrane, D. Nepstad, E. Mendonza, F. Brown, J. Guerreros*, unpublished data from three Amazon forest types). The maximum amount of plant-available water that can be stored in the soils was calculated for the forested areas of Brazilian Amazonia using soil texture data from 1147 soil profiles[29–31]. Rainfall data through December 30, 1998, were obtained from 60 automated weather stations scattered across Brazilian Amazonia, which also provided air temperature data that we used to estimate potential evapotranspiration (*INPE*, unpublished data).

ENSO-related drought can desiccate large areas of Amazonian forest, creating the potential for large-scale forest fires. Because of the severe drought of 1997 and 1998, we estimate that approximately 980,000 km² of Amazonian forest had completely depleted plant-available water stored in the upper ten meters of soil by the end of the 1998 dry season. An additional 570,000 km² of forest had exhausted all but 250 mm of plant-available soil water by this time (Figure 1 b). The largest concentration of these potentially flammable forests is in eastern Amazonia in the vicinity of Marabá, Pará state, where ranching and farming activities provide abundant sources of ignition to fire-vulnerable forests. This is also the region of greatest logging activity (Figure 1 a). We estimated the areal extent of forest surface fire in the vicinity of Marabá by measuring forest status from an airplane at 1104 sample points along 750 km of transects in southeastern Pará state, late in the 1998 dry season. In 39 percent of the forest that we flew over, ash could be seen in the understorey. Approximately 10 % of the 45,000-km² study area was recently-burned, standing forest.

Forest impoverishment through logging and surface fire causes a significant release of carbon to the atmosphere that is not included in existing estimates of the Amazonian carbon balance[1,32,33]. Logging kills or damages approximately 10, 20 and 40 % of living forest biomass for light, moderate and high intensities, respectively, with approximately one fourth of this biomass reduction converted into long-lived wood products[1,13,14,22]. By comparison, deforestation reduces biomass by 94 % of the original forest value[1]. We made a preliminary estimate of the carbon released from logging by multiplying the area of logging within each harvest intensity class (low, moderate and high) (Table 1) by a biomass reduction of 5, 10 and 20 % (assuming that half of the biomass that is killed or damaged either remains alive or makes its way into long-lived wood products). In 1996, logging released approximately 4 to 7 % of the net annual carbon release estimated for deforestation in the Brazilian Amazon (ca. 0.3 × 109 Mg yr⁻¹)[1]. When logged forests are burned in Amazonia, two field studies have found that 10 to 80 % of the remaining live forest biomass is killed[9,23]. If we assume that all forest surface fires take place in forests that were logged at moderate intensity, and that these fires kill an average of 10 to 20 % of remaining live forest biomass, then surface fires in years of average rainfall release an amount of carbon that is 7 to 24 % that of deforestation (using high and low estimates of the area burned, Table 1). Although additional research is needed to refine these preliminary estimates, it is clear that logging and surface fire combined release globally significant amounts of carbon to the atmosphere, at a scale of approximately one tenth to one third of the emissions released through deforestation.

Cryptic forest impoverishment can virtually eliminate undisturbed forest in regions with seasonal drought and high concentrations of wood mills, such as Paragominas in eastern Amazonia. Thirty years after settlement, 62 % of the land surface in a 3,600 km² area surrounding Paragominas is classified as "forested" using conventional deforestation mapping techniques (Figure 2 a); one half of this land surface is mandatory forest reserve on private land. But when we map those forests that have been logged or burned (based on our interviews of landholders and detection of logging and forest fire scars in Landsat TM images[10,21]), we find that only 6 % of this area supports undisturbed forest (Figure 2 b). This "cryptic" forest impoverishment may be even more common in other Amazonian regions. Landholders reported a higher incidence of forest surface fires in southern Pará and Mato Grosso, where seasonal drought is more severe than in Paragominas.

Satellite-based deforestation monitoring is an essential tool in studies of human effects on tropical forests because it documents the most extreme form of land-use, over large areas, and at low cost. But this monitoring must be expanded to include forests affected by logging and surface fire if it is to accurately reflect the full magnitude of human influences on tropical forests. Large-scale tropical forest burning during severe drought episodes may impoverish vast areas of these species- and carbon-rich ecosystems. Large areas of tropical forest in Amazonia[16], Indonesia, Malaysia, Congo and Mexico are subjected to seasonal drought which, if exacerbated by increasingly frequent ENSO episodes[34], could render these forests vulnerable to large-scale conflagrations, damaging timber and wildlife, releasing carbon to the atmosphere, provoking respiratory ailments, and increasing the likelihood that these impoverished forests will burn again. These considerations point to the

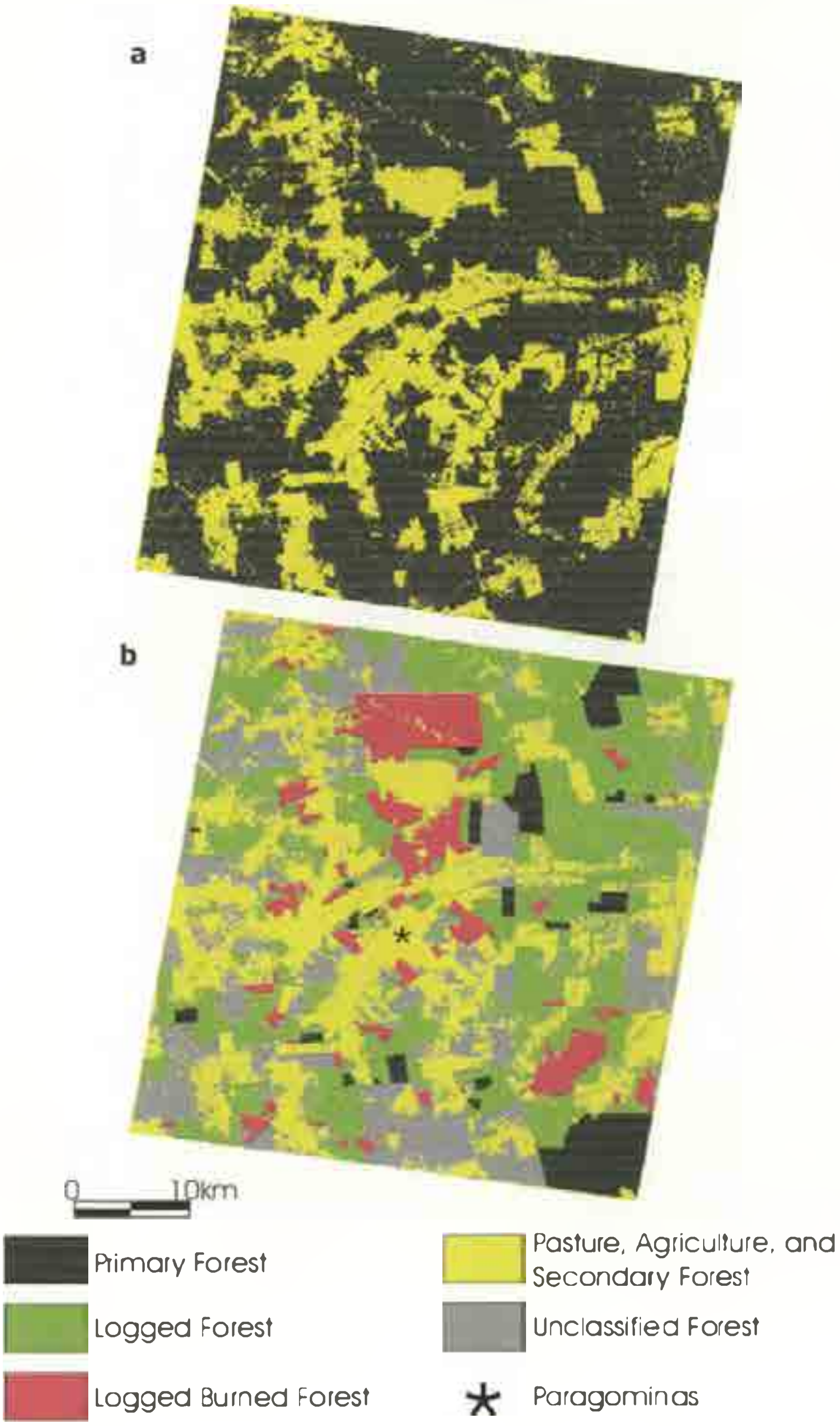

Fig. 2: Map of forest cover in the vicinity of Paragominas, northeastern Pará State. a. Landsat TM image, 1991, classified as non-forest (pasture, agriculture, secondary forest) and forest. This type of classification is the basis of the Brazilian government's deforestation estimates[4–7]. According to this analysis, 62 % of this landscape supports forest. b. The same Landsat TM image with data from interviews of ranch owners and areas of selective logging detected in the image[10,21], showing the area of forest that has been logged and burned. According to this analysis, only 6 % of this landscape supports undisturbed forest.

urgent need to replace conventional logging practices in moist tropical forest regions with low-impact harvest techniques[22,35,36], and to encourage cost-effective investments in the prevention of accidental forest fires by Amazonian farmers and ranchers[37]. Both of these changes are unlikely to occur unless access to these forest lands provided by expanding roads, electrical grids and water transport systems is sharply curtailed[36].

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Forests in Africa: Options for Sustainable Development and Climate Change Mitigation

Peter G. H. Frost

Abstract

Africa supports almost 16 % of the world's natural forested land and 35 % of other wooded, non-forest, lands. Together, these account for about 16 % of the global total aboveground biomass. Between 1980–1990, forest and other wooded lands in the African tropics declined by 0.35 % p.a., representing an annual rate of conversion of 2.33 Mha to other land cover types and an average annual release of at least 203 Mt carbon to the atmosphere. The greatest reductions are occurring in tropical southern and Central Africa where the annual rates of loss are 0.74 and 0.57 Mha yr^{-1} respectively. Much of the loss in southern Africa is the result of conversion to agricultural land, whereas in Central Africa it is associated with deforestation due to logging of tropical forests and to shifting agriculture. This paper focuses primarily on the potential for carbon offset and climate-change mitigation initiatives in tropical southern Africa in the context of the Kyoto Protocol, though many of the issues raised are more broadly applicable throughout the continent.

The predominant vegetation across tropical southern Africa is *miombo*, a mix of dry deciduous forests and woodlands in which the dominant trees show remarkable physiognomic and floristic uniformity. Average aboveground carbon density is about 41 Mg C ha^{-1} (range: 30–66 Mg C ha^{-1}) in wetter regions (1000–1400 mm rainfall p. a.), to 25 Mg C ha^{-1} (range: 10–35 Mg C ha^{-1}) in the drier parts (600–1000 mm rainfall p. a.). The woody component accounts for more than 95 % of these amounts. The limited information on root biomass suggests that about the belowground carbon pool ranges from 5 to 35 Mg C ha^{-1}. Average soil carbon densities range from 61 Mg C ha^{-1} in relatively shallow soils underlying dry *miombo* to 129 Mg C ha^{-1} in the deeper soils under wet *miombo*. The estimated average carbon pools in dry and wet *miombo*, excluding the transient litter pool, are therefore about 99 to 192 Mg C ha^{-1} respectively.

Most *miombo* tree species regenerate vigorously from root stocks after being cut. Recorded mean annual increments in biomass in coppiced woodland are 2.2–3.4 Mg ha^{-1} yr^{-1} in wet *miombo* and 1.4–1.6 Mg ha^{-1} yr^{-1} in dry *miombo*, representing a potential rate of carbon sequestration in aboveground biomass of 0.6–1.5 Mg C ha^{-1} yr^{-1} depending on rainfall and site conditions. There is no information on root biomass increments or the rate at which soil carbon accumulates on abandoned disturbed lands. The rates of growth of exotic tree species grown in village woodlots is similar to the rates of growth of indigenous species, but higher rates are recorded under experimental conditions where appropriate, but costly, management can be consistently applied.

Given that local people depend on a wide diversity of goods and services from indigenous woodlands, and given the experience in the region with initiatives designed to encourage sustainable use and management of woodland resources, there would seem to be much potential for projects aimed at securing benefits related both to sustainable development and climate-change mitigation. Such projects could include initiatives aimed at protection of regenerating woodlands from premature harvesting and damage by fire; the application of low-impact logging and post-harvest management of logged areas; agricultural intensification, aimed at reducing the need to expand cultivation of agriculturally-marginal lands; and further establishment of plantations, among others. There is an understandable asymmetry in the balance of objectives of the proponents and hosts in such collaborative projects. For them to succeed in the long term, it is imperative that effective ownership is transferred to, and is willing assumed by, local communities. For this to happen, the benefits to the communities concerned must be significant, tangible, relatively immediate, and fairly and equably distributed. The potential for leakage is high given the communal nature of land tenure over much of the region. Some projects may also carry significant risks to the conservation of biodiversity. Threats to the durability of these climate-change mitigation projects lie in the highly dynamic and often unpredictable social, political, economic and environmental changes that currently characterize the region. These and other issues are discussed and the feasibility of the range of initiatives assessed.

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Deforestation and Climate Effects

Yongkang Xue

Many areas in the world have been experiencing land surface degradation during the past century. Anthropogenic effects, such as over-exploitation of land resources by means of overgrazing, poor irrigation, and the destruction of woody vegetation, have played an important role in this process. For example, the major desertification processes in northern Africa are manifested in degradation of the vegetation cover and accelerated water and wind erosion (c.f. *Gormitz*, 1985). Such land degradation processes have occurred in conjunction with rapid population growth in the region over the last 50 years. Similar degradation has also been observed in China (*Xue*, 1996).

There are significant climate anomalies in conjunction with the desertification in these areas. In tropical northern Africa, since the late 1960s, the Sahelian region has experienced the longest drought in this century (*Xue* and *Shukla*, 1993, *Xue*, 1997). Data over mainland China from 1951 to 1990 reveal that China has been drying since the 1950s (*Xue*, 1996).

Many studies with different models have been conducted to investigate the role of biosphere feedback on climate anomalies. In this paper, I will only present the results from the Sahel studies.

In addition to long term drought, there are several characteristics of the Sahel region that have contributed to its importance in desertification-atmosphere interaction research. The Sahel climate is dominated by the monsoon system, which is generated by thermal gradients. Any changes in the gradients may substantially affect the monsoon flow. The boundary conditions modify the diabatic heating (latent and radiative heating), which in turn changes circulation and rainfall at seasonal and interannual time scales. The continental scale land mass and relative flat orography (excluding eastern Sahel) warrant that such land surface characteristic-atmosphere interaction play a major role in the regional climate and also make such interactions relatively easy to detect in model simulations.

In earlier studies, simple surface – layer models are used for sensitivity studies. Only a single land surface parameter is tested each time. Albedo is the first land property variable used for interaction study (*Charney*, 1975). In the desertification area, surface albedo becomes higher, which results in more reflected short wave radiation from land surface to space. Land surface loses radiative energy. Therefore, it typically reduces the heat fluxes to balance the energy budget at the surface. The atmosphere becomes cooler in response to the changes in surface condition. Sinking motion therefore is produced, which reduces the rainfall. Although the simulation results from albedo hypothesis are consistent with the drought in desertification area, there is an obvious problem if only albedo effect (without surface water cycle change) is considered. In simulations with increased surface albedo, in addition to reduced precipitation, high surface albedo also produces cool surface temperature due to less net radiation at the surface, which contradicts to observations: higher temperature is always associate with desertification.

To further this study, the effects of soil moisture and hydrological cycle have also been investigated. (For example, *Walker* and *Rowntree*, 1977). Most studies show that less initial soil moisture would lead to less precipitation due to reduced moisture source. Furthermore, cloud is also reduced as there is less surface evaporation. More short wave radiation reaches the ground, which increases the net radiation at the surface. High net surface radiation and reduced evaporation cause high surface temperature. The combined effects of surface albedo and soil moisture have also been studied (for example, *Sud* and *Molod*, 1988). These modeling studies consistently demonstrate that land surface had a significant impact on the Sahel climate.

Real atmosphere-biosphere interaction processes are, however, much more complex and involve many parameters. Therefore, sophisticated land surface models are needed to realistically assess the impact of desertification on the Sahel drought. With coupled biosphere-atmosphere models, land surface conditions can be changed more realistically than in previous experiments. More simulations of real climate anomalies and a better understanding of the influence of land-atmosphere interactions are the main goals in these studies.

To explore the impact of land degradation in the Sahel on seasonal climate variations and soil water balance, the coupled Center for Ocean-Land-Atmosphere (COLA) GCM/Simplified Simple Biosphere Model (SSiB) model has been integrated over several multi-year periods, using different initial atmospheric conditions (*Xue*, 1997). COLA GCM is a global spectral model and has been used for many climate studies (*Kinter* et al., 1996). SSiB is a biosphere model for global and regional climate studies (*Xue* et al., 1991). The size of each grid box in the COLA GCM is approximately 1.8 degrees (latitude) × 2.8 degrees (longitude). Climatological sea surface temperatures (SST) are used as the lower atmospheric boundary conditions over the oceans.

For numerical simulations, a world vegetation map is read into the coupled surface-atmosphere model to provide the land surface conditions required by SSiB. Twelve vegetation types are recognized by SSiB, including trees, short vegetation, arable crops, and desert. Different vegetation and soil properties, including surface albedo and leaf area index are defined for each vegetation type. For land surface degradation simulations, the normal vegetation types in a specified degradation area are changed to shrubs with bare soil (a result of land degradation), altering the prescribed vegetation and soil properties. The selections of the degradation area, which are enclosed by the heavy lines in Figure 1 b, are based on currently

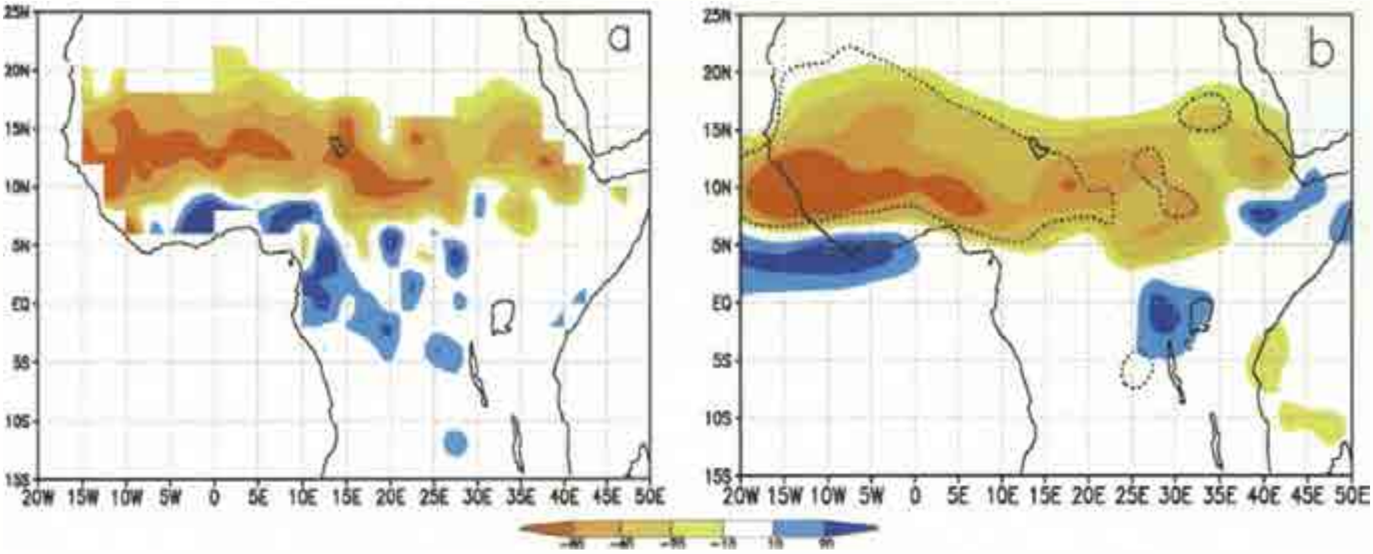

Fig. 1: JAS rainfall differences (mm/mo). (a) Observed difference between the 1980s and the 1950s; (b) simulated difference between desertification and normal land condition.

available information. Because of the internal variability in GCMs, ensemble means are used to detect climate impacts.

The July-August-September (JAS) rainfall differences between the degraded and control simulations are shown in Figure 1b. The rainfall is reduced in the degraded area, but increases slightly to the south. This dipole pattern is consistent with the observed pattern for dry climate anomalies in Figure 1a, which show the JAS rainfall differences between the 1980s and the 1950s. The simulated rainfall in a test area (from 9 N to 17 N, and 15 W to 43 E), including most of the degraded area, is reduced by 39 mm month^{-1}, close to the 45 mm month^{-1} observed reduction.

The JAS surface air temperature is higher in the degraded simulation than the control, which is consistent with the observed JAS temperature difference between the 1980s and the 1950s. In the test area, the simulated surface air temperature increases by 0.8 K, close to the observed increase over the same area, 1.1 K.

The river discharge variability in tropical northern Africa and the impact of land-surface degradation on this variability are also investigated. A number of studies have shown that many rivers in the region have had substantial reduction between the 1950s and the 1980s. The simulated soil moisture, surface runoff, and subsurface drainage in degradation experiments have also decreased, consistent with the reduction in rainfall. To compare the runoff at grid points in GCM simulations with observed river discharge, a linear river routing scheme is applied. The simulated river discharge from control and

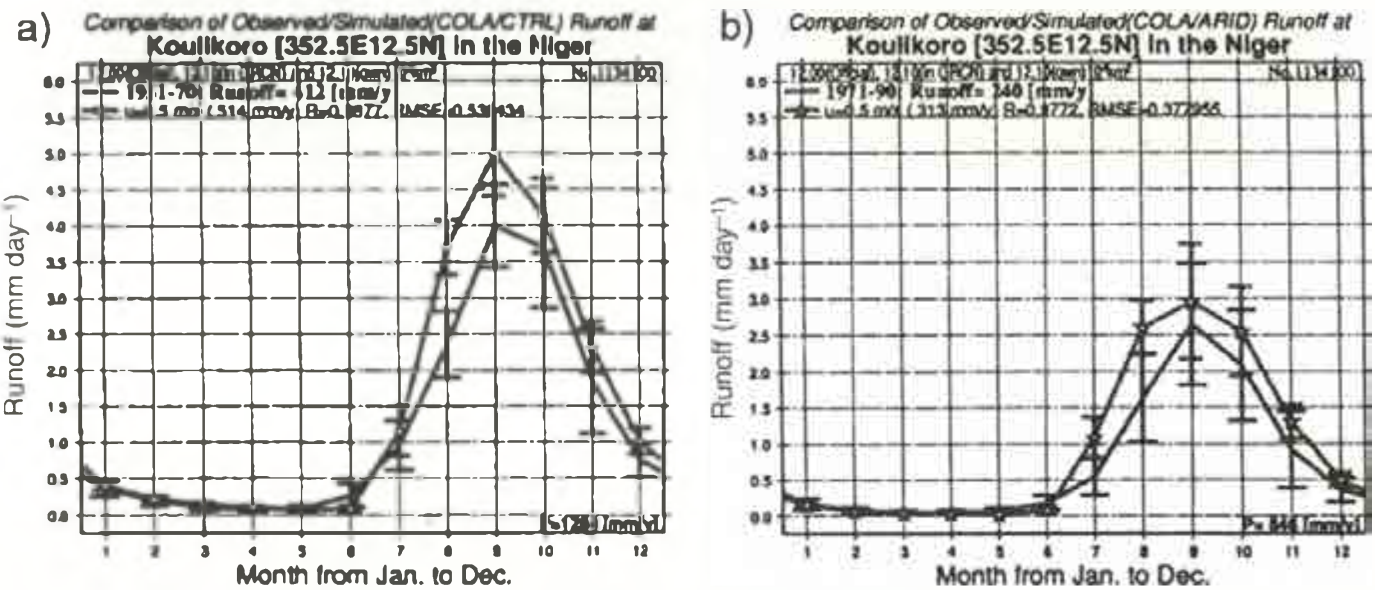

Fig. 2: Comparisons of simulated and observed runoff. (a) Control run and observed mean from 1951–1970; (b) Desertification run and observed mean from 1971–1990.

degradation experiments at the Koulikoro station, located at the upstream of the Niger River, represent the mean runoff from the south western Sahel region and are used to compare with the observed 1951–1970 mean and the 1971–1990 mean, respectively. The mean monthly discharges are simulated fairly well and the difference between control and degraded simulations is consistent with the observed difference between 1951–1970 and 1971–1990 (*Oki* and *Xue*, 1998).

The numerical simulations show that land surface processes are important aspects of the climate anomalies in Sahel. Desertification increases the surface air temperature, and reduces the summer rainfall, runoff, and soil moisture over the Sahel region. The impact is not only limited to the specified desertification area and the JAS period, but also affects the region to the south of this area and continues into the autumn. These results are in line with the observed climate anomalies, which suggest that desertification could cause regional climate anomalies.

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Potential of Forests to Control Regional and Global Climate by Evapotranspiration

Fritz Gassmann

Abstract

The predictions given so far by global circulation models (GCM) might be incomplete, because they lack a dynamical vegetation with the potential of structural changes. As an illustration for the possibility of vegetation-mediated abrupt climate changes, not described by today's GCMs, a conceptual model called VILLIGENATOR is proposed. Its characteristics differ substantially from those of GCMs by incorporating homeostasis, critical thresholds, abrupt phase changes and hysteresis rather than a well-defined climate sensitivity. Investigations of nonlinear systemsperformed during the last decades reveal the VILLIGENATOR characteristics being ubiquitous for the behavior of complex systems and so, it seems wise not to exclude them as realistic possibilities also for the global climate system.

Introduction

Very important insights for global climate dynamics come from ice cores, beginning with the first drillings on Greenland [1] and on Antarctica [2] in the 1980s showing surprisingly rapid climatic fluctuations during the last ice age (Heinrich events) and including the last interglacial (Eem) showing about 2 K higher temperatures than are observed today (ca. 15°C in the global average). Showing no important fluctuations in these ice cores, the Eem was considered being analogous to the Holocene that was also rather stable. This picture of "turbulent" ice ages and "laminar" interglacials was made seriously uncertain by the analysis of the most recent Summit ice core from Central Greenland drilled in the GRIP (Greenland Ice core Project) between 1990 and 1992 [3, 4]. Whereas the rapid fluctuations during the glacial time were confirmed, extremely rapid changes were detected [3] also during the Eem-interglacial (135–115 kyr before present BP). According to this ice core, the longest stable warm period encompassed only 2700 years or 14 % of the Eem. The remaining 86 % of this warm time were disrupted by many sharp transitions between possibly 4 different distinct climatic states, separated from each other by roughly 2 K : A warm state (Holocene plus 2 K), a Holocene state, a Interstadial state (Holocene minus 2 K) and a glacial state (Holocene minus 4 K). Transitions between these states show no regular pattern and occurred within a few decades. An example of such an event is shown in Figure 1, where a transition took place from the warm state to the Interstadial, persisting for 750 years and was then followed by a jump back to the warm state. As causes for these transi-

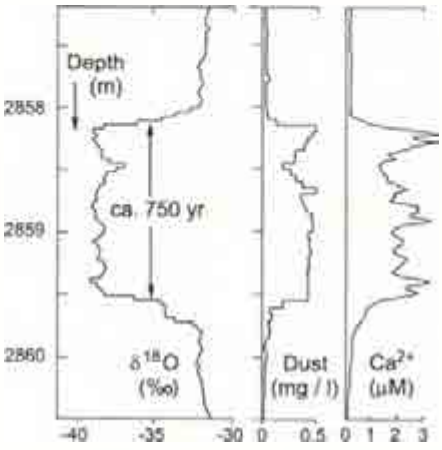

Fig. 1: Abrupt transitions between the Eem warm state and the Interstadial occurring 131 kyr BP for unknown reasons. The good correlation between $\delta^{18}O$, dust and Ca-content underline the reality and severity of the changes. Shown are 18-year-averages (adapted from [3]).

tions, variations of the solar activity or volcanic eruptions cannot be completely excluded, but the observed behavior does not seem to be a typical fingerprint of one of these processes. Were it the sun, we would expect a more oscillatory behavior and were it volcanoes, we would expect a more irregular dust content on rather small time scales. Not only are we unable to find the cause-effect chain explaining the observations, but also the observations themselves might be misleading. Only 28 km west of the European GRIP ice core, the American GISP2 (Greenland Ice Sheet Project 2) core was drilled. Whereas the two ice cores show perfect agreement over 2700 m covering about 100,000 years they do not match at all during the Eem period around 125 kyr BP. It is possible that ice flow may have altered the chronological sequences of the stratigraphy for the bottom part of one or both of the cores by producing shear folds [5].

The overall picture concerning behavioral patterns of the global climate system evolving from the ice core analyses and other information sources can tentatively be summarized as follows: It is difficult to define a "normal" state of the global climate system. Rather, several different states can be found for the same parameter values (multistability) and abrupt transitions between these states seem to be the rule. From this point of view, several crucial scientific questions arise:

- Does the global climate system have different coexisting quasistable states and if yes, how are the states nearest to the actual Holocene state characterized? Of special interest would be of course the next warmer state above today's climate.
- What is the reason for the stability of the Holocene climate being exceptional in the context of the last 250'000 years and are there critical thresholds? Especially important would be the existence of a critical atmospheric CO_2-level.
- How do climate transitions look like? One of the most important questions in this respect is the time scale of the transition process (years, decades or centuries).

Potential of climate – vegetation interaction: A model approach

A subsystem almost neglected so far in the study of climate dynamics and therefore only marginally present in Atmosphere Ocean Global Circulation Models (AOGCM) is terrestrial vegetation, the living surface of the earth. The reasons for this striking fact are simple: The climate discussion started from the side of the atmosphere, mainly represented by atmospheric physicists. As logical next steps, the abiotic compartment cryosphere (ice sheets) and the oceans, also treated as abiotic compartments, were coupled to the atmosphere. One might object that vegetation is incorporated into AOGCMs since the beginning because of its contribution to the energy balance of the surface. This is absolutely correct, but it has to be realized that vegetation is treated in these models as a abiotic, passive surface responding mechanically and immediately to changes in atmospheric and soil parameters. Only very recently, some climate modelers begin to realize the importance of vegetation dynamics i.e. the facts that vegetation is growing, changing and has a memory of the past, in short, that vegetation is living!

In the following, we show how important broad qualitative features of Eem and Holocene climate might be explained with a simple conceptual model simulating only some of the basic life-processes. In this model, the normally formulated ice-albedo feedback with its long time scale of thousands of years is replaced by a nonlinear albedo-feedback mediated by vegetation (mainly northern medium and high latitude forests) that has the potential to react on shorter time scales of decades and depends on the seasonal temperature amplitude. As main result, the observed instabilities in the Eem as well as a stable Holocene climate arise naturally and deterministically within a simple framework. The aim of the proposed model VILLIGENATOR is analogous to Prigogine's BRUSSELATOR proposed in 1968 [6] that was intended to make oscillating chemical Belousov-Zhabotinsky type reactions [7] plausible rather than realistically simulating all the processes showing a much richer behavior than the simple model.

Imagine the northern hemisphere being represented by a heat capacity equivalent to a 70 m deep ocean mixed-layer transforming the varying incident solar energy into a temperature variation. This yearly temperature cycle, in turn, influences growth or decay of biomass M, that is coupled to the planetary albedo by evapotranspiration and cloud formation and so enables a feedback mechanism controlling temperature as shown in Figure 2. As the model is aimed at analyzing stability of the Holocene climate, the energy balance equation has been line-arized around the preindustrial mean global temperature of roughly 15°C. The two dynamic variables of the model, ΔT and ΔM, describe the deviation of the spatial average of the northern hemisphere temperature from this mean and the deviation of the biomass quantity M from its Holocene mean respectively. Thus we write for the energy balance:

$$\kappa \frac{\partial}{\partial t} \Delta T = -B\,\Delta T - C\,\Delta M + A \sin(\Omega t) + \Delta F \quad (1)$$

where K is the mean heat capacity of the ocean's mixed layer ($3 \cdot 10^8\ Jm^{-2}K^{-1}$ equivalent to a 70 m water column), $\Omega = 2\pi/1yr$, A, B and C are constants and ΔF represents climate forcings of different origin (variations of the solar constant, variation of yearly average of incident solar radiation due to eccentricity variations, volcanic eruptions, El Niño – Southern Oscillation and other internal chaotic forcings as well as anthropogenic greenhouse gas forcing).

The term $B\Delta T$ represents instantaneous feedback processes used in most climate models caused by the variation

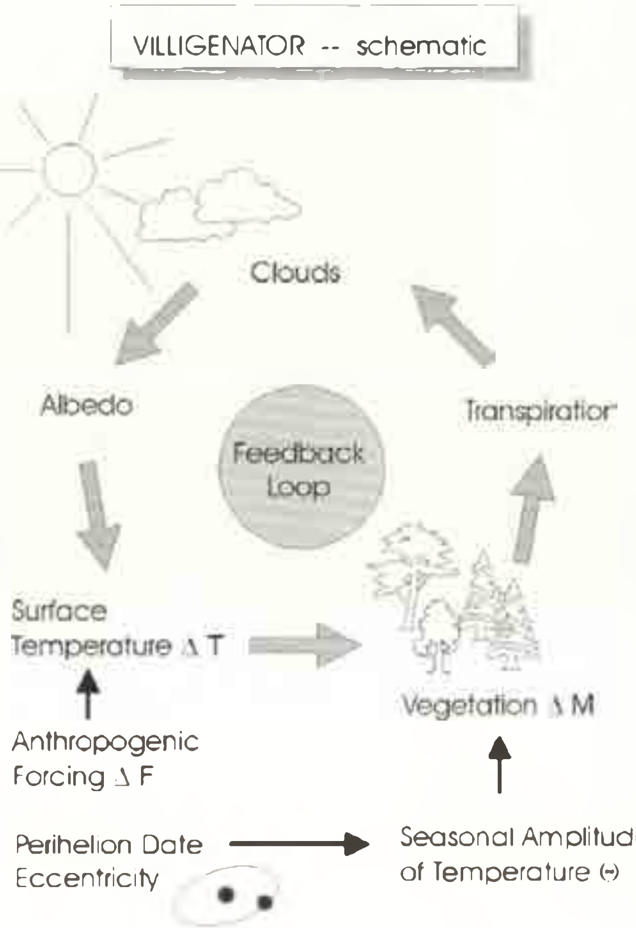

Fig. 2: Schematic representation of the conceptual atmosphere-vegetation model VILLIGENATOR.

of infrared emission, cloud albedo, sea-ice and snow albedo as well as the water vapor greenhouse effect due to temperature variations. B is related to the feedback factor β by:

$$B = \frac{B_{IR}}{\beta}, \quad B_{IR} = 4\sigma T_{eq}^3 \approx 3.8\ Wm^{-2}K^{-1} \quad (2)$$

Here, B_{IR} is the derivative of the black-body radiation resulting from the above mentioned linearization, σ is the Stefan-Boltzmann constant and T_{eq} is the equivalent radiation temperature of the atmosphere (i.e. an average mid-tropospheric temperature of about –18°C). Together with the radiative forcing approximation [8]

$$\Delta F = 6.3 \ln \frac{c}{c_0} \quad (\text{in } Wm^{-2}) \quad (3)$$

elating the anthropogenic forcing ΔF to the actual CO_2 concentration c and the respective preindustrial value c_0, the important climate sensitivity-parameter ΔT_{2C} (i.e. the mean global asymptotical equilibrium temperature increase for a doubling of the prein-dustrial atmospheric CO_2 concentration assuming that no structural changes of the climate system occur) can be calculated:

$$\Delta T_{2C} = (6.3 \ln 2)\frac{\beta}{B_{IR}} = \beta \cdot 1.15\,K \quad (4)$$

According to [9, p. 31], an exact value of the climate sensitivity is not known, but it is assumed to lie within the interval ΔT2 C= 1.5...4.5 K. The example given below was calculated with β = 2 positioned near the center of this uncertainty interval, but sensitivity tests show that β is not an important parameter, i.e. the overall features of the model do not change even with a very small β < 1. It has to be noted here that, in the framework of this model, climate sensitivity loses its original sense because abrupt phase transitions between predefined temperature levels at critical parameter values will dominate rather than a gradual change enabling the definition of a linear correlation coefficient between forcing and temperature increase.

The term CΔM in equation (1) represents the coupling between the quantity M and the energy balance. ΔM has been normalized and confined to the range [–1, +1] and therefore, ±C/B define two stationary states in addition to the "Holocene state" H with ΔT = 0. These two symmetrical states are called "Eem optimum state" E and "Interstadial state" I for the + and – sign respectively. With our choice of C = 1.7 Wm^{-2}, the resulting stationary states are ΔT_E = +0.9 K (= +C/B) and ΔT_I = –0.9 K, but fortunately, the sensitivity of the model on the value of C is small and therefore, the main results will not depend on the exact value chosen. Because the term –CΔM represents an albedo variation, it should be compared with the average planetary albedo α = 30 % that reduces the incoming average solar radiation by α·Q/4 (Q = solar constant = 1367.5 Wm^{-2}). Therefore, the maximum variation of the coupling term –CΔM is equivalent to an albedo variation in the range 29.5...30.5 %. It will be shown below that the northern forests have the potential to induce such an albedo variation.

The term A sin(Ωt) in equation (1) is an approximation for the seasonal variation of solar irradiation on the northern hemisphere. The amplitude A is a function of the eccentricity of the earth's orbit ε (today 1.5 %), the spring equinox date (today March 22) and the perihelion date (today January 3). The range of A depends on e in the following way:

$$A = \frac{Q}{4}(1-\alpha)\cdot(a_0 - 2\varepsilon) \ldots\ldots \frac{Q}{4}(1-\alpha)\cdot(a_0 + 2\varepsilon) \quad (5)$$

a_0 is the amplitude of the insolation of the northern hemisphere normalized to Q/4 for ε = 0 and has the approximate value of 0.408. The largest variations reached ±20 % in Eem due to a relatively large ε = 4 %. This contrasts with the much smaller variation of the annual average of incident solar energy DI used in ice-age simulation models being

$$\Delta I = \frac{Q}{4}(1-\alpha)\frac{\varepsilon^2}{2} \quad (6)$$

giving an eccentricity forcing of only +0.2 Wm^{-2} in Eem (ε = 4 %) and +0.03 Wm^{-2} today (ε = 1.5 %). Whereas e shows a periodicity of roughly 100 kyr (the time between two interglacials), precession of the earth's rotation axis completes a full cycle every approximately 20 kyr, comparable with the length of the Eem interglacial (135–115 kyr BP). During half a cycle (10 kyr), perihelion date shifts from winter to summer and therefore the seasonal amplitude of solar irradiation increased by 40 % during Eem. Variations of the tilt of the earth's axis (today 23.5°) with a period of 41 kyr has been neglected being of lower importance for our stability considerations.

The equation for the quantity ΔM has been chosen as follows:

$$\frac{\partial}{\partial t}\Delta M = \mu\,\Delta T\left\{1-\left(\frac{\Delta T}{\lambda}\right)^2\right\} \qquad (7)$$

μ and λ are constants. For small ΔT, the third order term can be neglected and the resulting dynamical system for the yearly averages becomes equivalent to a damped oscillator: The term $A\sin(\Omega t)$ vanishes when averaged over a year and the averages of ΔM, ΔT and ΔF are equivalent to elongation, velocity and driving force respectively. The answer of the system to a small and constant force ΔF is therefore a transient damped oscillation leading to a new equilibrium, i.e. the system corrects any small and slow forcing variations and shows perfect *homeostasis*. In this situation, an experimentally observed climate sensitivity would be exactly zero. For ΔT in the order of λ, the nonlinear term cannot longer be neglected and integration over a year transforms equations (1) and (7) into the approximate form:

$$\begin{aligned}\frac{\partial}{\partial t}\Delta\hat{T} &= \frac{1}{\kappa}\left\{-B\,\Delta\hat{T} - C\,\Delta M + \Delta F\right\}\\ \frac{\partial}{\partial t}\Delta M &= \mu\cdot\Delta T\left\{1-\left(\frac{\Delta T}{\lambda}\right)^2 - \frac{3}{2}\left(\frac{\Theta}{\lambda}\right)^2\right\}\end{aligned} \qquad (8)$$

Θ is the temperature amplitude resulting from equations (1) and (5):

$$\Theta \approx \frac{Q}{4\kappa\Omega}(1-\alpha)(a_0 \pm 2\varepsilon) = 1.64 \pm 0.32\ \mathrm{K} \qquad (9)$$

According to this model, the Holocene state with ΔT = 0 can lose its stability in two different ways. First, an increasing eccentricity leads to the following two *critical values* for Θ without any change of the forcing ΔF:

$$\Theta_1^{*} = \sqrt{\frac{2}{3}\left(\lambda^2 - \frac{C^2}{B^2}\right)} \quad \text{and} \quad \Theta_2^{*} = \lambda\sqrt{\frac{2}{3}} \qquad (10)$$

The two critical values for the temperature amplitude, related to ε according to equation (9), define a *hysteresis*-interval. Within this interval, all three states termed E, H and I with ΔT = +C/B, 0, −C/B respectively, are simultaneously stable (multistability). For Θ smaller than Θ_1^*, only H is stable and for Q larger than Θ_2^*, both states E and I are stable, but not H. The sensitive parameter λ has been set to 2.2 K to guarantee stability of today's climate and at the same time instability of the H state in parts of the Eem range. The last constant μ controls the abruptness of a climate transition and has been set to 0.2 $K^{-1}\,yr^{-1}$ to keep the time derivative of the yearly average of ΔM below about 5 % per year for transitions in Eem compatible with observed transition times of the order of 20 yr [3]. According to this model, a stable Holocene climate with very low climate sensitivity would be compatible with *abrupt transitions* in Eem between three different states.

The second way for this model to lose stability of the H-state reflects the today's situation with constant and relatively low eccentricity (ε = 1.5 %) and increasing anthropogenic forcing ΔF. For slowly and linearly increasing ΔF, the model shows a constant but somewhat increased temperature following a short transient. As soon as ΔF = C = 1.7 Wm^{-2}, the feedback control for temperature is not longer effective because the increasing normalized biomass touches its maximum value ΔM = +1 and stabilization cannot longer be maintained. Therefore, temperature ΔT begins to rise proportionally to forcing ΔF until a critical value is reached where the system shows an abrupt transient to the warmer E-state with ΔM = −1 then being the only stable state. The transient is driven by the collapsing biosphere (ΔM decreases from +1 to −1) and whence reduced evaporative cooling of the earth's surface leading to a temperature increase feeding back to a further reduced biomass. The total temperature increase during this transient is 2·C/B = 1.8 K leading to a highly stable E-state. To return to the H-state, the forcing would have to be reduced to a considerably lower value of ΔF. With our model parameters, this hysteresis interval lies between the following boundaries:

$$\begin{aligned}\Delta F_1^{*} &= B\sqrt{\lambda^2 - \frac{3}{2}\Theta^2} - C \approx 0.7\ \mathrm{Wm^{-2}},\\ \Delta F_2^{*} &= \Delta F_1^{*} + 2C \approx 4.1\ \mathrm{Wm^{-2}}\end{aligned} \qquad (11)$$

With today's forcing of 1.5...2 Wm^{-2}, according to this model, the system has left the stable plateau and global temperature rises parallel to the forcing. This could explain the absence of a clear signal until relatively recently and the low increase of only about 0.3...0.6 K up to now. The temperature increase, still according to this model, will continue until the critical forcing of 4.1 Wm^{-2} will be approached, i.e. roughly up to an effective CO_2-doubling equivalent to a forcing of 4.4 Wm^{-2}. After an abrupt change to a global climate perhaps similar to the optima of Eem will have occurred, returning to the today's Holocene climate would be practically impossible due to the large hysteresis range of 3.4 Wm^{-2} as shown in Figure 3.

For the interpretation of the quantity M, instantaneously working feedback processes have to be excluded because of the analytical form of equation (7). Therefore, all the processes being responsible for the value of the feedback factor β are no candidates for the interpretation of M. Further, equation (7) is

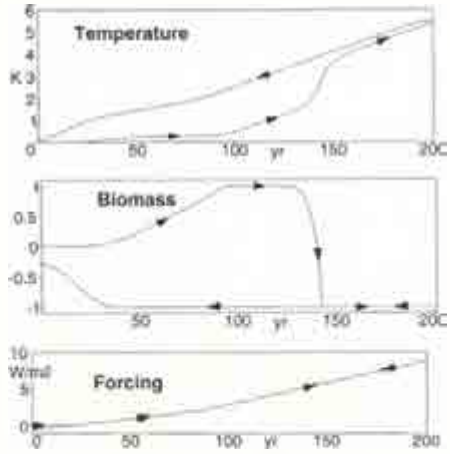

***Fig. 3:** Variation of temperature ΔT (top) and of biomass ΔM (middle) simulated with the conceptual model VILLIGENATOR for constant eccentricity ε = 1.5 % but slowly varying anthropogenic forcing ΔF (bottom). Forcing is zero until year 20, then increases by 3 Wm^{-2} per century until ΔF = 2 Wm^{-2}, thereafter slope is 6 Wm^{-2} per century. After 200 years, the simulation continues with decreasing forcing (from right to left) to show hysteresis. With today's forcing of 1.5...2 Wm^{-2}, the system is still inside the hysteresis range but has left the stable plateau with almost constant ΔT ≈ 0.3 K. If the forcing exceeds the critical value of 4.1 Wm^{-2} (see text), the model system displays an abrupt climate change mediated by a collapsing biosphere.*

hardly compatible with ocean-climate interactions, because M must be a continuously growing quantity for $\Delta T > 0$. We propose here to identify M with the extent and vitality of temperate and Boreal forests for the following reasons:

- forests evaporate important amounts of water and can control climate by cloud formation [10]
- a longer growing season due to higher temperatures tends to increase the extent and vitality (the evaporation potential) especially of temperate and Boreal forests (changes of seasonal insolation do almost not affect tropical regions and so, tropical rain forests are not considered here)
- equation (7) expresses the typical limited regulation potential of biological systems observed at every scale [11]: a linear stabilizing response guarantees homeostasis in a limited range confined by nonlinear saturation effects that can lead to instabilities at critical parameter levels.

The first of the above cited reasons needs further clarification. Climate control is assumed here by a transpiration-cloud-albedo feedback loop and so, it has to be shown that this process is large enough to be effective. Evapotranspiration of the terrestrial biosphere is estimated to account for about 15 % of the global water cycle (evaporation by the oceans contributes the remaining 85 % [12]). Evaporation by soils, lakes and rivers in the region of Germany amounts to roughly 23 % of total evapotranspiration [13]. Assuming the cloud albedo of 20 % [14] being proportional to global evapo-transpiration, the contribution of the terrestrial biosphere to the global albedo can be estimated to $0.2 \cdot 0.15 \cdot 0.77 = 2.3$ %. From the total terrestrial land biomass of 1837 GtC (soil and plants), 37 % fall into the categories of temperate evergreen forests, temperate deciduous forests, Boreal forests and wood/shrubland being concentrated on the northern hemisphere [15]. Again assuming proportionality, their contribution to the northern hemisphere albedo is estimated to $0.023 \cdot 0.37 \cdot 2 = 1.7\%$. This ratio clearly exceeds the above mentioned albedo range of $\pm 0.5\%$ needed within the framework of our conceptual model, that could be realized by a growth or decay of roughly 1.5 % per year over 20 years. We think that a realistically needed variation of the northern biosphere is even smaller because the potential per water molecule to affect the hemispheric albedo might be considerably larger for water evaporated by terrestrial plants than for sea water. This because of three reasons: First, mountains amplify deep convection and cloud formation and second, due to the daily cycle of boundary layer stability (over land, low stability during day and over the sea mainly during night), land clouds are formed pre-dominantly during the day and so reflect more sunlight compared to the same amount of sea clouds. Third, water evaporated over the continents might enhance cloudiness over-proportionally due to convection and condensation processes constituting a soil-precipitation feedback [16]. For these reasons, a limited stomatal climate control seems realistic.

All the above mentioned mechanisms are valid only for the warm season and can therefore support the functional form of equation (7) only for positive ΔT. The symmetrical negative part of the function pro-ducing the I-state is of secondary importance here but an interpretation based on snow or ice-accumulation is not excluded.

Conclusions

The above presented VILLIGENATOR provides an example for a simple approach being able to explain different, seemingly unrelated aspects of the global climate system. Although our model has many limitations (one being that it cannot de-scribe spatial variations in any detail), it does explain some important qualitative features of the observed Holocene and Eem climates and transparently demonstrates a mechanism being sensitive to eccentricity and so offering an explanation for the fundamental differences between Holocene and Eem climates. The main results can be summarized as follows:

- a stable Holocene climate being characterized by an active biological mechanism leading to homeostasis and showing almost negligible climate sensitivity
- for a small and linear increase rate of the anthropogenic climate forcing (e.g. 0.015 Wm^{-2} per year), the model gives a constant temperature increase (0.3 K) over a limited time interval, being correlated only with the rate of forcing increase and not with the absolute forcing. This might give an explanation for the plateau with more or less constant temperatures between about 1940 and 1980.
- as soon as ΔM reaches its maximum value, stabilization is not longer possible and temperature increases parallel to forcing, as observed since 1980.
- for a temperature increase ΔT of 0.5 K, the model gives an increase rate of the average normalized biomass of 0.026 per year being equivalent to a carbon sink of 1.5 Gt per year (based on an estimated affected plant biomass of approximately 200 GtC equivalent to $M = 1.7/0.5 = 3.4$). This result is compatible with the "missing carbon sink" of 1.6 ± 1.4 Gt per year (explained here as the control signal for stabilization)
- as soon as a critical forcing is exceeded, the system responds with an abrupt temperature increase and a collapse of a part of the biosphere (ΔM displays a sudden transition from +1 to −1).
- for the Eem interglacial ($\varepsilon = 4\%$), the model shows an interesting structure of different stability regimes: for perihelion in January a stable Holocene type climate, for perihelion in July a stable Eem optimum or Interstadial climate, for intermediate perihelion dates stability of all 3 climates. As a result of forcing fluctuations of the order of a few Wm^{-2}, abrupt transitions between the different stable climates can occur. Within the above mentioned hysteresis range, the "activation energy" needed to trigger a transition is sensitive to variations of the amplitude of the yearly temperature cycle and so, transition probabilities due to a constant stochastic forcing considerably vary within relatively short time intervals (centuries) in Eem. Further, in many situations, transitions occur directly between the E and I state, and the intermediate H state, though stable, is difficult to reach. These properties seem compatible with the general behavior of the Eem climate as observed with the GRIP ice core [3].
- because transpiration takes place mainly during daylight and during the warm season, day-night and summer-winter asymmetries of climate change as observed in Central Europe [17] are a natural outcome of the proposed conceptual model.

Our analyses should not be construed as proof that global climate is actively controlled by the northern biosphere. The quantity M might allow other interpretations leading to a similar analytical form of equation (7) and therefore similar results. It would not be surprising, however, if more detailed analyses would show that the active biological part of the earth's surface significantly contributes to climate control, so supporting the idea of the "Gaia hypothesis" [18]. In fact, a refinement of the above described model by *Füssler* [19, 20] taking into account more detailed physiological processes, especially a feedback-loop involving root-dynamics under drought, leads to a similar hysteresis behavior as described above. In addition, other theoretical investigations with simplified models [21] underline the importance of atmosphere-vegetation feedbacks. Simulations with GCMs taking also increasing atmospheric CO_2 concentrations into account clearly show significant physiological and structural vegetation feedbacks in the climate system [22]. Finally, it is expected that a CO_2 doubling would induce major changes in broad vegetation types of about two-thirds of the forests in medium and high northern latitudes [23, p. 5–7].

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Effects of Forests and Forest Harvest on Floods, Erosion, and Channels: A Temperate Perspective

Gordon E. Grant

Abstract

Controversy surrounding the role of forests and effects of forest management on streamflow, erosion, and watersheds extends back at least as far as Plato. More recently, instrumented experimental watersheds have become key proving grounds for testing the types and strengths of mechanisms relating timber harvest and road construction to discharge regimes, mass wasting, surface erosion, and changes in channel morphology. At first glance these small catchment studies collectively reveal a confusing suite of responses to forest activities, ranging from little change to dramatic shifts in hydrologic and geomorphic regimes for certain types of treatments and events. New work is helping to explain this wide variability in watershed response as resulting from the interplay of climatic and antecedent conditions with the physiology and structure of vegetation, interactions between hillslopes, road networks and stream networks, all within the underlying constraints of geology and geomorphic setting. Examples from small catchment studies in the U.S. Northeast, Southeast and Pacific Northwest highlight the importance of experimental watersheds for illuminating specific perturbation-response mechanisms critical to testing assumptions and models of watershed behavior, and allow examination of long-term trajectories of system change in response to disturbance. How best to apply results from these small catchments to management of larger drainage basins remains an issue, however.

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Hillslope Hydrology and Shallow Landslides Forecasting in a Deforested Environment

Mauro Casadei & Enzo Farabegoli

Abstract

One of the many consequences of deforestation is the widespread mass erosion of steep hillslope environments. The removal of trees weakens the soil mantle by removing root anchoring to the bedrock and increasing the effective water inflow leading to the water table rise and subsequent instability. Shallow landslide initiation potential related to deforestation has been mapped in the past in the US Pacific NW thanks to a topographically-driven slope stability model developed by *Montgomery & Dietrich* (1994).

In this work, the model was run on a humid-temperate area in the Italian Northern Apennines where deforestation has already produced intensive erosion, leading to widespread badland landforms. The results fit excellently with the detailed (1:5000) mapping of the observed instabilities, confirming the ability of the model to assess the instability pattern in absence of tree anchoring. Forested areas have a lower density of shallow landslips and the effective friction angle increases from about 19° to 25° due to the added root strength pseudocohesion. On the contrary, no clear effects on hillslope hydrology were reconstructed from the available date. This suggests that afforestation acts as an effective hillslope protection within steep slopes whose gradient approaches the colluvium friction angle. In lower gradient areas, where the stability is rather dominated by local hydrology, the effectiveness of afforestation is still unclear.

Keywords: deforestation, shallow landslides, hillslope hydrology, digital elevation models.

Introduction

The linkage between deforestation and hillslope erosion is a primary factor in the land degradation processes. The most common consequence is the widespread development of shallow soil slips, which often evolve into catastrophic debris-flows, which often result in economical damages and losses of human lives.

Hillslope stability is controlled by: i. local topography, ii. geometry of the slip plane, iii. water table elevation, and iv. geotechnical parameters of the material prone to failure. In the present case, the material is the soil-vegetation complex overlying the bedrock interface (Fig. 1).Tree removal changes both the hydrological and the geotechnical setting of the colluvial mantle. Hillslope hydrology is altered in terms of interception, evapotranspiration, infiltration rates and root uptake; furthermore road logging often change the spatial pattern of surface runoff and its nature (from saturation overland flow to hortonian runoff). Root strength pseudocohesion improves the overall geotechnical parameters of the soil-root complex, providing anchoring of thin colluvium to the underlying bedrock (*Sidle* et al. 1985, *Riestenberg* 1994).

The interaction between hillslope hydrology and shallow slope stability has been long time investigated (*Anderson & Burt* 1978, *Johnson & Sitar* 1990, *Reid & Iverson* 1992). Computer-based models have been developed (*Okimura*

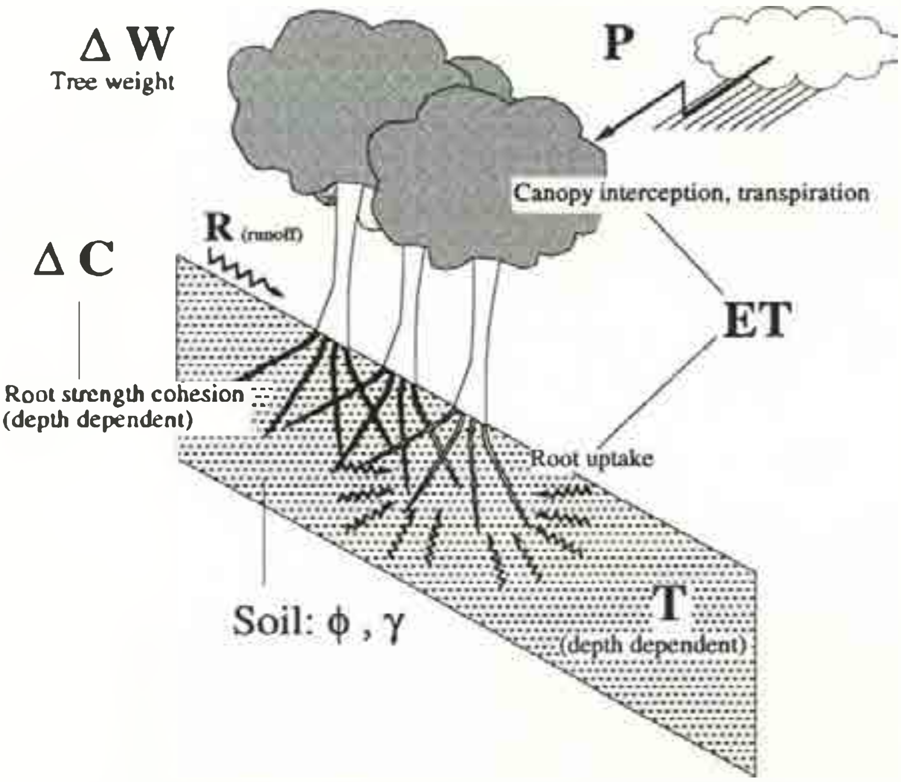

Fig. 1: Idealized cross-section of the hillslope soil-vegetation mantle, where shallow landslips typically occur, and the physical parameters involved.

& *Ichikawa* 1985, *Montgomery & Dietrich* 1994, *Wu & Sidle* 1995; *Duan* 1996, *Pack & Tarboton* 1997) in order to predict the critical conditions under which the water table rises to the critical elevation for triggering the failure of a colluvial mantle. In particular, Montgomery & Dietrich's model was successful in mapping the relative landslide potential based upon detailed digital elevation models. The following assumptions are made: 1) "infinite slope" conditions (*Skempton & DeLory* 1957), which implies a ground-parallel slip surface, located along a permeability threshold; 2) steady-state hydrological conditions, when water inflow equals Darcian outflow, an assumption that may realistically reflect the hillslope situation in the wet season. Under these conditions, detailed DEMs (≥10 m grid spacing) can be used to map topographic gradients and the degree of convergence (unit drainage area), needed to compute steady state water balance according to *O'Loughlin* (1986). By assuming a reasonable range of effective friction angle and saturated bulk density of the colluvium, it is possible to map for each elementary parcel the value of precipitation ≈ 900 mm/yr.), although high intensity rainfall events (up to 150 mm/d) have been recorded in the past years.

The local geological setting is rather complicated (*Farabegoli & Forti* 1997), as an autochtonous sequence is overlain by a sedimentary melange ("Chaotic Complex") composed of scaly clays which include variable size lithic blocks, resembling the franciscan melange patterns. The autochtonous sequence features Messinian gypsum (Gessoso Solfifera fm), overlain by the montmorillonitic clays of the Colombacci fm. (upper Messinian), which in turn are covered by the Pliocene Blue Clays (with some sandy horizons) and the Pleistocene S.Andrea Clays member from the Imola Yellow Sand fm.).

The occurrence of mudstone bedrock in the Centonara catchment explains the presence of "calanchi" landforms, a sort of badland morphology very common in the Italian clayey formations. They usually occur on steep antidipslopes, featuring bare hillsides, highly crenulated morphology and several mudslide events being driven by a dense gully network. The channel network is superimposed to the gully network; with a consequent very high drainage density (up to 20–25 km/km² – *Farabegoli* et al. 1994) related to low order streams (seldom > 2° order). The opposing, N-facing dipslopes feature lower gradient topography often associated to bedding plane discontinuities; in fact these hillsides are generally modelled by deep seated translational failures, and are covered by a thicker colluvial mantle (≥ 1 m), which takes longer to saturate and give rise to channel heads (drainage density ranging around 5–6 km/km²).

The sample area features the well known *Calanchi dell'Abbadessa* in the central portion of the S-facing hillslopes, finely dissected by mudslides channels. The N-facing hillsides feature some shallow translational slides, but has no evidence of recent deep seated movements, possibly because of the inclusion of huge lithic blocks within the clayey melange matrix. In the western and eastern catchment portions (respectively the headwaters and outlet areas), where the geotechnical soil properties are better (sandy bedrock), agricultural crops condition surface and subsurface hydrology.

A historical data collection outlines some significant phases (Table 2) in the land degradation, which fit into the overall Italian and Mediterranean picture, whose triggering factors are: i: removal of Mediterranean oaks for agricultural and grazing practice (*Zangheri* 1966; *Verstappen* 1983, *Naveh* 1986, *Yaalon* 1997); ii. periods of agricultural neglect, such as after the fall of the Roman empire (e.g. *Naveh* 1986). The latest phase of upland erosion can be estimated by the critical hydrological ratio q/T, where q = effective rainfall (m d⁻¹) and T = soil mantle transmissivity (m2 d⁻¹). Low critical log q/T values mean that instability will occur with less rainfall, implying higher failure potential; high critical q/T values mean the soil mantle is able to drain water faster, so that the water table will not reach its critical elevation. In the Oregon Coast Range, a reasonable value for log Q/T has been found to be around -2.5. Having determined the critical hydrological ratio, if we knew the precise spatial distribution of T, we could then assess the critical amount of effective rainfall q needed to trigger instability. Similarly, a different set of q/T values is related to soil mantle saturation and subsequent overland flow. Therefore, by mapping actual instabilities and

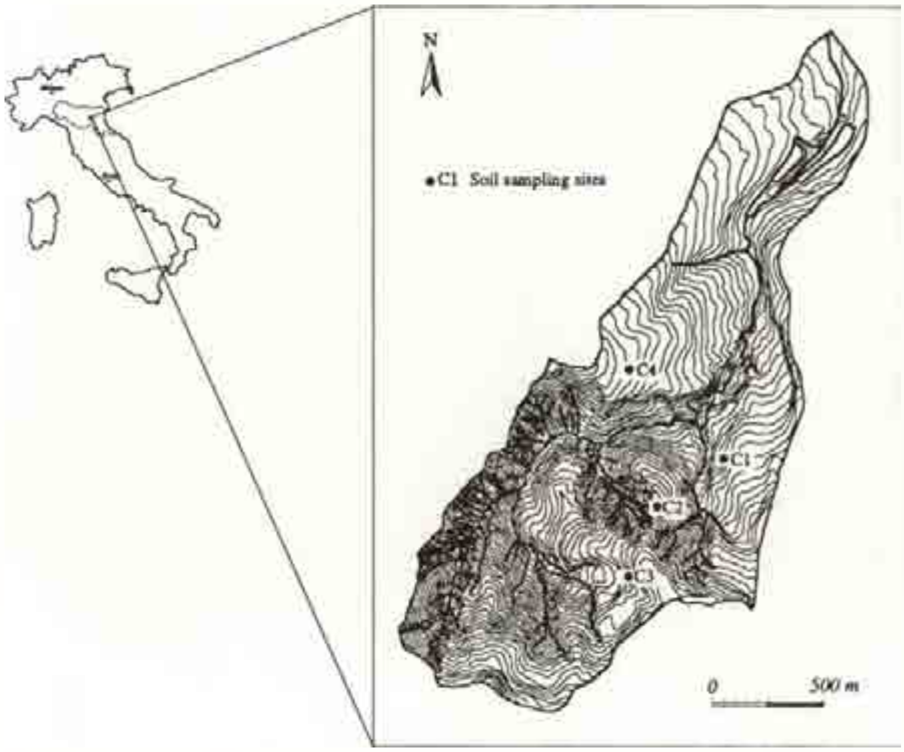

Fig. 2: Index map and topography of the Centonara catchment. Contour elevation spacing is 5 m.

saturation zones, it is possible to assess by back-analysis the hydrological ratios that acted in the past.

For the sake of simplicity, the model does not take explicitly into account vegetation-hillslope interaction. However, it has been successfully used by local authorities (Oregon Department of Forestry) to predict the location of debris flow source areas, by neglecting tree contributions, that means in case of deforestation. The purpose of this work was to verify the predicted results of the model in the Italian Northern Apennines, where old strong deforestation and partial recent afforestation has already occurred, and land use changes have fully produced their consequences.

Table 1: Log q/t values and associated combinations of effective rainfall q (mm d⁻¹), transmissivity (m², s⁻¹), and hydraulic conductivity K_s (m s⁻¹) given a sample soil thickness of 1 m.

q(mm d^{-1})	Log q/T	T(m^2 d^{-1})	K_s(m s^{-1})
20	−1.5	1.6	$1.8 \cdot 10^{-5}$
50	−1.5	0.63	$7.5 \cdot 10^{-6}$
100	−1.5	0.31	$3.7 \cdot 10^{-6}$
20	−2.5	0.16	$1.8 \cdot 10^{-6}$
50	−2.5	0.063	$7.5 \cdot 10^{-7}$
100	−2.5	0.031	$3.7 \cdot 10^{-7}$

Materials and methods

The Centonara catchment is a 2.7 km² wide watershed located about 15 km SE of Bologna in the Italian northern Apennines (Fig. 2), where the climate is substantially humid-temperate, (annual comparison with the oldest IGM (Italian Geographic Military Institute) maps which dates around 1890 (Fig. 3). With this aid, headscarp retreat rates have been estimated around 3 m yr.⁻¹ in a similar catchment a few kms to the west. In the Centonara catchment, the highest retreat values were estimated between 40 and 90 m for the period 1890–1978, for the gullies NE and W of the Pieve di Pastino. The afforestation west of Ca' Pivani was only partially present, as the overall land use of the catchment was devoted to vineyards; nowadays the current cultivations have shifted to durum wheat, sorghum and grasslands, whereas the northern part of the catchment is now a Regional Park, with protected calanchi landforms and vegetation (mostly shrublands).

Slope stability back analysis

Back-analyses were performed to assess the parameter ranges which produced soil slips in the past. These ranges differentiate according to several factors including lithology, bedding orientation and past/present land use. The present work deals with the latter effect.

A landslide inventory (Fig. 4) was carried out in the field in 1998–99 on an extremely detailed scale (1:2500). The upslope drainage area and topographic gradient was measured for each landslip scar (Fig. 5) and plotted on a log-log graph against the critical failure envelopes given different values of q/T and Δ, for the whole catchment as well as differentiating by land use (Table 3, Fig. 6)

Table 2: Phases of land degradation in the Centonara catchment area.

Year	Event description
Roman-post Roman age	Deforestation during roman empire and land abandonment at its fall occur. The widespread hillslope erosion is reflected by a huge shift (up to 25 km) seawards of the shoreline.
XII–XIII century	Demographic explosion, and related intensive crop exploitation without rotation (wheat and vineyards), coupled with deforestation.
1158	Abandonment of the church of S. Cristina di Settefonti because of landsliding
1593	The relics of Beata Lucia di Settefonti are moved from the S. Cristina church to the S. Andrea church
1602–1663	The Poggio Scanno-Monte Armato community disappears because of the isolation caused by landsliding
1702	The S. Donato church is destroyed by a landslide
Post 1861	After the unity of Italy, the industrial explosion gives a pulse to deforestation
1960–1990	Deforestation and country abandonment incentivate strong land degradation

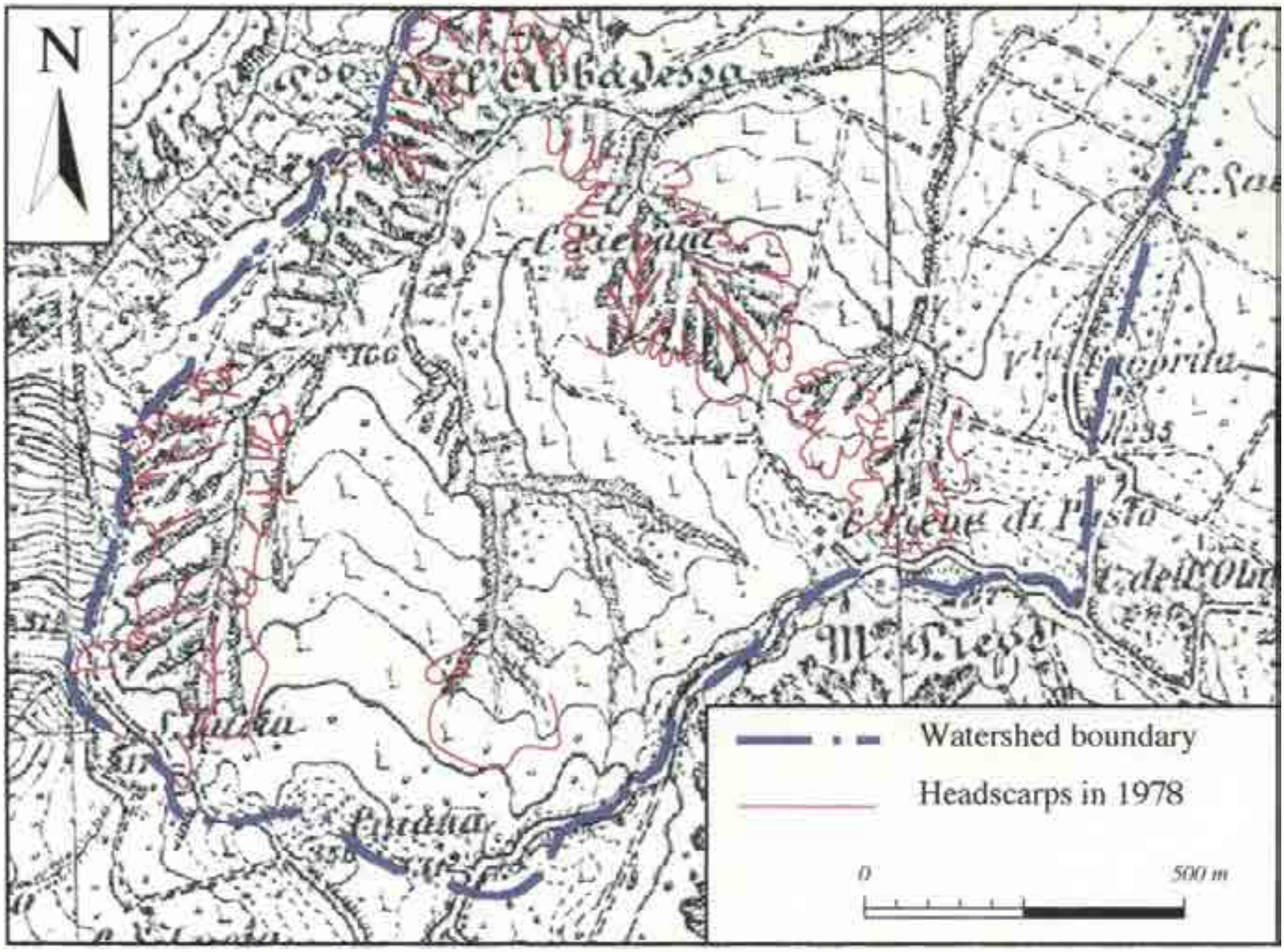

Fig. 3: 1890 topography of the southern part of the Centonara catchment from the IGM 1:25000 map. The 1978 situation shows a cliff retreat up to 90 m in the gullies W of Pieve di Pasto, 40 m in the eastern channels.

Table 3. Critical log q/T and Ø values at failure obtained by back-analysis, discriminating by land use.

Land use	log q/T	Ø
Bare soil	–2.398	19°
Shrublands	–2.5	24°
Forest	–2.5	25°
Grasslands	–2.398	25°
Shrublands + bare soil	–2.398	19°
Grasslands + bare soil	–2.398	19°
Grasslands + shrublands	–3.176	19°
Arable lands	–2.398	19°
Arable lands + shrublands	–2.778	19°
Grasslands + pastures	–2.5	19°
Reforestation + shrublands	–2.398	19°
Orchard + shrublands	–2.778	19°
Arable lands + forest	–2.778	24°
Forest + pastures	–2.6	25°

The range of friction angles was verified by means of some shear tests on disturbed soil samples collected in the field, which gave similar critical state ∅ value (Table 4). This confirms that the friction angle mobilized in the field is lower that the peak strength, and suggests a failure mechanism including progressive failure, probably linked to seasonal mud-cracking and water table fluctuations.

The same procedure was applied to the channel sources reported in the topographic map in order to obtain the q/T values that acted in the past to produce colluvium saturation and hence a channel source. In particular, the log q/T values obtained range from –1.7 to –3.2, overlapping with the range of critical values for landslips. This procedure only allows to reconstruct an upper boundary of the actual log q/T values, because the saturation areas actually occurring in the field extend farther upslope of the mapped channel sources. A further campaign is currently in progress to map the contraction/expansion of the saturated areas, related with rainfall events. However, the procedure used in this work allows 10 check the magnitude of the

Table 4. Geotechnical properties from colluvial soil samples.

Sample #	Lithology	W_p (%)	W_L (%)	$\varnothing_P$ (°)	$\varnothing_R$ (°)
1	Sandy loam	17.8	33.6	32.3	31.9
2	Clayey sand	31.4	65.5	21.7	19.8
3	Clayey sand	25.6	56	n/a	n/a
4	Sandy loam	33.9	43		

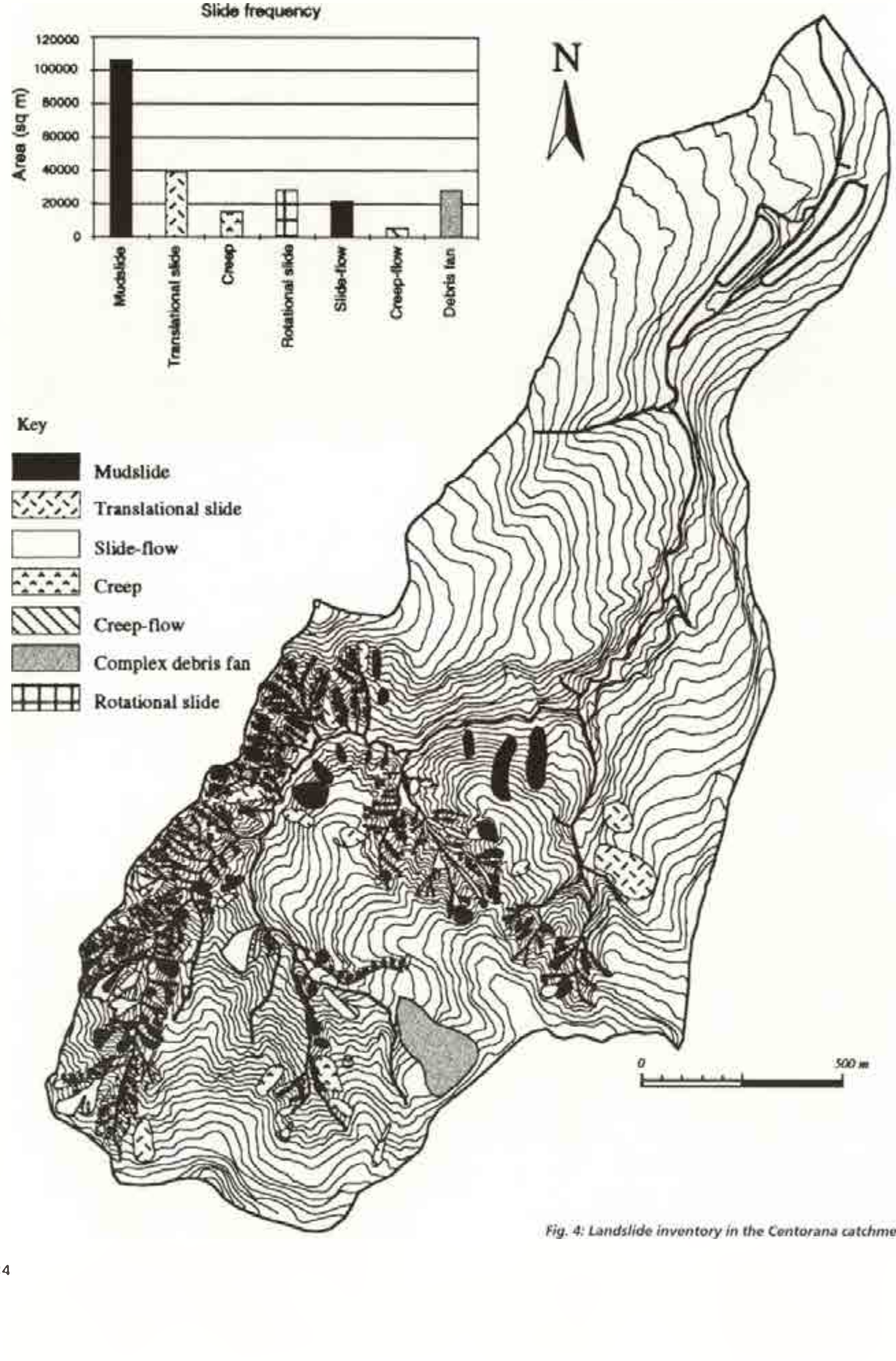

Fig. 4: Landslide inventory in the Centorana catchment

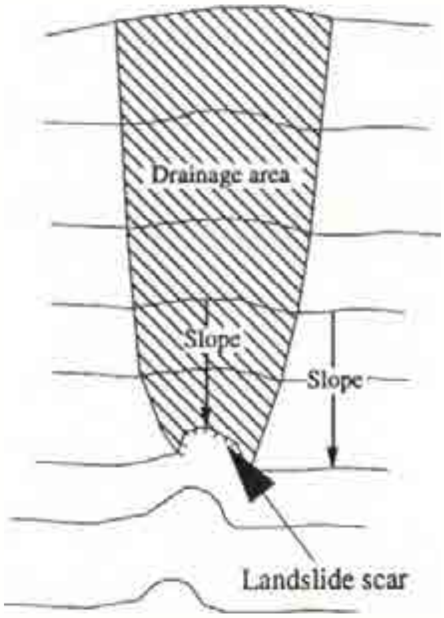

Fig. 5: Back-analysis procedure of existing soil slips: upslope drainage area and topographic gradient are extracted from the topographic map and plotted on a log-log graph.

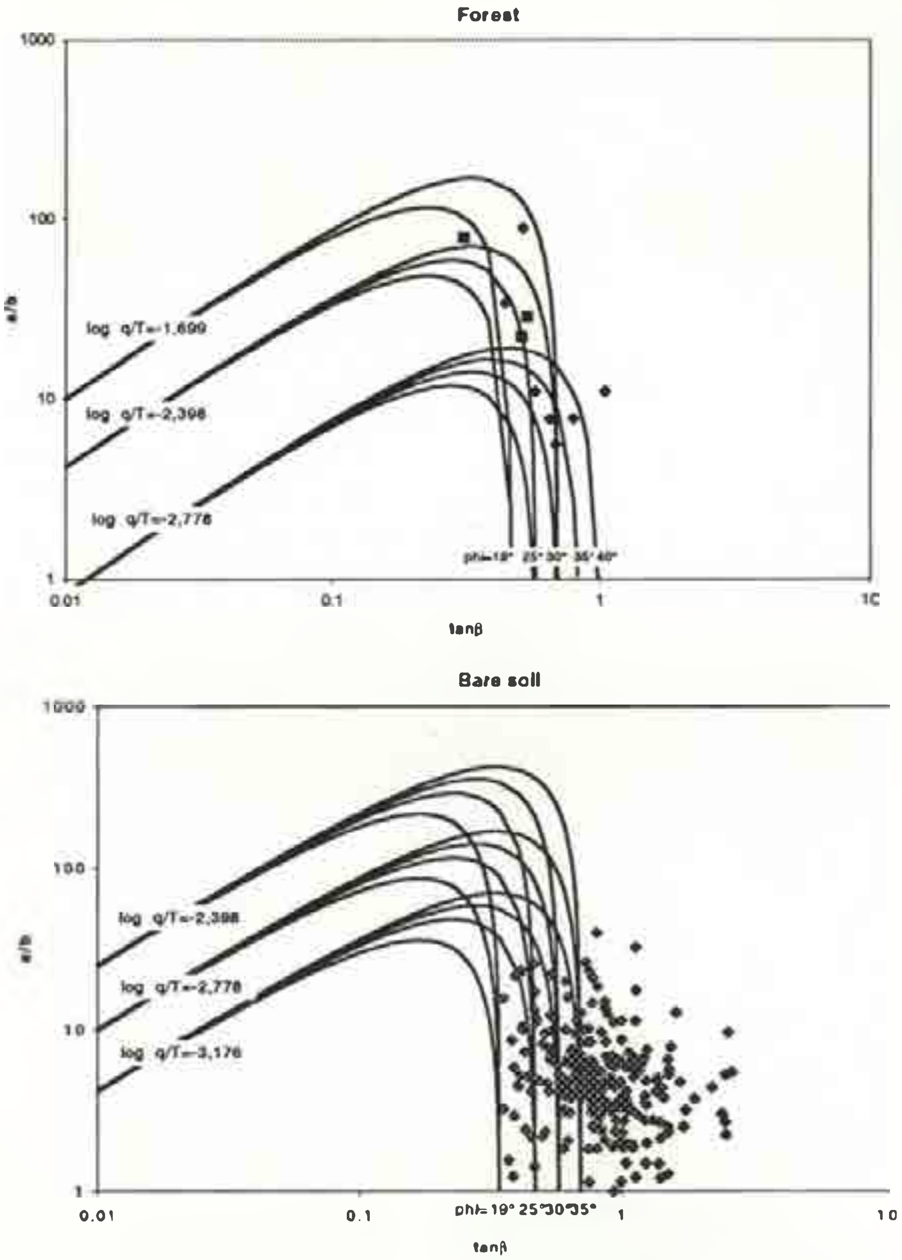

Fig. 6: Backanalysis: log-log diagrams of landslips differentiated by land use. Dots represent single landslide scars.

reconstructed hydrological parameters 10 be used in the model.

Model run

The digital elevation model was extracted by digitizing the contours (5 m elevation spacing) from the 1:5000 topographic maps released by the Cartographic Survey of the Emilia-Romagna Region (1978). The coordinates of the vertices were interpolated into a 10 m spaced grid DEM, whose detail is regarded as sufficient for hillslope hydrology models (*Zhang & Montgomery* 1994).

The model run produced: 1) the slope map, not shown here, using a steepent descent calculation; 2) the map of unit drainage area (Fig. 7), calculated using the *Quinn* et al. (1991) algorithm; 3) the relative landslide potential map (Fig. 8–9), expressed as the critical log q/T values predicted for failure. The latter maps were obtained using the friction angle range (19°–25°) held by the back-analysis and the geotechnical shear tests.

Discussion

The mapping of landslide potential reflects excellently the spatial pattern of observed landslips. Unconditional instability is detected in the badland area, where topographic gradient exceeds the expensed range of friction angles (19°–25°): here the soil mantle may reach only temporary stability due to factors such as soil suction, but in the long run, it will fail leaving exposed the denuded bedrock. In such areas, very thin diffuse failures may occur under dry conditions, independently of seasonal rainfall. On the other hand, N-facing dipslopes clearly show a dependency of instability to the local hydrological setting, controlled by the degree of flow convergence.

Therefore steep hillslopes (e.g. whose gradient approaches ∅) are very sensitive to small changes in slope or friction angle, whereas intermediate gradient areas are rather sensitive to the hydrological input, friction of unit drainage area.

The role of forest in the stability of local hillslope is evident from Figure 6: 1) the density of soil slips is much lower than the overall failure density; 2) the lower bound for friction angle ranges around 25°, a significantly higher value than those obtained from shear tests. The reason should be ascribed to the additional root strength pseudocohesion

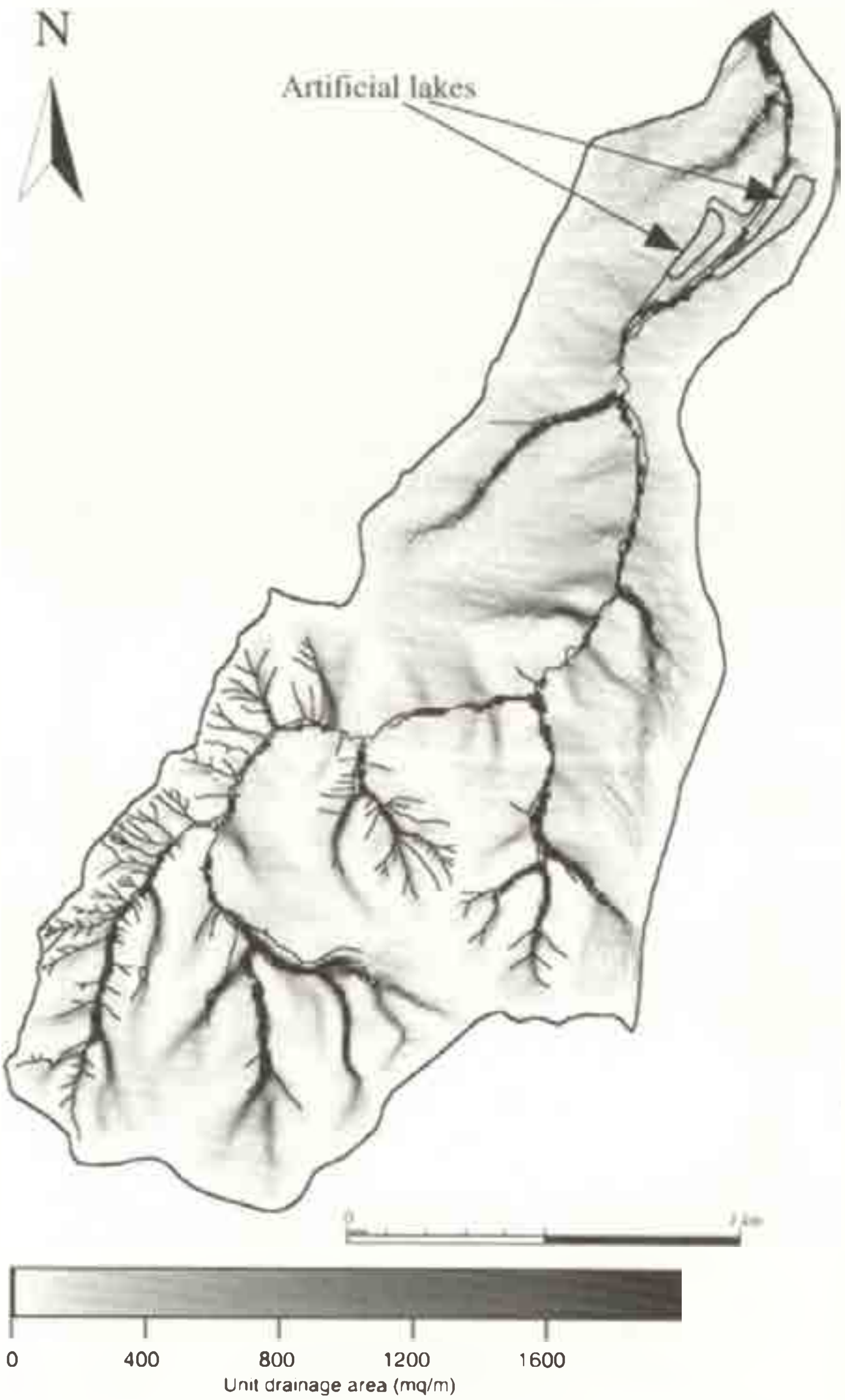

Fig. 7: Map of the unit drainage area (mq/m) calculated from the DEM and channel network from the 1:5000 topographic map. Some shift between observed streams and accumulated flow is due to grid artifacts.

provided by the vegetation. However, the hydrological effect provided by the forest is not clear from this analysis, reflecting the current uncertainties due to the complexity of forest hydrology (e. g road runoff).

On the other hand, where bare soil and bedrock outcrops occur, widespread failure occur with a mobilized ranging around 19°; the hydrological backanalysis yields very low q/T values (from –2.398 to –3.176 for mixed grasslands/shrublands), related to the thin (0–35 cm) colluvium mantle typical of calanchi (*Casadei & Farabegoli* 1998). Landsliding is therefore related to unconditional instability, virtually independent of water input.

Conclusions

The effective geomechanical properties obtained from backanalyses, geotechnical shear tests and simulations consistently range between 19–25°, differing substantially from the previously watersheds investigated by Dietrich hand coworkers in the US Pacific NW, where the bedrock is significantly (∅ ≈ 35°–45°). The highest value correspond to reforested areas, where the additional root strength helps increasing by at least 6° the effective friction angle. The experimental runs of the model show that an increase of ∅ from 19° to 25° decreases by about 6 times the amount of unconditionally unstable areas in the Centonara catchment, meaning that afforestation measures will be particularly effective. Furthermore, the growth of older, more mature forests in similar catchments have shown to be able to stabilize hillslopes up to 30°–35° steep.

The departure from the predicted pattern of instability within the afforested area is consistent with the overall picture. From the practical viewpoint, the increase of effective friction angle in afforested areas and the associated little change in the lumped q/T hydrological ratio, suggests that afforestation works as an effective protection for slopes whose topographic gradient is close to the soil friction angle. On the other hand, the effectiveness of forest plantation for lower gradient areas (where the most important factor is the hydrological ratio q/T) still needs further tests due to the complexity of forest hydrology.

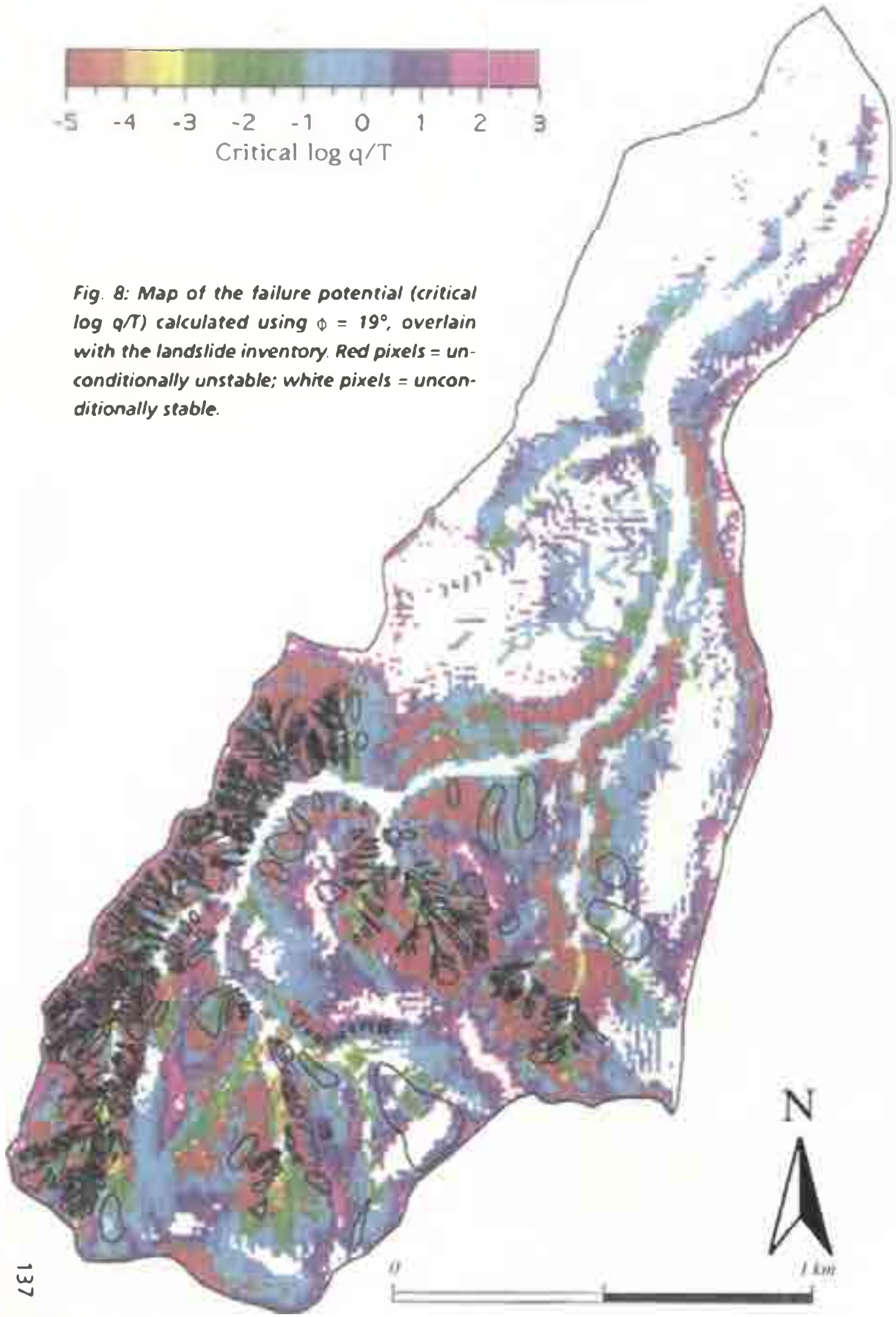

Fig. 8: Map of the failure potential (critical log q/T) calculated using ϕ = 19°, overlain with the landslide inventory. Red pixels = unconditionally unstable; white pixels = unconditionally stable.

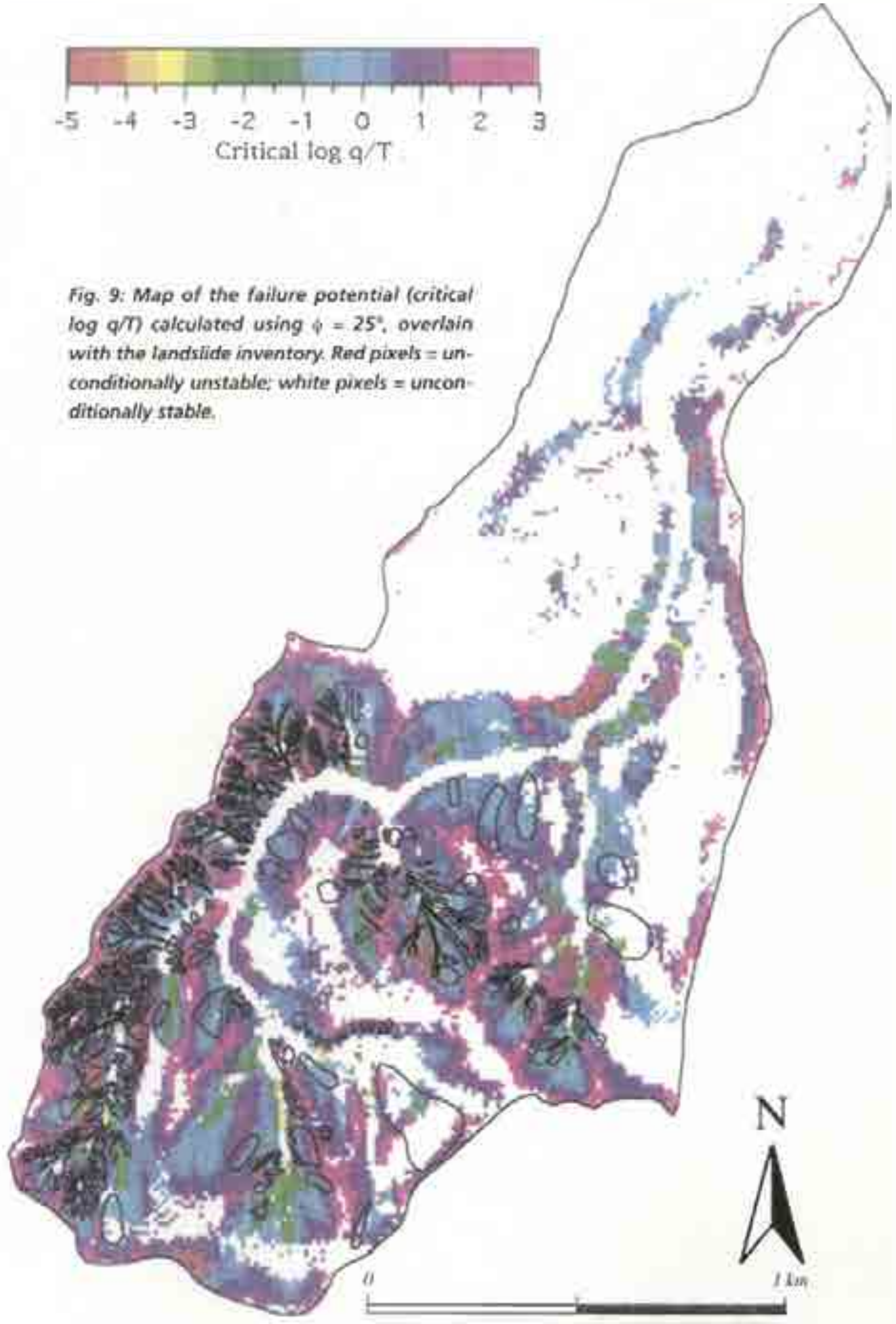

Fig. 9: Map of the failure potential (critical log q/T) calculated using ϕ = 25°, overlain with the landslide inventory. Red pixels = unconditionally unstable; white pixels = unconditionally stable.

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Additional Contributions and Poster Presentations

Waldkalkung mit Asche

Ergebnisse eines Praxisversuches im Rheinisch-Westfälischen Schiefergebirge*

Norbert Asche und N. Nolte

Problemstellung

Ziel einer ökologisch orientierten Volkswirtschaft ist, Neben- und Restprodukte der Güterproduktion als Ausgangsbasis für andere Produktionen zu nutzen. Im Idealfall würde dies zu einer Kreislaufwirtschaft führen, wie sie in natürlichen Ökosystemen realisiert ist. Um diesem Ideal näherzukommen, wurde vom Bundestag das Gesetz zur Vermeidung, Verwertung und Beseitigung von Abfällen (Kreislaufwirtschaftsgesetz) 1994 beschlossen. Damit jedoch Reststoffe einer Produktion in anderen Bereichen eingesetzt werden können, müssen diese Reststoffe bestimmte Mindestanforderungen erfüllen.

Für Düngemittel und Bodenhilfsstoffe sind diese Kriterien in der Düngemittelverordnung verzeichnet. Mit der ersten Verordnung zur Änderung der Düngemittelverordnung wurden Brikettier-Braunkohlenaschen (TAV) – ein Reststoff der Stromproduktion aus rheinischer Braunkohle – für den Einsatz im Landbau zugelassen. Ob diese TAV-Aschen auch zur Bodenschutzkalkung in Wäldern geeignet sind, wird heftig und kontrovers diskutiert. Was bisher jedoch fehlt, ist ein Praxisversuch, um die Wirkung der TAV-Asche im Waldökosystem kennenzulernen. Um diese Kenntnislücke zu schließen, wurde 1994 ein Feldversuch im Forstamt Arnsberg angelegt. Ergebnisse dieses Versuches werden im Folgenden vorgestellt.

Versuchsfläche und Versuchsbestand

Für den Versuch wurde eine 1 ha große Fläche in der Abt. 73, in unmittelbarer Nähe einer seit 1982 von der LÖBF betreuten Kalkversuchsfläche (Abt. 67) angelegt. Wichtige Kennwerte der Flächen sind in der untenstehenden Auflistung zusammengestellt.

Lage:	490 m über NN – Forstamt Obereimer, Abteilung 73 bzw. 67
Wuchsgebiet:	Sauerland
Wuchsbezirk:	Nordsauerländer Oberland
durchschnittlicher Jahresniederschlag:	1.000 mm
durchschnittliche Temperatur:	7 °C
Geologie:	untere Arnsberger Schichten des Oberkarbon überlagert von Fließerde
Bodentyp:	Pseudogleye – Braunerde
Humustyp:	Moder
pH-Wert:	3,40–4,48 (H_2O) 3,01–4,11 (CaCl2)
Basensättigung:	8,6–5,2 %
Bestockung:	Buche (*Fagus sylvatica*), Alter: 130–150 Jahre, vollbestockt
Null-Fläche (1 ha):	keine Behandlung
TAV-Fläche (1 ha):	Ausbringung von 6t Braunkohleaschen pro ha im März 1994

TAV-Asche

Am 09. März 1994 wurden mit einem Kreiselsteuer auf der Versuchsfläche 6 t TAV-Asche ausgebracht. Die Zusammensetzung der Asche und die auf der Fläche ausgebrachte Elementmenge sind in Tabelle 1 aufgelistet.

Tabelle 1: Zusammensetzung der TAV-Aschen und auf der Fläche ausgebrachte Elementmengen (6 t/ha TAV-Asche).

	Gew.-%		kg/ha
SiO_2	3,4	Si	95,4
Fe_2O_3	10,1	Fe	423,0
Al_2O_3	2,0	Al	63,5
CaO	60,2	Ca	2581,5
MgO	4,9	Mg	175,5
Na_2O	0,2	Na	8,9
K_2O	0,2	K	7,5
SO_2	9,2	S	222,0
MnO	0,4	Mn	16,3
BaO	<0,2	Ba	
TiO_2	0,1	Ti	
P_2O_5	<0,5	P	13,1
Cl	0,7	Cl	43,8
	mg/kg		g/ha
Cu	n.w.	Cu	
Cd	n.w.	Cd	
Zn	<2	Zn	
Pb	31	Pb	186,0

Säureneutralisationskapazität (SNK)

Untersuchungen zur SNK der TAV-Aschen hatten gezeigt, daß diese nur unwesentlich geringer ist, als die von Naturkalken und somit ein wichtiges Kriterium für ihren Einsatz im Rahmen der Waldkalkung erfüllt ist. Auch liegen die Schwermetallgehalte der TAV-Asche in einem Bereich, der auch in Naturkalken auftreten kann. Ob der Schwefel-Gehalt der Aschen ein Grund ist sie nicht für die Waldkalkung einzusetzen, wird bisher auf theoretischer Grundlage diskutiert. Hier können die erarbeiteten Ergebnisse zu einer sachorientierten Entscheidung mit beitragen.

Sickerwasser

Aus ausgewählte Kennwerten der Sickerwässer sind für die Tiefen 10 cm, 30 cm

* Extract of a Poster, figures are not reproduced here.

Tabelle 2: Stoffverlagerung mit dem Sickerwasser in kg/ha
Sickerwassermenge (geschätzt): 1994 – 400 mm, 1995 – 400 mm, 1996 – 200 mm.

	Mg		Ca		Al		Cl		NO_3		SO_4	
	Null	TAV	Null	TAV	Null	TAV	Null	TAV	Null	TAV	Null	TAV
	Tiefe 10 cm											
1994	2,0	25,3	5,2	24,0	5,0	9,8	11,4	25,8	38,6	129,0	24,6	105,9
1995	3,0	16,4	6,8	12,8	6,1	4,8	11,1	20,3	61,0	83,9	27,6	48,6
1996	1,4	6,8	3,4	7,1	3,2	2,0	5,7	7,7	21,5	33,7	19,2	26,2
	Tiefe 30 cm											
1994	1,8	12,3	5,4	15,8	5,0	5,6	8,5	18,6	13,1	29,0	33,8	84,6
1995	2,5	10,4	7,9	13,2	4,5	4,8	10,8	16,2	32,5	29,7	32,2	74,9
1996	1,2	5,8	3,2	4,5	2,9	3,0	6,1	7,6	18,8	24,7	17,2	30,5
	Tiefe 90 cm											
1994	1,5	5,0	4,6	8,5	6,8	9,2	9,7	19,5	10,0	12,4	52,1	88,0
1995	1,5	7,0	4,1	7,4	7,4	8,5	12,3	22,2	18,9	13,1	50,3	87,4
1996	0,8	3,7	1,8	2,9	3,9	4,7	7,0	11,7	10,2	7,4	22,6	42,3

und 90 cm ist deutlich zu erkennen, daß direkt nach der Ascheausbringung stark erhöhte SO_4, Ca, Mg und Al Konzentrationen in der Tiefe 10 cm gemessen wurden. Hohe NO_3 Konzentrationen Ende 1994 waren begleitet von deutlich erhöhten Al und auch Mg Gehalten. Bis Ende 1996 haben sich die gemessenen Konzentrationen denen, die auf der Kontrollfläche gemessen wurden stark angenähert.

In der Tiefe 30 cm zeigen die Ergebnisse der Sickerwasseranalyse, daß die SO_4 und Mg Konzentrationen auf der TAV-Fläche hoher sind als auf der Kontrollfläche. Nach der Ascheausbringung stiegen mit einer Zeitverzögerung von ca. 6 Wochen die SO_4 und Mg Gehalte in dieser Tiefe deutlich an und blieben bis Ende 1996 gegenuber der Kontrolle erhöht. Weniger stark ausgeprägt ist dieser Anstieg bei Al und Ca (hohe Gehalte 1994 → Makroporenfluß). Die Nitratkonzentrationen unterscheiden sich auf den Flächen im Zeitverlauf nur wenig.

In der Tiefe 90 cm sind die bereits in 30 cm Tiefe gefunden SO_4 und Mg Konzentrationsunterschiede zwischen den Flächen ebensfalls ausgeprägt. Deutliche Konzentrationsänderungen als Folge der Ascheausbringung wurden bisher nicht gemessen. Steigende SO_4 Werte deuten sich schwach ab Ende 1996 an. Die pH-Werte auf den Versuchsflächen unterscheiden sich mit Werten zwischen 3,5–4,5 kaum.

Stoffverlagerung mit dem Sickerwasser

Multipliziert man die Sickerwasserkonzentrationen mit der Sickerwassermenge, so laßt sich die Stoffverlagerung im Boden abschätzen. In der Tabelle 2 sind diese Daten für die Versuchflächen zusammengestellt. Hierbei wurden mittlere Elementkonzentrationen des jeweiligen Jahres berechnet und geschatzte Sickerwassermengen (im Anhalt an Daten des DWD) verwandt. Die Kalkulation zeigt, daß nach 3 Jahren ca. 90 kg/ha SO_4 bzw. ca. 30 kg/ha S aus dem Boden der TAV im Vergleich zur Kontrollfläche mehr ausgetragen wurden. Dies bedeutet aber auch, daß nach 3 Jahren nach ca. 80 v. H. des ausgebrachten Schwefels noch im Boden gespeichert sind.

Mineralboden

Die Kationenaustauschkapazitat (Ake) weist im humosen Oberboden Werte von ca. 150 meq/kg und im Unterboden Werte von ca. 60 meq/kg auf. Die Austauscher des Mineralbodens sind zu ca. 95 v.H. mit sauer wirkenden Kationen belegt, wobei Al dominiert. Auf eine aktuelle Säurebelastung deuten hohe H- und Fe-Gehalte im Oberboden hin. Die Basensättigung von ca. 14 v.H. in der Schicht 0–4 cm auf der TAV-Fläche kann durch eine fruhere – aber nicht dokumentierte – Bodenschutzkalkung bedingt sein.

Buchenernährung

In der Tabelle 3 sind mittlere Elementgehalte der Buchenblätter zusammengestellt. Gemessen an den Ernährungsgrenzwerten von Bergmann sind die Bäume auf der Kontrollfläche ausreichend mit Ca und N versorgt, unterversorgt mit P, Mg und K und deutlich überversorgt mit Mn.

Durch die Ascheausbringung wurde die Ernährung der Buchen mit Ca und Mg deutlich verbessert, insbesondere im zweiten und dritten Jahr nach der Flächenbehandlung. Auf die Versorgung der Bäume mit K hat sich die Ascheausbringung mit verminderten K-Blattgehalten im ersten Jahr ausgewirkt. Im zweiten Jahr stiegen diese Werte wieder deutlich an und erreichten Werte, die auch auf der Kontrolle gemessen wurden. Deutlich erhöhte Mn-Gehalte der Buchenblätter auf der TAV-Fläche zeigen, daß durch die Aschezufuhr die Verfügbarkeit dieses Elementes erhöht wurde. Das N/K-Verhältnis ist im Vergleich zur Kontrolle nur geringfügig ungünstiger. Trotz der mit der Asche ausgebrachten hohen Schwefelmenge ist

Tabelle 3: Elementgehalte bzw. –verhältnisse der Buchenblätter auf den Versuchsflächen. Mittelwert von jeweils 3 Bäumen.

Fläche	Jahr	mg/g TS								
		Mn	Ca	K	Mg	N	S	P	N/S	N/K
Null	1994	0,9	4,4	8,6	0,9	23,6	1,7	1,3	13,6	2,8
	1995	1,0	4,7	8,1	1,1	26,6	2,0	1,5	13,1	3,3
	1996	0,8	4,0	6,0	1,1	23,5	1,7	1,3	13,5	3,9
	1997	0,8	3,2	5,7	0,6	22,5	1,5	1,2	15,3	3,9
TAV	1994	1,2	6,3	4,9	0,9	20,3	1,5	1,1	13,3	4,1
	1995	1,5	9,2	6,2	2,1	24,7	2,0	1,4	12,6	4,0
	1996	1,2	8,4	5,1	1,5	21,5	1,7	1,2	13,0	4,2
	1997	0,9	7,0	5,4	1,3	21,7	1,4	1,1	15,1	4,0
ausreichende Versorgung		<0,1	3,0–15,0	10,0–15,0	1,5–3,0	19,0–25,0		1,5–3,0		

das N/S Verhältnis nicht verändert und bewegt sich weiterhin in einem physiologisch bedingten engen Bereich.

Schlußbetrachtung

Nach einer Versuchsdauer von drei Jahr konnten bisher keine negativen Effekte im Waldökosystem erkannt werden. Zudem wurden bisher keine durch die Aschen bedingten erhöhten Schwefelausträge in 90 cm gemessen. Das bedeutet, daß noch ca. 80 v.H. des in den Wald ausgebrachten Schwefels noch im System ist und in/an der Bodenmatrix adsorbiert ist. Welche Prozesse hierfür verantwortlich sind ist noch zu klären. Ob die Schwefeladsorption im Boden dauerhaft erfolgt (z.B. Bildung schwerloslicher Minerale) oder aber unter bestimmten Bedingung reversibel ist und zeitverzögert zu erhöhten Austrägen führt, wird die Weiterführung der Messungen zeigen. Die hier vorgelegten Ergebnisse zeigen bisher, das Aschen, die bestimmte Anforderungen erfüllen im Rahmen einer volkswirtschaftlich erforderlichen Kreislaufwirtschaft für die Waldkalkung eingesetzt werden können. Diese ersten bisher positiven Zwischenergebnisse müssen aber durch weitere Untersuchungen besser abgesichert werden.

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Der Wald hat Hunger – Betrachtungen zur Waldernährung*

Norbert Asche

Vorbemerkungen

Der Wald hat Hunger; eine Aussage, die auf den ersten Blick überrascht. Überrascht deshalb, weil wir i.d.R. über die Leistungen des Wald sprechen, über den Holzzuwachs in m³, über die Wasserspende in bewaldeten Wasserschutzgebieten, über die Fähigkeit des Waldes große Mengen Gase und Stäube aus der Atmosphäre zu filtern aber nur selten der Frage nachgehen, wie der Wald dies alles leistet bzw. welche Prozesse ihn zu allen diesen Leistungen befähigen.

Betrachten wir die in einem Wald ablaufenden Prozesse, so kann die verwirrende Vielfalt der Beziehungen (Umwelt – Pflanzen, Pflanze – Tier, u.a.) auf die elementaren Prozesse der Bildung von Biomasse oder Körpersubstanz und deren Zersetzung im Zuge der Mineralisation zurückgeführt werden.

Die Bildung von Biomasse oder besser die Fixierung von Strahlungsenergie in chemische Energie (Zucker und die daraus aufgebauten organischen Stoffe) und die hierzu erforderliche Mineralstoffaufnahme (z.B. Ca, Mg, K, Mn) wird von den ‚grünen Pflanzen' geleistet. Diese pflanzliche Substanz wird von allen nicht zur Photosynthese befähigten Lebewesen (Tiere, Pilze, u.a.) als Energiebasis für ihre Lebensäußerungen und den Aufbau eigener Körpersubstanz benötigt. Die Nutzung der von anderen Lebewesen produzierten Biomasse durch die zahlreichen Organismen in einem Wald ist einer der vielen kleinen, kaskadenartigen Schritte, die letztendlich dazu führen, daß die organischen Stoffe wieder in ihre Grundsubstanzen zerlegt bzw. mineralisiert werden. Hierbei werden auch die Mineralstoffe freigesetzt und stehen dann für eine erneute Aufnahme zur Verfügung.

Mineralstoffe und Pflanzenwachstum

Mineralstoffe sind elementare Bestandteile von Lebewesen. So ist z.B. das Zentralatom des Chlorophyll das Magnesium, Calcium ist wichtiger Bestandteil der Zellwand, Stickstoff ist Bestandteil von Nucleinsäuren und Eiweiß, Phospor ist unverzichtbar für den Elektronentransfer; Eisen, Mangan, Kobalt, Kupfer, Zink sind Baustoffe für verschiedene Enzyme und Redoxkörper; Kalium, Calcium, Magnesium sind wichtige Stoffe zur Regulierung des Wasserhaushaltes der Pflanze. Diese Aufzählung ließe sich noch erheblich erweitern. Wichtig ist, daß für zahlreiche Prozesse des Lebens Mineralstoffe genauso wichtig sind wie Wasser oder Sonnenlicht und das sie unmittelbar und über den Umweg über den Baustoffwechsel die Wuchsleistung, also die Menge fixierten Kohlenstoffes, beeinflussen. Auf Standorten mit einer ausgewogenen Mineralstoffversorgung und einer Bodenreaktion im Bereich von pH 5–7 ist die Deckung des Mineralstoffbedarfes der Pflanzen leicht möglich. Auf diesen Standorten wird die Höhe der Biomasseproduktion durch die Wasserversorgung und das Kleinklima bestimmt.

Auf Standorten die keine ausgewogene Mineralstoffversorgung aufweisen und die durch eine stark saure Bodenreaktion gekennzeichnet sind (pH < 4) ist es für die Waldbäume oftmals kaum möglich den für ein ungestörtes Wachstum nötigen und ausgewogenen Bedarf an Mineralstoffen zu decken. Auf derartigen Standorten kann es zu einer Nährelementunterversorgung, zu Mangelerscheinungen oder zu Nährstoffungleichgewichten kommen, die negative Folgen für die Vitalität des Baum haben können. Während ein latenter Mangel nur analytisch zu belegen ist, weisen spezielle Symptome (z.B. Mg: Interkostalchlorosen auf älteren Blättern; K: Blattspitzennekrose mit kurzem Übergang zum lebendem Blatt, Wurzelfäule; Fe: strohgelbe Intercostalchlorosen bis Weißfärbung junger Blätter mit grünen Blattadern; *Larcher* 1980, *Bergmann* 1988) auf einen Mangel an Mineralstoffen hin, der eine ungehinderte Entwicklung der Pflanzen nicht mehr erwarten läßt.

* Extract of a Poster, figures are not reproduced here.

Waldnutzungen, Mineralstoffentzüge, Boden- und Waldzustand

Wälder wurden schon frühzeitig (Beginn vor ca. 5000 Jahren) auf den nährstoffreichen und für die landwirtschaftliche Nutzung gut geeigneten Standorten gerodet. Die verbliebenen Wälder waren durch die Zeitläufte eine wichtige wirtschaftliche Resource, die in den Jahrhunderten unterschiedlich intensiv durch Holzernte, Streurechen, Viehweide usw. genutzt wurden.

Mit diesen Nutzungen wurden den Wälder erhebliche Mengen an Nährstoff entzogen. Wird z. B. die Laubstreu eines Jahres einem Buchenwald entzogen, so verliert das Waldökosystem damit ca. 3 t Biomasse/ha, ca. 25 kg K/ha, ca. 11 kg Ca/ha, 2–3 kg Mg/ha und zahlreiche weitere Nährstoffe (Tabelle 1). Wird diese Nutzung über mehrere Jahrzehnte betrieben und gleichzeitig das Holz des Waldes genutzt, so führen diese Nutzungen sehr schnell zu Nährstoffentzügen, die mehrere hundert kg/ha betragen können. Können diese Nährstoffe aus der Verwitterung der Gesteine und Minerale nicht wieder ersetzt werden, so verarmt der Boden, die aufstockenden Waldbäume zeigen Mangelerscheinungen oder werden durch weniger anspruchsvolle Pflanzen (z. B. Birke, Heidekraut) ersetzt. Eine eindrückliche Beschreibung einer über lange Jahre betriebenen Biomassenutzung, die die nachschaffende Kraft des Bodens überstiegen hat, liegt aus dem Eggegebirge von KAMLAH (1929) vor:

„... *Nach einer aus dem Jahre 1786 stammenden Revierbeschreibung des ... Forstmeisters Grotian war damals der Kamm des Gebirges und dessen nördlicher Teil von jedem Baumbestand entblößt und wo sich in den tieferen Lagen und im Süden ein solcher noch fand, verdiente er noch eben die Bezeichnung Räumde... Den Boden überzog bei völliger Freilage ein reicher und üppiger Heidefilz, auf den Raumden und in verlichteten Beständen wucherte die Heidelbeere. Anscheinend haben diese unerfreulichen Zustände lange Zeit geherrscht, denn sonst könnten ihre Einwirkungen auf den Boden nicht jetzt noch so deutlich ausgeprägt sein... Gesteinverwitterung, klimatische Einflüsse und Vegetation haben nun eine Boden geschaffen, der sich allen Bodeneinschlägen wie folgt beschreiben läßt: Soweit Boden frei von jedem Baumwuchs lediglich von Heidefilz bedeckt gelegen hat, ist unter einer Bleicherde von 10–30 cm Mächtigkeit, die an einzelnen besonders ungünstigen Stellen eine Stärke bis zu 70 cm erreicht, ein 2–6 cm starkes Orterdeband vorhanden. Dieses Orterdeband ist die Folge der vorhergegangenen Verheidung und verschwindet schon dort, wo Beerkrautvegetation unter dem lichten Schirm einiger Waldreste den Boden deckt. Die Bleichzone tritt aber auch hier in gleicher Stärke und Intensität auf und nimmt nur dort nach beiden Richtungen hin ab, wo von alters her geschlossene Waldteile sich erhalten haben.*"

Tabelle 1: Biomass-, Potassium-, Calcium- and Magnesium-Supply (kg/ha) in a Beech Ecosystem on Acid Cambisol (Braunerde) in the Solling 1968 (Ellenberg 1986; Tab. 111, Extract).

Alter (Jahre) 120	Baumteil		Biomasse TS in kg/ha	Kalium kg/ha	Calcium kg/ha	Magnesium kg/ha
	Blätter		3078	24,6	11,1	2,2
	Blüten, Früchte		360	1,3	1,6	0,3
	Äste	Holz	25960	33,5	24,0	5,7
		Rinde	6500	8,1	52,7	2,4
	Derbholz	Holz	222900	175,2	118,9	40,1
		Rinde	15500	30,3	96,3	16,6
	Totholz		687	0,7	0,4	0,2
	Wurzeln		37070	57,4	64,6	15,2
Summe	oberirdirsch		**275005**	**274,0**	**305,0**	**67,5**

Die Nutzungen in unseren Wäldern beschränken sich heute i. d. R. auf die Entnahme des Stammholzes und die hiermit verbundenen Nährstoffentzüge liegen in einer Größenordnung, die durch die nachschaffende Kraft der Böden ausgeglichen werden kann. Durch die großräumigen Luftverunreinigungen werden derzeit große Mengen an Schad- (z. B. Säuren, Schwermetalle) und Nährstoffen (z. B. Stickstoff) in die Wälder eingetragen, die ihre ökosystemneutrale Aufnahmekapazität z. T. deutlich übersteigt. Die hohe Säurebelastung von ca. 1–4,5 keq pro (ha*a) (*Gehrmann* 1993) bewirkt eine weitere Nährstoffverarmung (z. B. Ca, Mg, K) und Versauerung der Böden. Gleichzeitig führen die hohen Stickstoffeinträge (ca. 20–60 kg/[ha*a]) zu einer unausgewogenen Pflanzenernährung und im Extremfall einer Übersättigung des Waldökosystems mit diesem wichtigen Nährstoff. Vitalitätsminderungen, erhöhte Anfälligkeit gegenüber pathogenen Organismen und eine verminderte Artenvielfalt können die Folge sein.

Mineralstoffversorgung von Buchenwäldern in NRW

Die ständigen Entzüge wichtiger, basisch wirkender Nährstoffe haben insbesondere auf basenarmen Böden bewirkt, das der Wald oder besser die Waldbäume ‚Hunger nach Magnesium, Calcium, Phosphor und weiteren Elementen haben'. Wie groß dieser Hunger ist, wird auf ausgewählten Versuchsflächen von der LÖBF untersucht. Dazu werden aus der Lichtkrone von jeweils 3 Bäumen je Versuchsfläche durch Zapfenpflücker 2 oder 3 Äste Ende Juli Anfang August entnommen. Die Blätter werden am Boden von den Ästen gezupft, in Transportgefäßen gesammelt und anschließend bei 60 °C bis zur Gewichtskonstanz getrocknet. Die Analyse erfolgte nach standardisierten Verfahren (RFA) durch die LUFA Münster.

Die Ca-Versorgung von vier Buchenbeständen auf sauren (pH-Wert [H_2O] 4) und basenarmen (Basensättigung der Austauscher < 10 v. H. der KAKe) Böden wurden zwischen 1991 und 1995 untersucht. Die einzelbaumbezogenen Ca-Gehalte weisen in den untersuchten Jahren eine gewissen Schwankungsbreite im unteren Bereich einer ausreichenden Ca-Ernährung (Bergmann 1988) auf. Dabei wurden die höchsten Blattgehalte in Monschau und die geringsten in Hilchenbach gemessen.

Die Magnesiumgehalte der Blätter weisen z. T. erhebliche Schwankungen in einzelnen Jahren auf. Allen Bäumen gemeinsam ist jedoch, daß sie, gemessen an den Daten von Bergmann (1988), einen deutlichen Mg-Mangel aufweisen. Auf der Fläche in Hilchenbach, wo Mg-Gehalte der Blätter im Bereich von 0,4 mg/g TS gemessen wurden, können

Tabelle 2: Relation of Mineral Nutrients in Beech Leaves.

Buchenblattanalyse Kontrollflächen, Mittelwerte je Baum

Zeitraum	Baum		K/Ca	N/P	N/K	N/Mg	N/Ca
1991–1995	7	x	2,2	18,1	2,9	34,2	6,1
		V%	15,5	8,0	14,1	14,9	6,5
Obereimer	8	x	1,4	18,8	3,7	24,7	4,9
		V%	17,0	5,1	12,6	11,6	6,3
	9	x	1,6	18,5	4,0	28,7	6,2
		V%	20,3	4,6	22,6	17,8	16,4
1992–1995	13	x	1,2	21,3	3,2	35,7	3,9
		V%	12,9	1,5	17,5	22,5	18,2
Monschau	14	x	1,2	22,7	3,9	32,7	4,5
		V%	8,3	8,1	19,6	10,1	14,5
	15	x	1,6	23,8	3,0	27,8	4,7
		V%	9,2	7,3	13,3	11,7	5,3
1992–1995	7	x	1,7	18,8	5,6	54,1	9,3
		V%	23,7	4,8	16,3	4,8	22,6
Hilchenbach	8	x	1,8	16,4	6,4	38,8	6,6
		V%	20,6	5,7	18,3	18,1	12,3
	9	x	1,1	16,5	4,6	38,2	5,0
		V%	36,0	7,8	15,4	23,8	32,5
1991–1995	13	x	1,7	22,7	4,0	35,5	6,9
		V%	14,9	11,2	17,8	21,5	21,5
Kleve	14	x	1,9	25,2	4,1	27,1	7,5
		V%	16,6	6,5	19,9	14,5	17,9
	15	x	1,8	23,5	4,8	24,7	7,1
		V%	14,9	3,5	9,5	25,6	21,6

x = Mittelwert V% = Variationskoeffizient

Buchenblattanalyse auf den 1983 gekalkt. bodenbearb. und 1990 gekalkten Flächen

Zeitraum	Baum		K/Ca	N/P	N/K	N/Mg	N/Ca
1991 – 1995	1	x	0,46	14,3	4,0	15,8	1,7
		V%	26,8	3,8	24,1	29,1	12,4
Obereimer	2	x	0,43	16,3	5,0	17,0	2,2
		V%	10,9	8,6	13,1	22,8	13,2
	3	x	0,32	12,0	4,8	12,1	1,5
		V%	17,9	18,0	20,1	26,8	17,3
1992 – 1995	1	x	0,56	17,0	3,3	16,7	2,8
		V%	17,7	6,4	6,9	15,7	14,8
Monschau	2	x	0,61	17,5	3,7	25,0	2,2
		V%	14,6	5,8	5,0	20,4	11,0
	3	x	0,43	13,3	4,1	16,8	1,8
		V%	17,8	4,0	10,3	25,3	8,1
1992 - 1995	1	x	0,46	12,0	3,5	39,6	1,6
		V%	16,7	10,9	19,4	21,7	10,3
Hilchenbach	2	x	0,47	14,1	4,7	21,0	2,2
		V%	16,7	5,7	14,7	25,6	6,8
	3	x	0,48	14,8	5,1	36,3	2,4
		V%	21,0	8,3	12,6	18,3	12,1
1991 – 1995	1	x	0,52	18,5	4,6	19,8	2,4
		V%	6,6	9,2	6,7	26.5	8,5
Kleve	2	x	0,57	19,5	4,4	14,9	2,5
		V%	14,4	9,3	7,5	28,7	8,2
	3	x	0,7	20,1	4,2	24,6	2,9
		V%	12,5	6,5	15,7	17,4	13,8

x = Mittelwert V% = Variationskoeffizient

Wuchsstörungen als Folge dieses Mangels nicht ausgeschlossen werden.

Die Stickstoffversorgung der Blatter auf den Kontrollflachen ist ausreichend. Einzelne Bäume auf den Flächen in Obereimer, Monschau und Kleve weisen sehr hohe N-Gehalte auf. Derart hohe Gehalte deuten auf eine Überversorgung mit diesem Nahrstoff hin und können dazu führen, daß diese Baume attraktiv für saugende und pathogene Organismen werden.

Die Verhältnisse wichtiger Nährelemente der Buchenblatter sind in Tabelle 2 zusammengestellt. Dabei kennzeichnen folgende Verhältnisse eine normale, ausgewogene Ernährung: N/P 12–17, N/K 2,5–3,3, N/Mg 12–22, N/Ca 1,8–3,3. Ein Mangel bzw. eine unausgewogene Ernahrung ist durch folgende Verhältnisse charakterisiert: N/P >24, N/K >4,7, N/Mg >24 und N/Ca >6,2. Nahezu alle Daten der Tabelle 2 zeigen, daß die Baume auf den Kontrollen nicht ausgewogen ernahrt sind. Dies gilt insbesondere für das N/Mg- und das N/Ca-Verhältnis, wo die Daten auf einen Mangel an Ca bzw. Mg oder aber auf eine sehr hohe Stickstoffversorgung der Bäume hinweisen. Das N/K- und das N/P-Verhaltnis zeigt Werte, die zwischen einer normalen Versorgung und dem Mangelbereich liegen.

Effekte der Waldkalkung

Durch die Zufuhr von 2 mal 6 t Hüttenkalk/ha, dies entspricht ca. 3500 kg Ca und ca. 510 kg Mg, konnte die Ca-Versorgung der Buchen deutlich verbessert werden und alle untersuchten Baume auf den unterschiedlichen Versuchsflächen weisen als Ergebnis dieser Nährstoffzufuhr eine ausreichende Ernährung auf.

Die Mg-Versorgung der Waldbaume konnte durch die Kalkausbringung verbessert werden (Bäume in Monschau und Kleve). Jedoch zeigt sich, daß die Versorgung der untersuchten Baume eine große zeitliche und räumliche Spannweite aufweist (z.B. Hilchenbach, Kleve) und das die ausgebrachte Mg-Menge nicht ausgereicht hat, den

Bäumen eine ausreichende Ernährung (Bergmann 1988) zu ermoglichen.

Die Stickstoffversorgung der Blätter ist auf den gekalkten Flächen ausreichend. Auffallend ist, daß die Stickstoffgehalte der Blätter auf diesen Flächen unter denen der entsprechenden Kontrollfläche liegen. Wichtig ist, daß trotz der hohen Stickstoffeinträge (20–60 kg N/(ha*a) die Kalkung zu einer ausgewogeneren Buchenernährung beitragt.

Aus der Tabelle 2 ist zu erkennen, daß sich das N/Ca und das N/Mg-Verhältnis in einem normalen, ausgewogenen Ernährungszustand kennzeichnenden Bereich auf den Kalkflachen bewegt. Das N/K- Verhältnis hat sich im Vergleich zu den Kontrollen nur wenig verändert. Deutlich verschlechtert hat sich demgegenüber das K/Ca-Verhältnis der Blätter.

Schlußbetrachtung

Hohe Entzüge basisch wirkender Nährstoffe durch Biomassenutzung und Säureeinträge haben zur Folge, daß die Waldbäume auf basenarmen Standorten heute einen erheblichen ‚Hunger' nach diesen Stoffen haben. Wenn wir die natürlichen Abläufe und die Stoffkreisläufe in den Wäldern fördern und unterstützen wollen, so müssen wir die Nutzungen und Belastungen in einer Größenordnung halten, die von den Waldokosystemen nachhaltig verkraftet werden können. Entzüge von Nährelementen, die über der nachschaffenden Kraft der Standorte liegen, bewirken, daß sich die Wälder mit ihren Pflanzengesellschaften ändern und eine nachhaltige, langfristige Nutzung nur noch eingeschränkt moglich ist.

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At the Beginning of the New Millennium German Forests are in a Critical Condition

An interim report after a 15 years stocktaking of forest decline in all 16 countries of the Federal Republic of Germany

Rudolf Beyse

At first, I would like to point out that in my estimation it is urgently necessary to finally take stock of the "Waldsterben" or the new types of forest damage or to use the English word *forest decline*, now at the threshold of the 21st century. It must be remembered that since the end of the seventies damages of trees in German forests have been observed in various regions but far away from industrial plants. There has been intensive research of this forest decline for some time. I would like to refer to the forest ecosystem research at the University of Göttingen, an applied science of forest ecology which produced new conclusions pointing the way for the future. By the way, the results from the officially required survey of forest decline as from 1983 are available for all the states in Germany, i.e. covering a period of 15 years in all. I will use the report of the condition of the forests ("Waldzustand") for the year 1998 in the form of a resume, in order to present and comment upon the conclusions of the survey conducted under the same parameters. From the point of view of natural science and from the point of view of environment policy, I am convinced that the above-mentioned period for research and systematic stock taking in the forests should be adequate in order to present a founded report (Balance). I regret to state that so far this has not yet happened. It goes without saying that a report alone is not sufficient, it is necessary at the same time to take urgent action that means counter measures for saving the forest in Germany.

The 1998-report of the Federal government about the condition of German forests documented: only 38 % of the trees in the forests can be classified as being sound.

The statement or identification of the damage to trees in the forests of all categories was arranged within uniform parameters between the Federal government and the 16 German states. On the basis of results of such a stock taking, which is usually conducted in the late summer, the responsible forestry department of the states draw up corresponding reports which are then summarised by the responsible department in the Ministry for Food, Agriculture and Forestry thus producing "a report about the conditions of forests in Germany". This official Federal government report is then presented at the end of November or early December on the occasion of a Federal press conference to the public:

In the following presentation of the results in the estimate of the damage to the trees in German forests – one can also say terrestrially or visible damage – I must point out beforehand that the damage to or the disease of the trees registered at five different grades of damage. A brief description of these five grades see below when mentioning the results for 1998.

- 41 % of trees are graded in Grade 1 (slight damage, 11–25 % loss of needles or leaves)
- 21 % of the trees belong to Grades 2–4, this means evident or better "serious damages" which is specified more precisely as follows:

Grade 2 = moderately seriously damaged with 26 to 60 % loss of needles or leaves
Grade 3 = seriously damaged with over 60 % loss of needles or leaves
Grade 4 = dead trees, that means dry or withered and without needles or leaves of course.

- 38 % were classified as being Grade 0, (these are the trees still sound or undamaged, but they are allowed to have lost up to 10 % of needles or leaves).

If we can now concentrate on the obviously or better seriously damaged trees, which are unfortunately summarised in the tree grades No. 2, 3 and

4 and then only consider the economically most important kind of trees the result is as follows:

- 37 % of the oak trees were seriously damaged
- 29 % of the beech trees, as before
- 26 % of the spruce trees, as before and
- 10 % of the pine trees, as before.

These specifications are average results for all age groups of the four named species. At this juncture I have to state the well-known fact, that trees older than 60 years are much more affected by serious damages than younger ones. The figures, stated for the year 1998, are as follows: The oaks taking the top-position with 47 %, followed by the spruces with 40 %, the beeches with 35 % and the pines (16 %). The white firs coming to 46 %, same as the larches.

The main problem is the hidden damage in the forest soil

The forest decline researchers in the University of Göttingen under Professor Bernhard Ulrich had already drawn attention at the end of the seventies to the special significance of the forest soil especially to their chemical condition. But it was only between the years 1987 to 1993 that all German states conducted a report concerning the condition of the soil in the forest (BZE). The results were documented in the "German Forest Soil Report 1996", Vol. I. We refer here to the second edition of this report from the Federal Ministry for Food, Agriculture and Forestry (*BMELF*), published in February of 1999.

In the preface of this report on the condition of the soil in German forests, the responsible Federal minister for nutrition declared the following: "The soil as part of the forest ecosystem will play a key role. It filters and retains water and acts as a buffer for the entry of other substances and, at the same time, is the site as well a source of nutrition for plants. Soil that is functionally sound is a prerequisite for vital forests. In the course of sustained forest economy the preservation of fertility of the soil will be considered of great importance."

Furthermore, the high level of entry of other dangerous substances from the atmosphere over the last decades has changed the soil and to some extent impaired its function. Moreover, it depends on the capacity of the soil to act as a filter, buffer and transformer of substances, whether, in the course of time, the forest ecosystem can absorb nitrogen input and acid deposition without serious damage to forests (forest decline).

Alarming results after researching the condition of forest soil

The forest soil reports mentioned before shows that on the basis of testing about 1800 samples in a screen of 8 by 8 km, following findings have been made:

There is an extensive overall acidification independent of substrate, and lack of chemical base of the top soil as well as a tendency to a levelling of the chemical condition of the top soil on a low level. Furthermore, it can be concluded from the established disharmony between pH-level, C/N ratio and humus form that the transformation processes of the soil are being overlayed by atmospheric inputs of acids and also of nitrogen.

Intensive pollution by immissions of the forest soil is also evident when considering the heavy metal content in the top layer of humus. The accumulated lead- and copper content around the humus reaches a potentially toxic concentration for soil condition investigation. With regard to the more mobile heavy metals zinc and cadmium it can be assumed that in the acid sites there are already larger amounts transferred into the mineral soil.

Certain parts of soil have to be referred to where there is an evident lack of nutrients and an unfavourable humus form. The predominant part of the nutrient pool that is available in the short and middle term is to be found in the humus cover thus constituting a particularly labile and endangered nutrient pool.

With regard to the evaluation of the nutrient situation of the spruce, pine and beech trees referring to the data from needle/leaf analysis, particularly in the northern part of Germany there is an indication of excessive provision of nitrogen thus resulting in a disharmony at the ratio of the nutrient elements (N/B, N/K, N/Mg). Furthermore, there is a minimal and to some extent very minimal widespread phosphor content in all areas. Particularly in mountainous regions, especially on sandstone, there are clear signs indicating a lack of magnesium provision.

Finally the sulphur content in the needles and leaves of pine and beech trees indicates the clear effect of immissions. The natural sulphur content in the spruce stands investigated was frequently in excess of the norm.

So much for the resumé for the most important results regarding the condition of forest soil conducted over 7 years (1987 to 1993) whereby, of course, certain aspects still have to be supplemented and completed. But this is however not the point. As per my estimation from the description of the bad condition of German forest soil the following conclusions can clearly be made: *The circulation of nutrients in the forest is considerably disturbed. The diagnosis can be made that the patient forest or the forest ecosystem is suffering from a very grave disturbance of circulation of nutrients which can lead to collapse.*

Consequences of the critical condition of German forests

Taking stock of the damages which have been occurring to forests in Germany for roughly 20 years, which the Minister for Food, Agriculture and Forestry characterizes as having "stagnated at a high level of damage", and the well-known fact that only one-third of the trees in German forests can be given a clean bill of health – we come to the following realizations:

The causes of these severe damages to trees and soil in the forest have by now been so clearly identified by scientists in nearly every discipline as to make further research actually unnecessary. However, it will indeed be necessary for scientists from various fields, such as forestry, pedology, ecology, agricultural science, water management, etc., to supervise the practical implementation of these research findings. It has now been proven that the amounts of nitrogen and acidogens acid rain has brought into the forests in the past twenty years or more greatly exceed the capacity of forest ecosystems to absorb them and provide a buffer. Humans themselves are the ones discharging these substances into the forest, however, primarily through incendiary processes in industry, motor vehicle traffic, private households and, not least, agriculture. Moreover, the soil acidification caused by the discharge of such substances or acids is continuously increasing and accelerating. These excessive amounts of nitrogen can only disturb the balance of nutrients and minerals in the vicinity of tree roots, and at the same time endanger ground water and thus drinking water, as well. These alarming findings, based on special studies of the soil in German forests commissioned by the federal government itself, should actually at long last be sufficient to cause steps to be taken immediately to combat this process and to save the German forest. In view of the severity of these damages and how important the forest is to people, the environment, the climate, etc., I consider a truly objective, public presentation and explanation of the damage to forests discussed above not only to be justified, but also to be urgently needed. After all, it is the duty of our representatives and the responsible ministries to inform people from all walks of life, and to point out the dangers and consequences of the gradual but certain destruction of the forest, especially in a country such as Germany, thirty percent of which is still covered by forests. This appeal is aimed not only at politics and business, but especially at science and the media.

The steps to be taken immediately against this ongoing "forest decline" can only be presented in outline form within the scope of this brief paper. Since the primary causes of damage to forests are mainly the result of emissions from increasing traffic and agriculture (factory farming, intense animal breeding) and power generation, these are the sectors in which we must make a start.

Although the numbers of private cars in Germany went down by roughly six percent to 41.5 million between 1992 and 1997, this number is forecasted to rise to fifty million private cars in the year 1999. Although new private cars use less fuel thanks to advanced technology, the simultaneous trend towards heavier, more powerful vehicles and an average fuel consumption of 8.9 litres per hundred kilometres have remained constant. However, the new VW Lupo is an exception to this rule, since it uses only three litres per hundred kilometres and it is hoped that this car will set new standards. It remains to be pointed out, however, that more than 57 billion litres of fuel are burned in car engines alone every year, releasing the incredible amount of at least 120 million metric tons of carbon dioxide (CO_2) the most important greenhouse gas. Added to this is truck traffic, which has increased by about 26 % since 1992 alone and will increase by another 25 % in the coming fifteen years, according to a forecast by the German automobile club, ADAC. Based on these and other data from the field of traffic, the following steps, among others, have been recommended.

1. a gradual increase in the tax on mineral oil of up to 25 Pfennig, dedicated to the long overdue promotion of local public passenger transportation;
2. setting the maximum average fuel consumption at five litres per hundred kilometres starting in the year 2005;
3. increased expansion of the network for hauling freight traffic by rail;
4. avoidance of traffic must be given top priority, and this through appropriate urban development measures, such as integrated living and working, or an environmentally friendly life style with regard to necessities and leisure time.

As far as the agricultural and power generation sectors are concerned, less intensive agricultural production is being demanded, as well as more efficient use of energy and energy-saving measures. Increased use of renewable sources of energy (wind, water, sun, biomass) would also be an important step.

To sum up, it is especially important and of the utmost urgency to reduce by law the amounts of sulphur dioxide, nitrogen oxides and ammonia which are polluting the air and to implement these laws in clearly defined, shorter periods of time.

I thank you for your kind attention and hope my statements have contributed to the important environmental topic of forest decline.

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Ozone Air Pollution in the Ukrainian Carpathian Mountain Forests

Oleg Blum

Abstract

Information on air pollution status of the Ukrainian Carpathians is essential for a better understanding of environmental stresses which affect valuable forest ecosystems of Central Europe. In this regard information on levels of ozone, one of the main components of photochemical smog and a strong phytotoxic agent, are of special interest.

Ambient concentrations of tropospheric ozone (O_3) were measured at four selected clean highland forest locations (Uzhoksky Pass, 850 m a.s.l.; National Park "Synevir", 1000 m a.s.l.; Carpathian Biosphere Reserve, 750 m a.s.l., and National Park "Vizhnitsa", 650 m a.s.l.) during four spring-summer periods, from May to September 1996–1998 by using O_3 passive samplers. The ozone passive samplers were calibrated against the Thermo Environmental Model 49 ozone monitor.

The 2-week long average concentrations in June-July in the Carpathians were in the range of 10,7–67,1 ppb and in July–August 21,9–79,6 ppb. In general the measured 2-week surface ozone concentrations in above-mentioned forests locations were similar the values determined in the highland forested locations of Poland and the Czech Republic. This is not surprising considering that probably most of the ozone precursors in the Carpathian sites originated in the highly polluted area of these countries. In general, the O_3 concentrations in the four mountain forested locations in Ukrainian Carpa-

thians were low or only moderately elevated. The measured concentrations were similar or slightly lower than the values determined in the forested locations of central and southern Poland (*Bytnerowicz* et al. 1993; *Godzik, B.* 1996) and the Czech Republic (*Bytnerowicz* et al. 1995). This is not surprising considering that probably most of the ozone or ozone precursors in the Carpathian sites originated in the highly polluted area of southern Poland and the northern Czech Republic. The predicted increase of automobile traffic in Ukraine and the neighboring countries and long-range transport of the air masses contaminated with photochemical smog may cause further increase of O_3 concentrations in the forested areas of the Ukrainian Carpathian Mountains.

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Forest Ecosystems and their Disposition to Changing Patterns of Global Nitrogen and Acid Deposition

Gerald Busch, Gerhard Lammel and Friedrich O. Beese

Abstract

A global assessment of the impact of the anthropogenic perturbation of the nitrogen and sulphur cycles on forest ecosystems is carried out for both the present-day (1980–1990) and a future (2040–2050) situation under a moderate scenario of economic development (IPCC IS92a). Results show that forest soils will receive considerably increasing loads of nitrogen and acid deposition in several regions of the world which enlarges the imbalance between acidification on the one hand and a biased fertilisation on the other. The regions which are most prone to these cumulative imbalances are identified in the subtropical and tropical regions of South America and Southeast Asia apart from the well known "hotspots" North-eastern America and Central Europe.

1. Introduction

The anthropogenic influence on global biogeochemical cycles lead to a new situation for forest ecosystems: Increasingly, multiple compounds of nitrogen, sulphur and carbon are simultaneously available in large quantities (regionally even in surplus). In the pre-industrial era, the mean global atmospheric N input was in the range of 1–5 kg N $ha^{-1}a^{-1}$ (1), (2). Therefore input of nitrogen has been the limiting factor for plant growth in most forest ecosystems until the beginning of the industrial revolution (1). During the last decades forests in Europe and North-eastern America have been in transition from nitrogen deficient to nitrogen saturated systems due to increasing nitrogen deposition. The impact of nitrogen deposition on plants and soil is through both fertilising and toxic effects, eutrophication and acidification. Responses of forest ecosystems are supposed to be highly non-linear and would not be captured by simple dose-response functions. To assess the response of forest ecosystems apart from nitrogen input knowledge of the nitrogen status and nutrient conditions is crucial [e.g. (3), (4), (5)].

Due to the emissions of acid forming gases (SO_2, NO_x) large amounts of acids are deposited as wet and dry deposition on soils and forest vegetation in industrialised regions. Since forest canopies have higher filtering capacity than other vegetation types and the majority of the deposition is washed to the soil, forest soils are most affected by the problems associated with acid deposition. Acidified soils and related nutrient imbalances (6–8) lower the resilience of forest ecosystems and increase their sensitivity to biotic or abiotic stress (9), (10), (11). In the last decades anthropogenic sulphur- and nitrogen emissions have been discussed in the context of acid rain (9), (10), (12) and have influenced policy in Europe and North America (e.g. LRTAP UN-ECE Second Sulphur Protocol, Clean Air Act).

It is the aim of this examination to show the disposition of global forest due to the dynamic of changing deposition patterns. As a consequence of population growth and rapid economic development, increasing loads of nitrogen and sulphur to the terrestrial ecosystems might well not remain limited to the known "hotspots" in Europe and North America but could expand and become critical as well for tropical and subtropical regions.

For quantification we use, besides other data sets, present-day and – under a scenario – future acids and nitrogen deposition data as produced by global scale models to show the regional distribution of the increasing bias between acidification of forest soils and Nitrogen fertilisation.

2. Methodology

2.1 Deposition assessment

We use depositional data from validated global models for the assessment of the extent and impact of atmospheric inputs to forest ecosystems. Due to data limitations for many regions of the globe such an assessment can still to date not be made based on monitoring data (13). Moreover, model application allows for the investigation of future scenarios. SO_y (= SO_2 + sulphate), NO_y (= NO_2 + HNO_3 + nitrate) deposition fields are calculated by a high-resolution general circulation model (GCM) of the atmosphere, ECHAM4 (14). NH_y = (NH_3 + ammonium) by a coarse global tracer model, MOGUNTIA (15).

We use emission inventories with

high spatial and monthly temporal resolutions (refer to (16), (17), (18) for details). We use NO_y deposition data from time slice experiments with ECHAM4, 19 vertical layers, 3.75°*3.75° horizontal resolution, and SO_y data from a numerical experiment, 19 vertical layers, 2.8°*2.8° horizontal resolution, with transient changes in anthropogenic SO_2 emissions and in greenhouse gas concentrations during the period 1860–2050 (19). NH_y deposition fields are taken from a run which uses monthly average temperature, winds, 10 vertical layers, 10°*10° horizontal resolution.

The atmospheric residence times of the pollutants under study are in the order of days. This implies the predominance of regional transport or, in other words, emission and deposition time and space patterns do match within weeks and within 300 to 3000 km, respectively [cf. (20) besides others].

2.2 Depositions and assessment under a future scenario

Under the assumptions of a future scenario (21) the same work is carried out for the years 2040–2050. The IS92a Scenario is one of six IPCC greenhouse gas emissions scenarios and refers to the following assumptions on economic, demographic and policy factors: Gross national Product (GNP) is assumed to grow with annual average rates of 2.9 % in between 1990 and 2025 and 2.3 % in between 2025 and 2050. Population assumptions are 8414 million people in 2025 and about 10000 million people in 2050. Emission controls internationally agreed upon or national policies enacted into law such as the Montreal Protocol, the U.S. Clean Air Act or the SO_x, NO_x and VOC protocols of the UN-ECE Convention on Long Range Transboundary Air Pollution are incorporated in the scenario. The expected development of the emissions are shown in Table 1. NH_3 emissions are scaled with the assumed growth of the agricultural sector. For a cautious assessment we assume no progression in acidification in relation to 1980–1990.

Table 1: Best estimates of present and future global emissions of NH_3, NO_x and SO_2

	Natural	Anthropogenic 1990	Anthropogenic 2050(1)
NH_3 (Tg N a^{-1})	11	43(2)	75(3)
NO_x (Tg N a^{-1})	9.5	27	43
SO_2 (Tg S a^{-1})	21(4)	80	143

(1) Based on IS92a (IPCC, 1992) projections; (2) Bouwman et al., 1997 (17); (3) Scaled with the growth of the agricultural sector; (4) Oceanic and terrestrial DMS, non-eruptive volcanoes (16)

Table 2: Deposition of nitrogen and sulphur compounds and their corresponding production of acidity in a nitrogen unsaturated plant-soil-system

Deposition	H^+-Production (mol/mol)	Deposition	H^+-Production (mol/mol)
H^+	+1	$(NH_4)_2SO_4/NH_4NO_3$	+2/0
NH_4^+	+1	H_2SO_4/HNO_3	+2/+0
NO_3^-	−1	H_2SO_4/NH_4NO_3	+2/0
SO_4^{2}	0	NH_4HSO_4/HNO_3	+2/+0

2.3 Resulting acid- and nitrogen loads

Acid loads resulting from nitrogen turnover in the soils (nitrification) are assessed conservatively, too, in so far as only the nitrification of ammonia is considered (see Table 3). Furthermore, the internally produced acid loads resulting from nutrient export in managed forests are neglected. Case studies of European forests show that this internal production of acids contributes between 10 and 50 % of the deposition related acid input (22). Compared to agricultural sites, forests receive higher rates of atmospheric deposition due to their aerodynamic roughness and a large receptor area. The such resulting higher loads of acid and nitrogen deposition are considered in this study, however, less than adequate and only for NO_y but not for NH_y: Surface roughness determines the dry deposition flux in the ECHAM model.

2.4 Forest soils and their sensitivity due to acid loads

In a first step nutrient deficient soils with low buffering capacity were identified to assess regions with potential destabilisation of forest ecosystems by acid deposition. Because of lack of data it is not possible yet to determine "acidity neutralisation capacity" of soils (ANC) on a global scale. Therefore, a simple approach on the basis of the "Soil Map of the World" (23) is carried out. To evaluate the buffering capacity of the topsoils the CEC-Data (Cation exchange Capacity) and the Base Saturation-Data (Na, K, Mg, Ca) are combined with the global distribution of forests (24) to identify forest soils with low buffering capacity. The assessment is focused on topsoils as the most important nutrient pool in soils with low buffering capacity. Topsoils provide the overall important habitat for soil biota and are seedbeds for young forest stands.

The assessment of buffering capacity of the soils due to acid load is carried out in a conservative way. Only the upper class boundaries of the underlying classification are used for the evaluation of the buffering capacity. The CEC which is taken into account shows the buffering capacity of soils at pH 7, whereas the selected soils show pH values lower than 5.5 or even lower than 4.5 (see Table 3). The actually effective CEC (ECEC) at these pH values is 25–70 % lower than

Table 3: Criteria for the selection of acid sensitive soils.

pH	Cation Exchange Capacity ($mmol_c g^{-2}$)	Base-Saturation (%)	Soil depth (m)	Mineral weathering (kmol $ha^{-1}a^{-1}$)	Buffering capacity (kmol ha^{-1})
<4.5	<4	<20 %	0.30	0.15	<24
<5.5	<4	20–50 %	0.30	0.15	24–60
<5.5	4–10	<20 %	0.30	0.15	24–60
<5.5	4–10	20–50 %	0.30	0.15	60–120

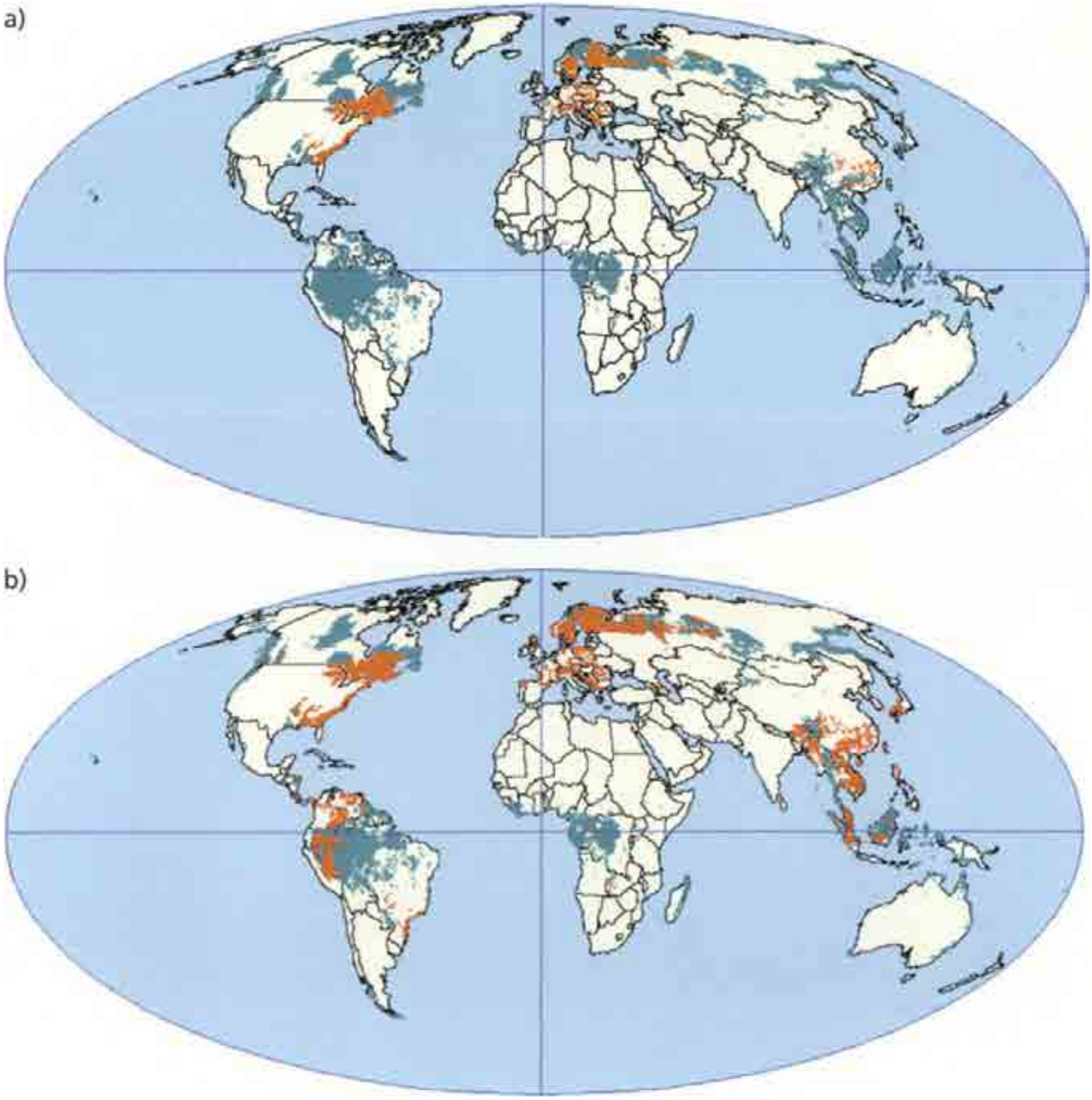

Fig. 1: Distribution of exceeded forest soils buffering capacity. a: today (1980 to 1990) and b: (2040 to 2050)
Red areas show forest soils with an exceeded buffering capacity while the green areas show the not affected areas of acid sensitive and nutrient deficient forest soils.

the potential cation exchange capacity at pH 7 (25).

Mineral weathering as an additional source of nutrients and buffering capacity allows for a buffering of 0.5 kmol $ha^{-1}a^{-1}$ of acids (referring to 1 m soil depth). This value is based on weathering rates cited in literature (26–29). This is a crude estimate and therefore very cautious in so far that the concerned soils refer to very poor parent materials.

We identified exceedance of buffering capacity as depletion of the buffering capacity of the forest soils by acid loads within 100 years or less, a time frame equal to the lifespan of many tree species.

In a second step the nitrogen deposition into forest ecosystems on acidified soils was classified. This was done under two aspects:

- Nitrogen deposition exceeds natural inputs. The respective threshold was set to 5 kg N $ha^{-1}a^{-1}$ (1), (2).
- Changes of nitrogen deposition in between the next 60 years were related to 1980–1990 deposition and to the threshold of natural inputs.

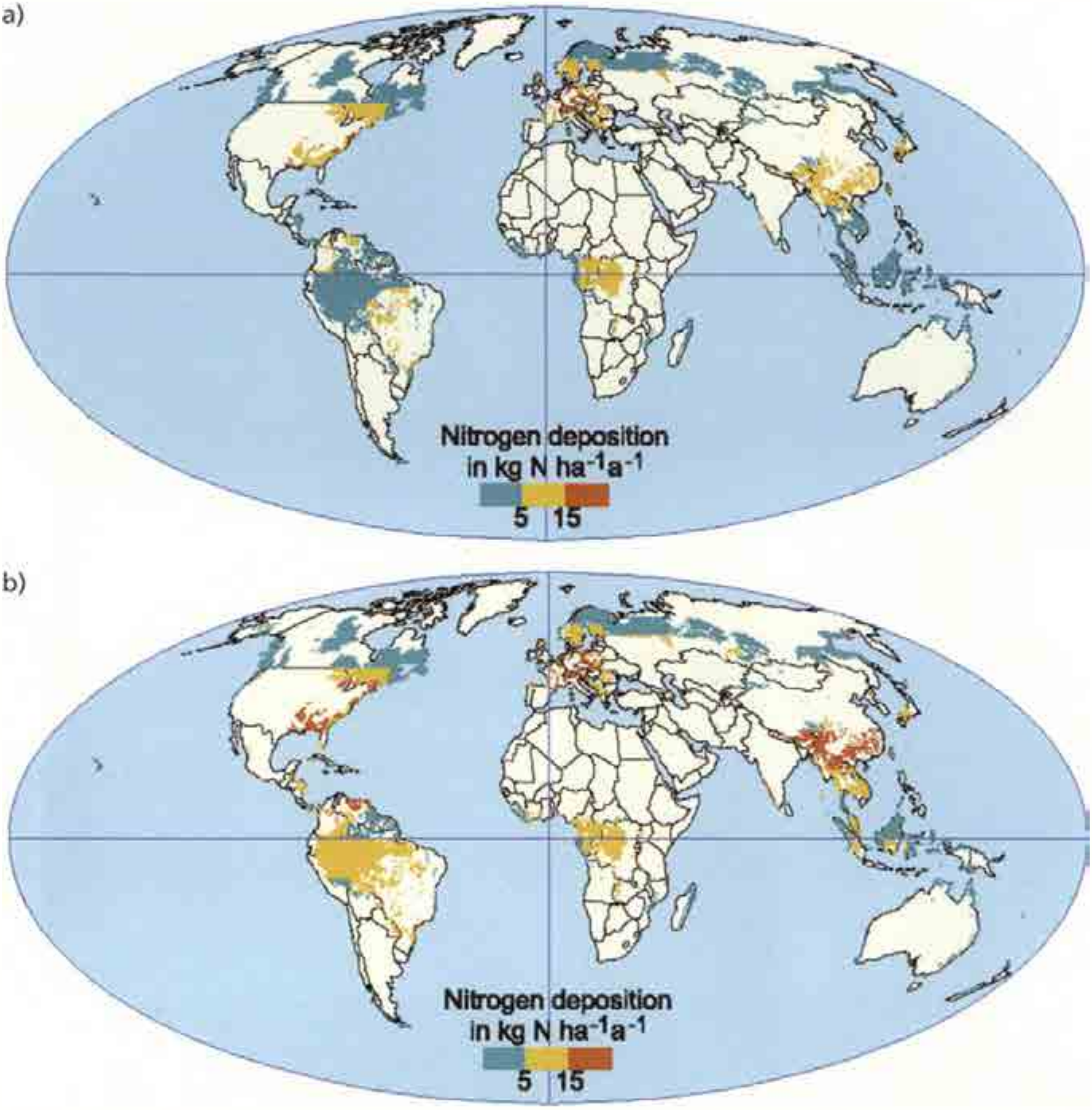

Fig. 2: Nitrogen deposition into forest ecosystems on acid sensitive and nutrient deficient soils. a: today (1980 to 1990) and b: (2040 to 2050).

3. Results

3.1 Exceedance of forest soils buffering capacity

In relation to acid input from 1980 to 1990, the buffering capacity of 1.8 Mio km² or 15 % of the acid sensitive forest soils tends to be exceeded in the next 25 to 100 years. Under the assumptions of the IS92a scenario this share more than doubles and increases to 4.0 Mio km² or 34 % in between 2040 and 2050. In 1980–1990 the mean buffering capacity of these soils based on our methodology had lasted for 65 more years. Under changed inputs this period tends to decrease in between 2040–2050 to 50 years, which is less than half the lifetime of most managed tree species. In 1980–1990 four regions are mainly affected by acid deposition which are the eastern part of Northern America, Europe, Scandinavia with north-western Russian Federation and Southern China. The situation in 2040–2050 changes in that way that the "old hotspots" are still present but the area of exceedance increases only moderately with the main increase taking place in the tropical and subtropical regions of South America, South and Southeast Asia (see Figure 1).

3.2 Nitrogen deposition on nutrient deficient and acid sensitive soils

In 2040–2050 nearly 54 % of the forest ecosystems on acidified soils are projected to receive a nitrogen load greater 5kg N $ha^{-1}a^{-1}$. About 850 000km^2 (8 %) of the acid sensitive soils or 510 000km^2 (17 %) of soils with an exceeded buffering capacity are likely to receive a nitrogen input greater than 15kg N $ha^{-1}a^{-1}$ in 2040–2050 which is assessed as a critical load for the temperate forests in Europe (30). Because of better soil conditions the affected area is smaller in India, Eastern North America and Europe. In absolute numbers the forests in the Eastern North America will be affected most but followed by those in Southeast Asia and China (see Figure 3).

Greatest changes in aerial distribution and increase of concentration will occur in the Asian region (see Figures 2, 3). Regions with acid sensitive soils and high N depositions are concentrated to China and Southeast Asia, Western and Central Europe and Eastern North America. Again, in absolute numbers Eastern North America shows the largest distribution of forest areas with an exceeded soil buffering capacity and high nitrogen deposition – followed by Southeast Asia, China and Europe.

4. Conclusion

It has been shown that under the assumptions of the IPCC IS92a scenario, the contrast between unbalanced nutrient input and acidification or nutrient depletion will become greater. Greatest changes are most likely to occur in subtropical and tropical regions of Asia but the well known hotspots of Europe and Eastern North America will remain. Forest areas with both depletion of soils buffering capacity and increasing nitrogen deposition will expand in several regions. The forest areas likely to meet these two risks are still a minor fraction of the global forest ecosystems, though.

Soils in forest ecosystems provide the transformation function for nutrient flows and material flows in general, besides other functions. Soils' nutrient reservoirs and buffering capacities get depleted in increasingly large areas. On the other hand, growth induced by increasing N availability triggers additional nutrient demand – which in most cases cannot be satisfied: We note that nutrient and acidification status of those soils which are subject to increasingly high inputs will necessarily change in foreseeable periods. Hence, changing soil conditions should be addressed in the context of further investigations, using global vegetation modelling.

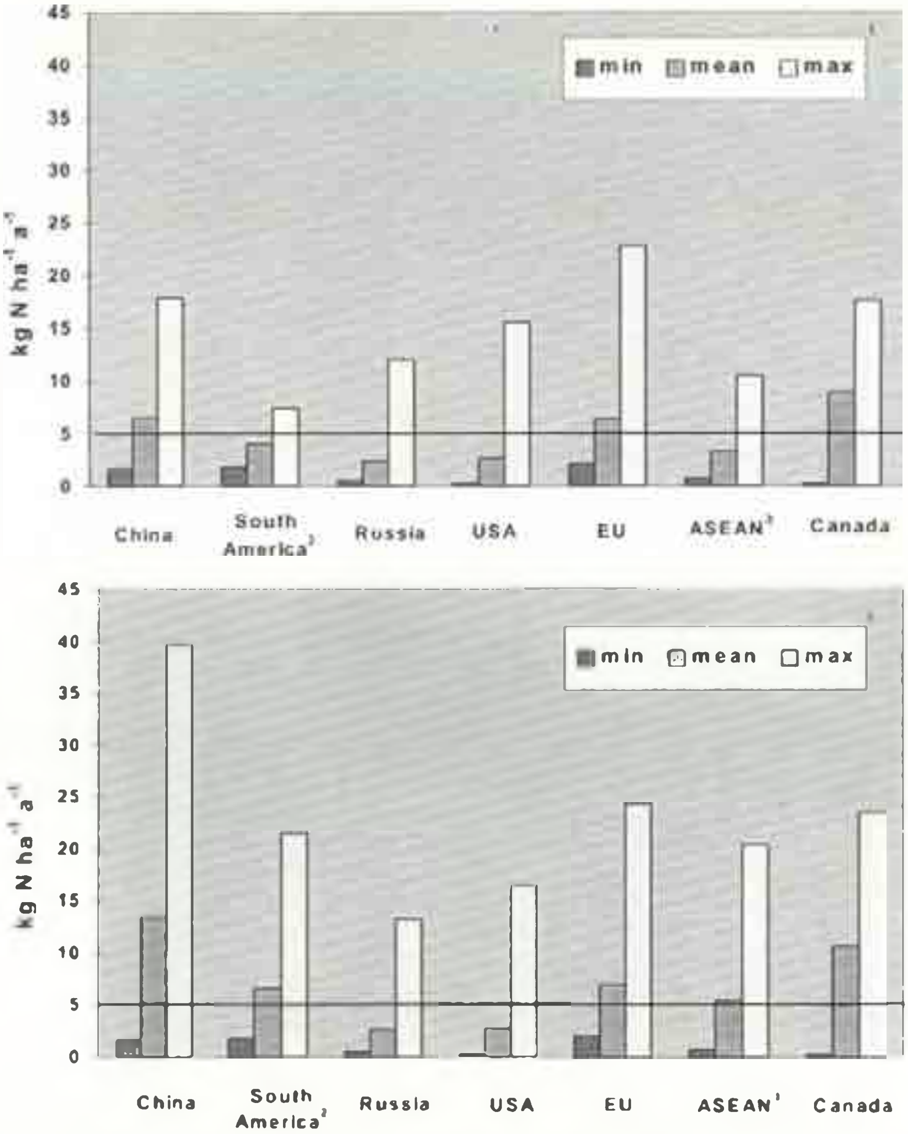

Fig. 3: Regional distribution of acid input into forest ecosystems on acidified soils with minimum, maximum and mean values in selected regions or countries. a: today (1980 to 1990) and b: (2040 to 2050)

2) Brazil, Ecuador, Bolivia, Columbia, Paraguay, Peru and Venezuela

3) Myanmar, Thailand, Laos, Vietnam, Brunei, Philippines, Singapore, Indonesia and Malaysia

dashed line: threshold of natural nitrogen input.

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Growth of Pine Forest Ecosystems (*Pinus sylvestris* L.) under Changing Climate and Pollution Stress

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A. Konopatzky and F. Suckow

Abstract

Since German unification and the breakdown of much of the industry in East Germany, the former high rates of atmospheric deposition have decreased drastically and their chemical composition has changed as well. A regional impact study was performed to get a quantitative assessment of forest growth under these conditions and to evaluate their further development, focussing on Scots pine as the most common species in eastern Germany. The area under investigation is the 'Dübener Heide' close to the industrial region of Halle – Leipzig – Bitterfeld.

The pollution pattern in the research area is dominated by a quite rapid change from high SO_2-immissions and high nitrogen inputs linked with a good base cation supply, to low SO_2-immissions with ongoing high nitrogen loads and an increasing soil acidification.

The combination of reduced SO_2-immissions and high nitrogen input led to a strong increase in the growth rates of the stands. Subsequently a substantial amount of the soils in the research area is saturated with nitrogen.

The process based forest growth model FORSANA was applied to simulate the growth dynamics of pine forest ecosystems under these conditions. The results of the simulation runs demonstrate the positive effect of reduced pollution loads on the growth of the stands. In general stemwood growth seemed to benefit relatively more than total growth. The reduction of the SO_2-immissions had also a distinct effect on the leaf area index. The scenario based calculations also made clear the sensitivity of the stands to water deficiency.

The results of the analysis demonstrate the impacts of pollutants on pine forest ecosystems and the future potentials and risks due to the positive and negative interactions of the different factors controlling forest growth.

Keywords: forest damage, forest growth modelling, FORSANA, emission, deposition, regional impact analysis, GIS, scenarios

1. Introduction

Until the year 1989 former East Germany (GDR) was one of the countries with the highest emissions of pollutants per capita in the world. The concentration of industrial facilities on few areas, the intensive use of soft coal as energy source in combination with an insufficient employment of emission reduction technologies led to steep gradients of pollution loads in this country.

Since German unification, the former high rates of air pollution had decreased drastically in East Germany and their chemical composition has changed as well. By 1992, emission of SO_2 had been reduced to 40 %, dusts to 20 %, and NO_x to 80 % of the values of 1989 (see Fig. 1), mainly due to changes in the economic structure and to the implementation of emission reduction technologies.

To get a quantitative assessment of forest growth under these conditions and to evaluate their further development, a regional impact analysis was performed, focussing on Scots pine (*Pinus sylvestris* L.) as the most common tree species in eastern Germany. The study was part of the project SANA (restoration of the atmosphere over East Germany), initiated and funded by the German Federal Ministry for Science and Technology (BMBF) in 1992.

2. Concept of the Study

For the analysis and simulation of the productivity of pine – forest ecosystems under changing pollution stress a process based dynamic model was developed. It was applied within a test area where different combinations of stress factors could be found.

Taking into account concentration effects (levels) as well as cumulative effects (loads), the spatial and temporal scales of the study and the selection of the ecosystem type were determined by the response time of forest ecosystems to changing disposition by air-pollutants (years to decades) and the present state of the art in modelling atmospheric chemistry and ecosystem dynamics. To estimate their further development, simple scenarios combining different climate and pollution regimes were created.

The theoretical background of the work was provided by the results of the forest decline research, considering especially the impacts of atmospheric SO_2-concentration, nitrogen and soil acidification on tree growth (e.g. *Nihlgard* 1985, *Ulrich* 1987, *Aber* et al. 1989, *Darall* 1989).

Two different time intervals were investigated:

- a retrospective time period between 1967 and 1989 for model testing purposes and statistical analysis and
- a prospective, scenario-oriented simulation period from 1990 to the year 2024 to study possible developments of for-

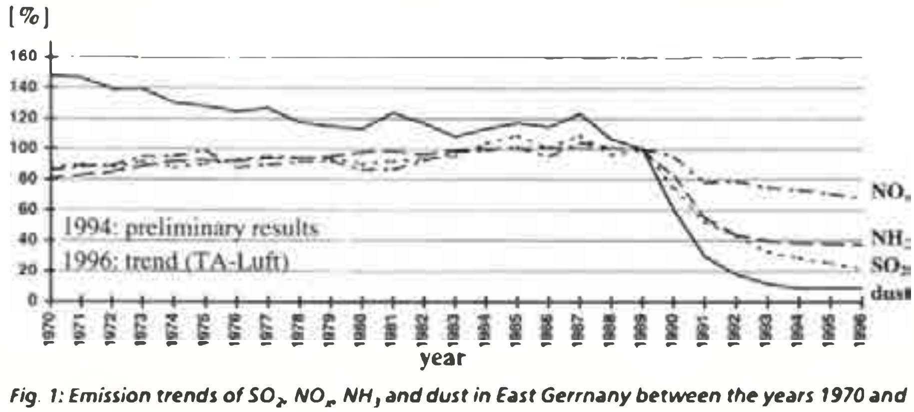


Fig. 1: Emission trends of SO_2, NO_x, NH_3 and dust in East Germany between the years 1970 and 1992 and estimated for 1992–1996 relative to the year 1989 (= 100 %) (Friedrich et al. 1996).

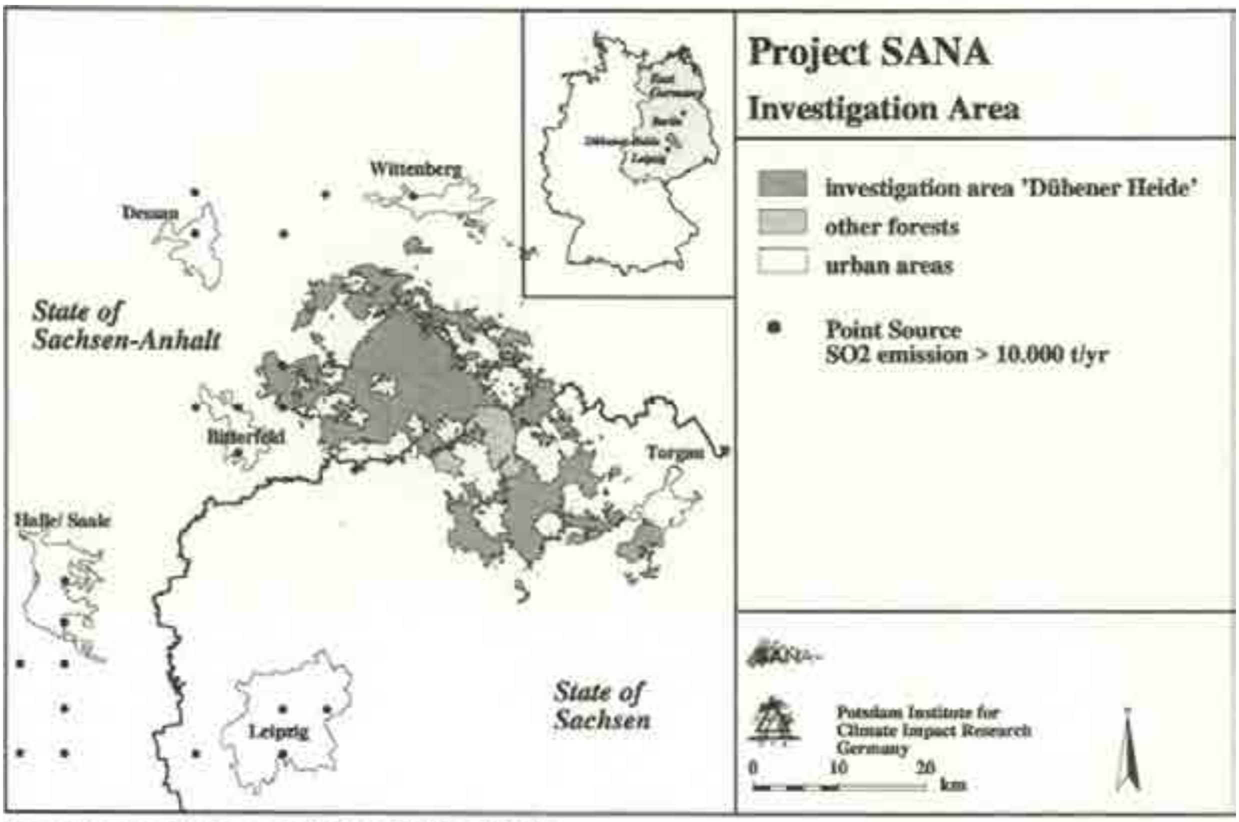


Fig. 2: Location of the investigation area Dübener Heide.

est stands under different combinations of climate and pollution.

The investigation area, the Dübener Heide, is located close to the industrial region of Halle – Leipzig – Bitterfeld (Fig. 2). Its size is about 600 km². 75 % of the area is covered by forests, about 50 % of them are even-aged stands of Scots pine, growing on sandy, anhydromorphic soils. The climate is characterized by relatively dry conditions (550 mm annual rainfall) and annual mean temperatures of 8.0–8.5 °C. The Dübener Heide was selected for the impact assessment, because data sets for soil and forest conditions since 1967 were available and different gradients of pollution loads could be investigated within short horizontal distances.

For the investigation three major components: a dynamic process-based forest growth model, a regional data base, and time series of driving forces were combined.

2.1 Forest Growth Model

The dynamic, process-based forest model FORSANA simulates the growth of coniferous forest stands over periods of years to decades. The model describes the response of physiological processes of the trees (assimilation, respiration and allocation) to the impact of daily weather and air pollution (mainly SO_2 and nitrogen) on daily time steps. Photosynthesis and respiration processes were derived from the model FORGRO (*Mohren* 1987). To simulate the influence of long-term environmental changes on tree growth, further physiological processes such as carbon allocation, tree mortality and soil processes were implemented.

Forest stand characteristics (stand height, stem diameter, stem volume and number of trees per unit area) are derived from the integrated values of daily tree growth on annual time steps. This allows influences such as forest management activities to be simulated. A detailed description of the model is given by *Grote* (1998) and *Grote & Suckow* (1998).

2.2 Regional Data Base

For the calibration and validation of FORSANA a georeferenced spatial database was installed (*Erhard & Flechsig* in press). For each forest stand, data sets measured at different times were collected and georeferenced with a geographic information system (GIS). Main elements of the data set are forest inventory data (tree species, age, height, diameter, yield, size of the stand), soil physical and chemical data, biomonitoring data (defoliation, discoloration), topography (elevation, slope and aspect) and depth of groundwater level. This database also enabled statistical analysis by testing of the relationships between the growth of the pine stands, the influence of pollution impacts, and the natural site characteristics.

To provide the forest growth model with a unique set of parameters for each stand, spatially homogenous units based on even aged forest patches were calculated using GIS overlay functions and algorithms.

2.3 Driving Forces

Meteorological data (temperature, humidity, rainfall, global radiation), the atmospheric SO_2-concentration and nitrogen input are the most important driving forces of the forest growth model.

Time series of measured meteorological data were available from climatological stations situated near the study area (DWD, German weather service). An emission data set was available, including daily values of SO_2, NO_x, NH_3, VOC and dust of point (e.g. power plants and industrial complexes) and non-point sources (e.g. traffic, private heating in 5×5 km spatial resolution) (*Friedrich* et al. 1996). By using these data as input for the Gaussian distribution model (*Zannetti* 1990) simulations of daily atmospheric SO_2-concentrations for several years (1970, 1974, 1982 and 1989) at a spatial resolution of 500×500 m were carried out and provided for this study (*Schaller* 1996). For estimating the deposition into the ecosystems, measured data were collected and interpolated.

The estimation of future emission trends was based on the objectives of the environmental protection laws of Germany concerning the regulation of emissions. The year 1989 was selected as representative for the emission situation of the former GDR, 1992 for the state of economic transition and 1996 (estimated values) as representative for the most likely future trends (see also Fig. 1).

Three different emission scenarios were constructed by making simple assumptions about future trends in emission and climate (Table 1):

- a "worst case" or "GDR" scenario, extrapolating the emissions of 1989 until 2024
- a "unification" scenario, extrapolating the emissions of 1992 until 2024
- an "emission reduction" or "best" scenario, reducing emissions of 1992 by approximately 40 % which is estimated as the trend due to execution of current emission reduction regulations.

For the construction of the climate scenarios meteorological data of the validation period were used. Meteorological years were classified into normal, wet and dry years with respect to the vegetation period by cluster analysis (*Gerstengarbe* & *Werner* 1997). A representative year was selected from each class. This approach was used, because reliable model outputs of general circulation models (GCM's) scaled down to an appropriate temporal and spatial resolution were not available for central Europe (*Cubasch* et al. 1995).

Table 1. ***Emission of the years 1989, 1992 and 1996 (estimated) in % in relation to the year 1989 (= 100%) (Friedrich et al. 1996).***

substance	1989 "worst case"	1992 "unification"	1996 "emission reduction"
SO_2	100	43	22
NO_x	100	79	68
NH_3	100	44	37
dust	100	18	9

Table 2. ***Precipitation of the representative years selected from the meteorological data 1967–1992 using cluster analysis. Precipitation of the growing season (mid of April until end of September) was also be considered in the analysis (data: German Weather Service).***

scenario year	meteorological year	precipitation [mm]		
		annual	growing season	%
dry	1982	364	167	46
normal	1990	551	327	60
wet	1974	761	346	45

Two climate data sets were used for the simulations (Table 2):

- a scenario "normal" representing the present climate conditions, with the relationship between "normal", "dry" and "wet" years of about 2:1:1 and
- a scenario "dry", where the number of "dry" years is increased after the year 2010:

year 1990–2010: "normal":"dry":"wet" = 2:1:1
year 2011–2024: "normal":"dry":"wet" = 2:3:1

Simulation runs were performed on a parallel computer system (SP2). The parallel simulation environment SPRINT-S was used (*Flechsig* 1998) to manage the data supply, to distribute the model runs to the different processors and to transfer the results to the GIS for visualisation.

3. Results

3.1 Growth Conditions in the Area

In the Dübener Heide forest damages have been observed since about 1950 and were mapped systematically the first time in the sixties using defoliation and needle discoloration as the most important indicators (*Lux* 1965). The classification is shown in Figure 3a. The gradient of decreasing damages from west to east seemed to be determined by the location of the main emittents and the dominating westerly winds. A second monitoring carried out 20 years later shows a quite similar pattern (Fig. 3b). The areas of severe to low damage expanded, but the most severe damages (zone 1a) disappeared. The dominating west – east gradient seemed to be modified by local impacts like corrosive effects of very high ammonia immissions (stock-farming) or the lowering of the ground water table because of drinking water extractions. Both factors led to severe forest damages mostly in the south-eastern part of the area, but only small patches were affected.

The results of the immission simulation for the year 1989 (Fig. 4) showed a gradient similar to the pattern of the forest damages. Average SO_2-concentrations attained about 150 $\mu g\ m^{-3}$ in the western part and about 50 $\mu g\ m^{-3}$ in the eastern part of the area. In the year 1970 the gradient of atmospheric SO_2-concentrations was quite the same but against the trend of the country wide SO_2-emissions (see Fig. 1) the average SO_2-concentrations reached 250 $\mu g\ m^{-3}$ and more in the west and 125–150 $\mu g\ m^{-3}$ in the east (see also Table 4).

The gradient of decreasing pollution from west to east as well as the trend of decreasing inputs from the beginning of the seventies to the end of the eighties was reflected in the bulk deposition data (Table 3). The chemical composition of the deposition was dominated by the elements Ca^{2+}, SO_4^{2-}–S, and Cl^-. For nitrogen no gradient in the deposition data was found. Only a local peak of high ammonia deposition was identified caused by the emissions of a fertiliser plant located near Wittenberg. At the beginning of the nineties, the deposition rates of most of the elements were much lower and almost no gradient could be found in the data sets. Only the amount of nitrogen deposition was still at the same level than the years before (Table 4).

***Table 3.** Bulk and wet deposition (kg ha' yr') at different sites and for different time periods. Data of the site "Neuglobsow" 100 km north of Berlin indicate "unpolluted" conditions. The location of the sites is shown in Figure 2.*

site	time period	prec. mm	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4–N	NO_3–N	SO_4–S	Cl^-	ANC
Torgau[1]	75–79	580	5.35	5.80	3.48	40.60	4.06	7.21	4.59	42.59	18.56	−1.84
Torgau[1,3]	10/84–10/89	508	4.70	2.03	0.81	18.29	1.47	6.31	4.25	23.74	16.76	−1.17
Bitterfeld[1]	77–80	540	6.50	6.48	4.86	184.14	8.10	7.13	6.22	127.96	38.88	−0.28
Bitterfeld[1,3]	10/84–10/89	476	5.80	2.62	0.95	59.02	3.67	6.65	4.09	52.43	15.71	−0.25
Leipzig[1]	01/85–03/89	476	5.17	4.24	2.52	49.98	4.33	8.17	3.89	56.43	10.09	−2.15
Leipzig[1]	93–94	557	4.39	1.87	0.66	4.72	0.51	5.59	3.49	9.15	2.97	−1.33
Wittenberg[1]	01/85–03/89	591	5.44	6.50	3.55	47.40	3.84	15.97	5.11	59.39	11.11	−3.61
Oschatz[1]	01/85–03/89	508	4.74	4.22	1.88	23.52	2.95	6.39	4.45	30.52	8.74	−1.73
Oschatz[1]	93–94	706	4.36	2.57	0.99	6.97	0.82	6.09	4.06	11.14	4.54	−1.43
Neuglobsow[1]	01/85–03/89	565	4.30	3.73	1.19	5.71	0.85	5.05	4.30	13.37	7.80	−1.53
Neuglobsow[2]	11/93–10/95	738	4.39	8.19	3.20	7.10	1.28	6.45	6.70	10.69	14.37	−1.57

[1] Möller & Lux (1992); [2] Schaaf et al. (1995); [3] wet only measurements
prec. = annual precipitation (mm); ANC = acid neutralisation capacity (keq/ha^{-1}).

***Table 4.** Mean values and standard deviation of atmospheric SO_2-concentration, interpolated deposition of Ca, SO_4-S and nitrogen, pH-values, BC/Al (K+Ca+Mg/Al), C/N (carbon/nitrogen)-ratio and nitrogen fertilisation per damage zone (see Fig. 3a) (Möller & Lux 1992. Schaller 1996; Konopatzky & Freyer in press).*

	zone 1a		zone 1b		zone 2		zone 3		zone 0	
	mean	s.d	mean	s.d.	mean	s.d	mean	s.d.	mean	s.d.
immission (μg m^{-3}yr^{-1})										
SO_2 (1970)[1]	253.7	25.33	208.3	25.51	190.6	31.97	187.5	35.39	154.4	14.59
SO_2 (1989)[1]	125.0	26.35	100.2	16.10	95.3	16.03	91.0	14.08	75.1	7.53
SO_2 (1993)[2]	56.4	2.97	51.8	4.12	51.2	4.85	51.1	5.77	51.1	4.88
deposition (kg ha^{-1}yr^{-1})										
Ca (1984–1989)[2]	64.3	7.09	62.5	12.17	50.2	17.77	46.0	11.60	44.3	10.66
Ca (1993–1995)[2]	10.0	1.18	8.6	0.75	9.2	0.81	9.4	0.70	9.4	0.51
SO_4-S (1984–1989)[2]	51.7	6.80	51.5	8.37	44.4	11.50	42.2	8.99	43.7	6.8-
SO_4-S (1993–1995)[2]	14.6	1.01	13.8	0.60	14.4	0.89	15.1	0.64	15.9	0.41
NO_3-N (1984–1989)[2]	6.3	0.55	6.6	0.98	5.7	1.35	5.3	0.94	5.3	0.81
NO_3-N (1993–1995)[2]	5.9	0.30	5.6	0.31	5.9	0.46	6.2	0.30	6.5	0.24
NH_4-N (1984–1989)[2]	6.7	0.29	7.0	0.53	7.1	0.87	7.3	1.20	7.0	0.96
NH_4-N (1993–1995)[2]	7.2	0.24	6.9	0.44	7.4	0.69	7.6	0.53	7.5	0.39
soil										
pH (1967/77)2)	5.5	0.52	4.7	0.46	4.4	0.48	4.2	0.54	4.0	0.37
pH (1991–94)2)	4.9	0.34	4.6	0.42	4.3	0.45	4.2	0.40	4.0	0.37
BC/Al (1967/77)[2]	533.6	502.5	80.2	50.67	59.4	57.81	52.8	80.15	28.5	49.42
BC/Al (1991–94)[2]	112.1	66.34	93.1	83.60	37.9	62.83	6.8	7.95	2.5	0.58
C/N-ratio (1970)	33.6	3.90	34.9	3.19	33.3	4.48	34.2	3.79	34.4	3.94
C/N-ratio (1992)	25.2	3.32	25.4	2.94	23.8	3.63	24.8	3.75	25.3	3.02
fertilisation (kg ha^{-1}yr^{-1})	408.0	198.3	535.8	215.0	445.5	316.4	327.8	337.5	299.0	253.3

s.d. = standard deviation
BC/Al = (K+Ca+Mg/A1) ratio (Sverdrup & Warfvinge 1993)
[1] simulated values
[2] measured and interpolated data

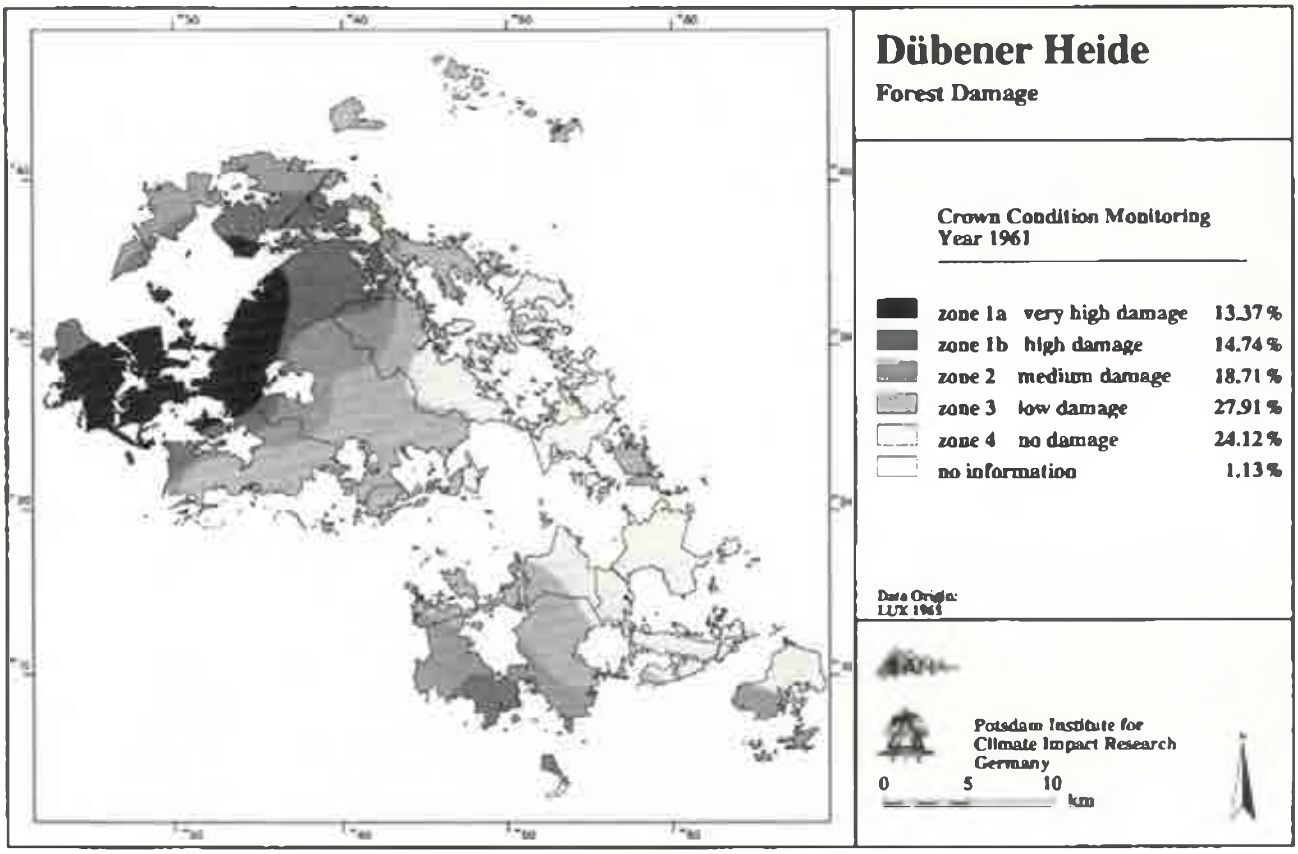


Fig. 3a: Forest damage zones of the year 1961 as described in Lux (1965).

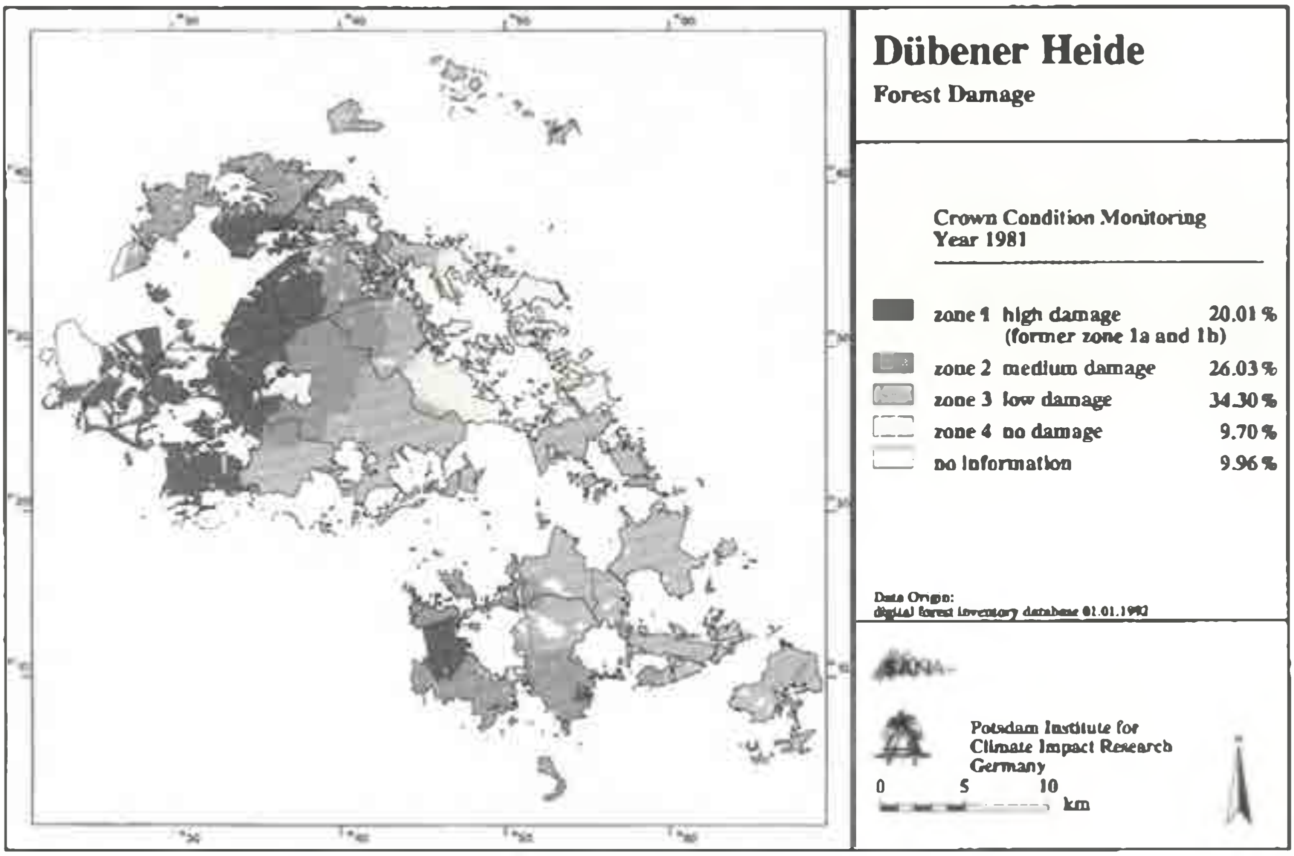


Fig. 3b: Forest damage zones of the year 1981 as described in the digital forest inventory data base of 1992.

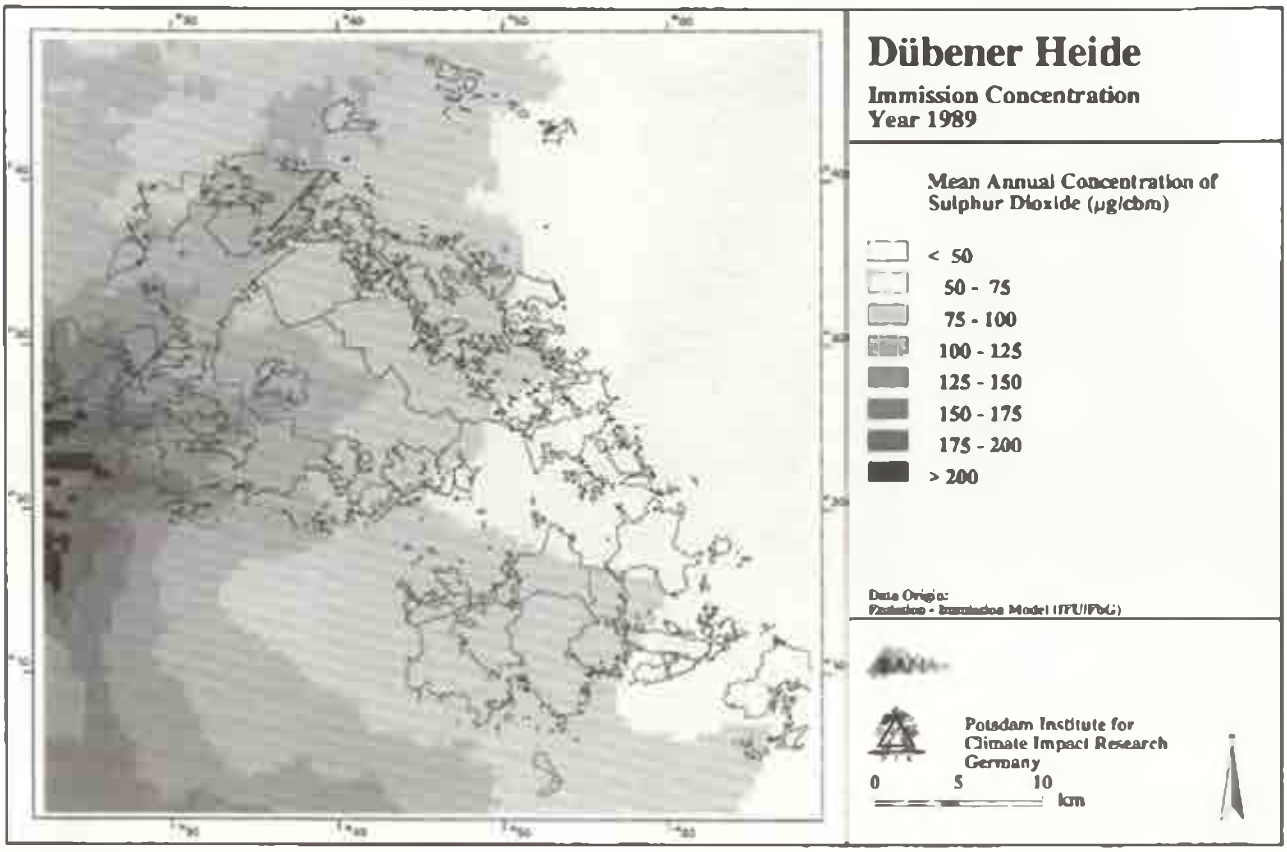


Fig. 4: Mean annual atmospheric SO_2-concentration in the year 1989 (Schaller 1996).

Due to the high amounts of fly ashes, which were emitted by burning soft coal for energy production proposes, the portion of dry deposition on total deposition was much higher in the western part of the area than in the eastern part (Table 5). These substances contained high amounts of Ca- and Fe-oxides (*Möller & Lux* 1992). The comparison of bulk or dry and total deposition data demonstrates that these measurements underestimate total deposition under such conditions (Tables 3 and 5).

High amounts of heavy metals (Pb, Cd, Zn and Cu) were also documented in the data sets. The ANC (acid neutralisation capacity), the balance between alkaline and acidic components (*Gundersen & Rasmussen* 1988), indicated that especially dry deposition components have increased the content of alkaline cations in the soil.

The spatial pattern of fly ash deposition was also reflected in the pH values of the soils (Figs. 5a and b). Both, the pH-values and corresponding to this the BC/Al (base cation/aluminium) ratio (Table 6) decreased between the years 1967/1977 and 1991–94 with the highest reduction in the western part of the area.

The nitrogen status of the soils was mapped at the beginning and the end of the investigation period by using humus type, C/N ratio and the distribution of ground vegetation species as indicators. The information was quantified by empirical functions as described in *Konopatzky & Freyer* (in press).

Table 5. Wet, dry, total annual deposition (kg $ha^{-1}yr^{-1}$) and the acid neutralisation capacity (ANC in keq $ha^{-1}yr^{-1}$) in the period 10/1984–10/1989 (Möller & Lux 1992).

station	d	Na	K	Ca	Mg	N	S	Cl	P	F	Fe	Mn	Zn	Cu	Pb	Cd	ANC
Bitterfeld	tot.	15.7	8.3	320	36.5	38.0	190.0	54.0	0.32	9.82	125.0	1.05	2.31	1.360	1.030	0.084	6.49
	wet	3.2	1.3	75	4.7	13.5	66.8	13.6	0.14	3.33	0.5	0.12	0.26	0.022	0.060	0.029	-0.25
	dry	12.5	7.0	245	31.8	23.9	124.2	40.3	0.17	6.49	124.5	0.93	1.05	1.340	0.970	0.055	6.68
Leipzig	tot.	11.0	7.6	170	19.5	24.0	120.0	45.0	0.16	1.51	57.0	0.66	2.93	1.280	0.630	0.070	2.01
	wet	3.8	2.4	58	4.4	16.0	51.4	28.6	0.10	0.88	1.2	0.15	0.77	0.130	0.110	0.036	-0.53
	dry	7.2	5.2	111	15.2	7.7	69.4	16.5	0.05	0.63	55.6	0.61	2.16	1.150	0.520	0.034	2.44
Torgau	tot.	6.4	3.8	52	5.0	23.0	61.0	34.5	0.22	2.52	10.9	0.23	0.81	0.110	0.130	0.033	-1.40
	wet	3.1	1.3	28	2.2	15.1	35.1	25.6	0.15	1.89	0.9	0.09	0.45	0.043	0.035	0.024	-1.17
	dry	3.3	1.5	23	2.9	7.5	25.4	8.8	0.06	0.64	10.0	0.14	0.36	0.067	0.095	0.009	-0.24

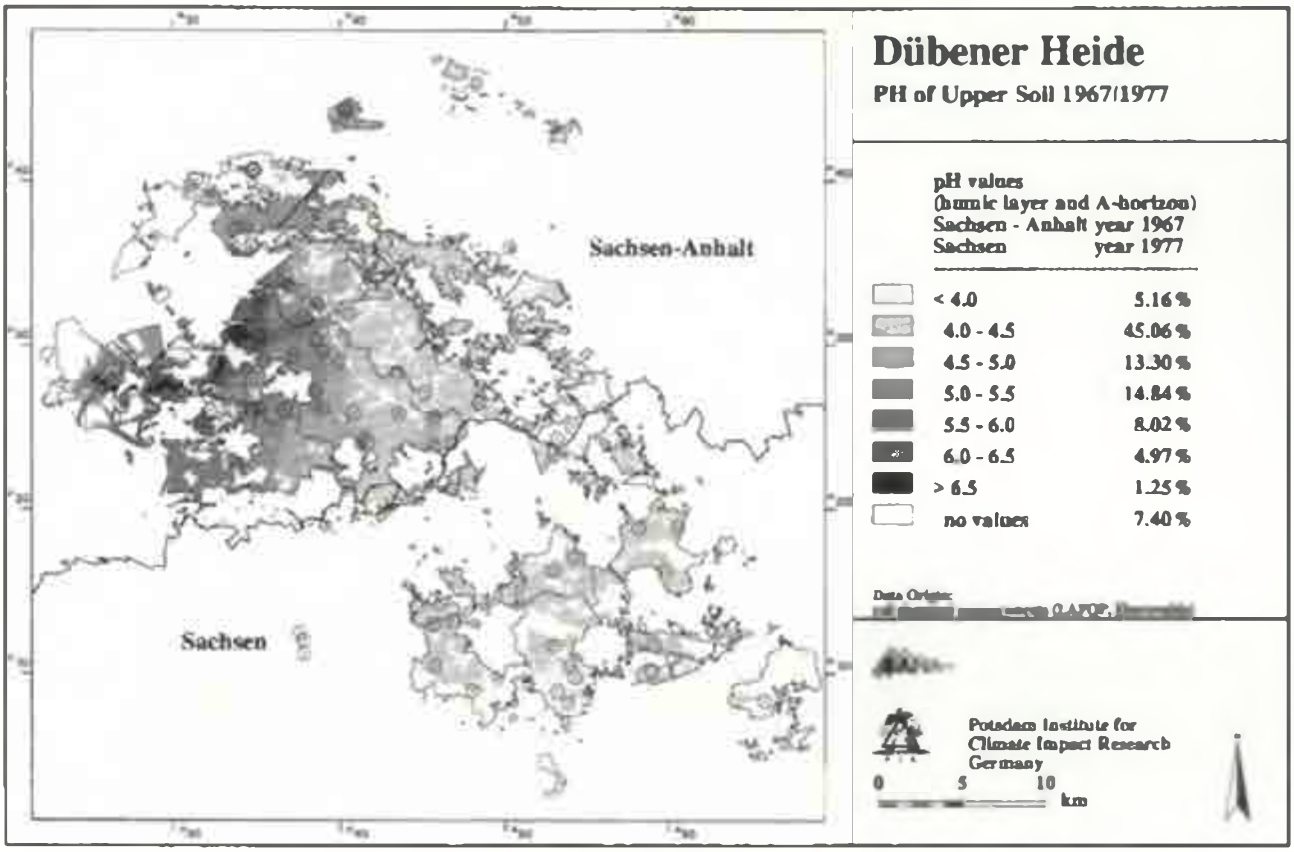


Fig. 5a: PH values of the year 1967/1977 of the upper soil (20 cm depth) as interpolated of soil chemical measurements (data: Konopatzky & Freyer in press).

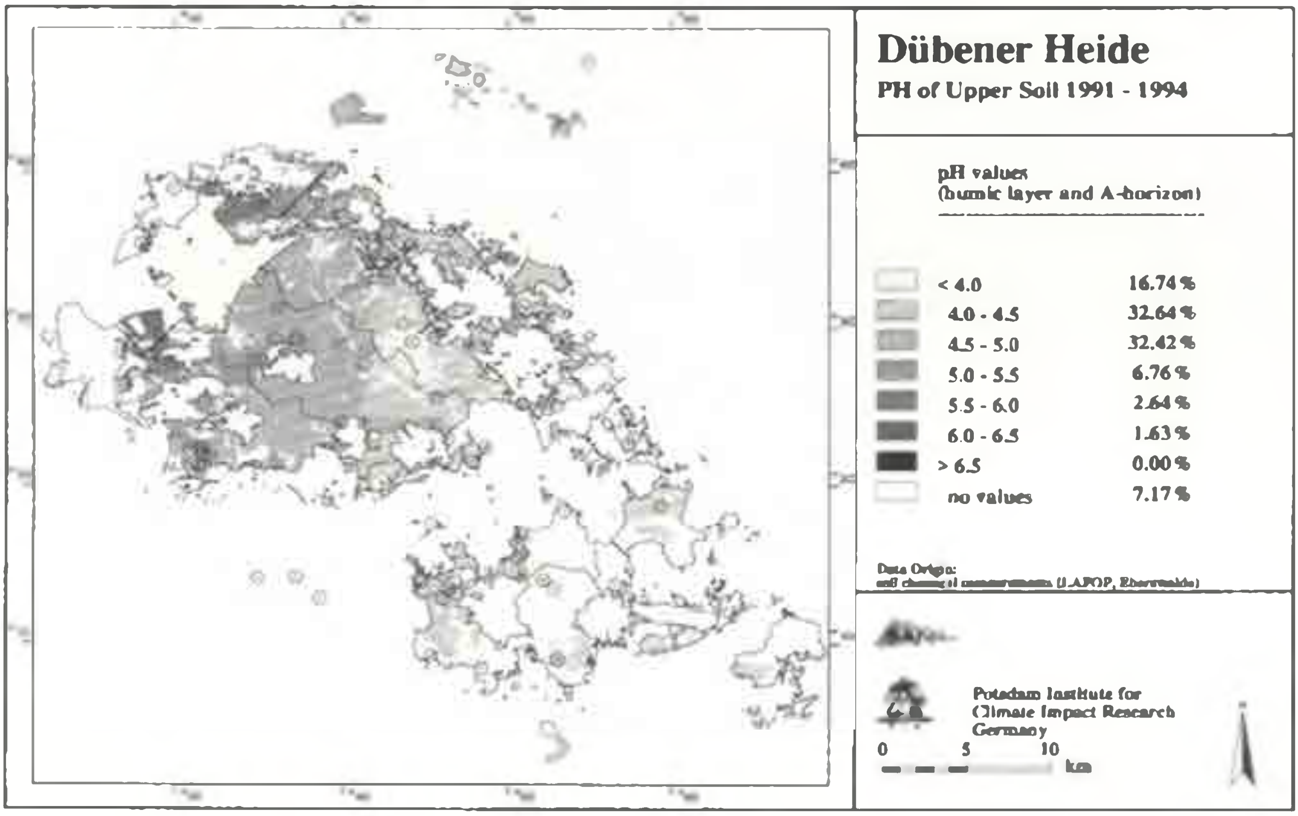


Fig. 5b: PH values of the year 1991–1994 of the upper soil (20 cm depth) as interpolated of soil chemical measurements (data: Konopatzky & Freyer in press).

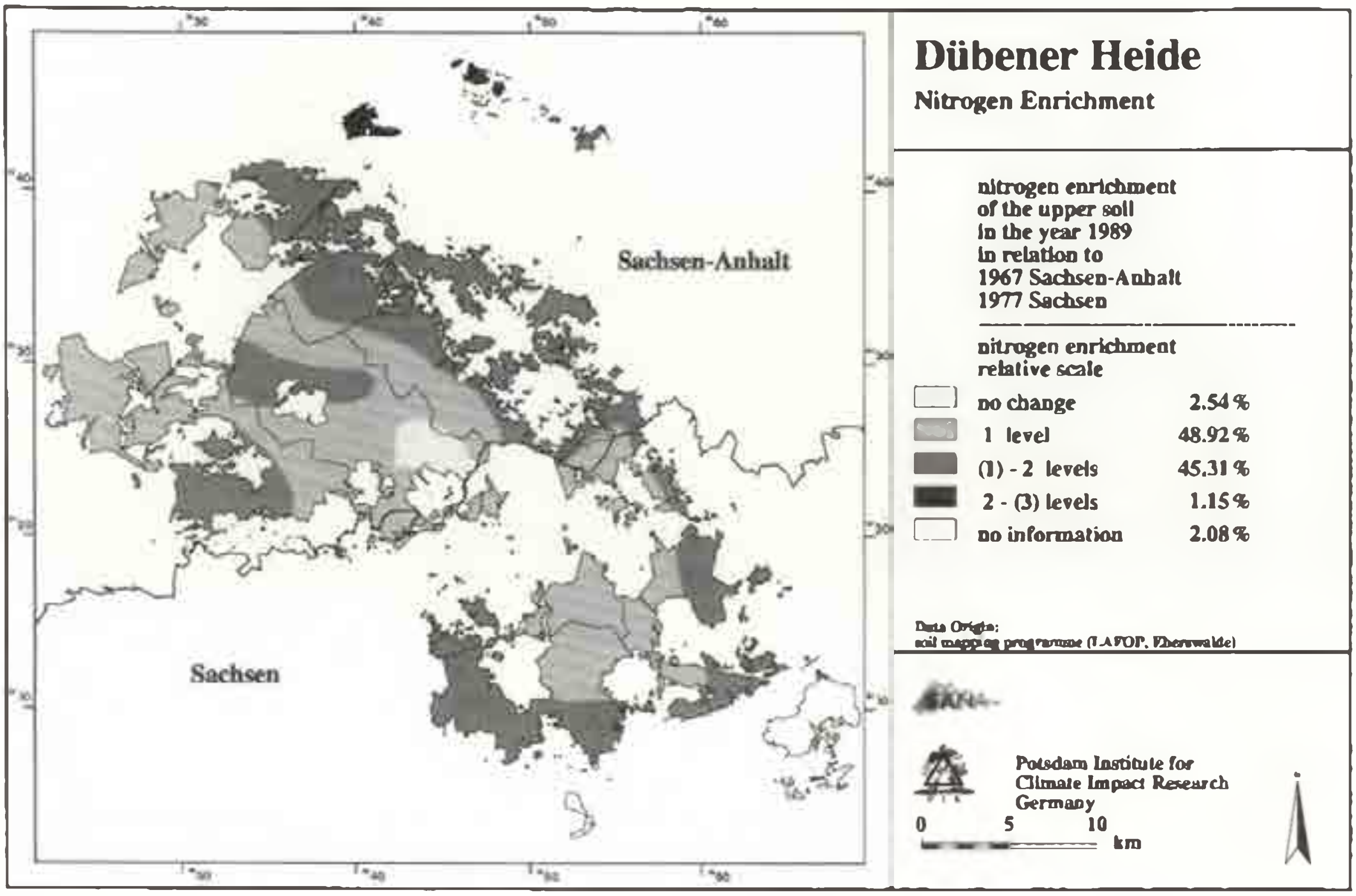


Fig. 6: Changes in nitrogen Status of soil (20 cm depth) as mapped 1967/1977 and 1992 using humus type, C/N-ratio and ground vegetation species (data: Konopatzky & Freyer in press).

To improve the growth conditions of the forests, N-fertilisation programmes were started in 1970. Urea fertiliser $[CO(NH_2)_2]$ was applied with amounts of 100–120 kg ha^{-1}N per year. Forest stands with severe damages (zone 1a) were mostly fertilised with about 400 kg ha^{-1}N, stands with less severe damages with 450–550 kg ha^{-1}N and low damaged stands (zone 3 and 0) with 300-350 kg $ha^{-1}yr^{-1}$ of nitrogen (see Table 4).

The changes in the nitrogen status of the soils (Fig. 6) corresponded neither with the amount of nitrogen fertilisation nor with the pattern of the nitrogen deposition. A general reduction in nitrogen input from the edge to the central parts of the forested area was observed with exception of a small strip just leeward of the location of some of the point sources with high emission rates. Corresponding to the pattern of changes in soil nitrogen status, the main source of nitrogen input into the forest ecosystems seemed to be diffuse nitrogen emissions from the surrounding agricultural areas. According to the results of the emission inventory, ammonia emission on these sites reached 40–50 kg $ha^{-1}yr^{-1}$ in the year 1989, especially in the south-eastern part of the area. At this time the average value for

Table 6. The Cation/Aluminium (K+Ca+Mg/Al) ratio of the years 1967 (Sachsen Anhalt) and 1977 (Sachsen) and 1991–1994 of the upper soil (20 cm depth) as interpolated of soil chemical measurements (See Fig. 2 and 5a, b; data:Konopatzky & Freyer in press).

+Ca+Mg/Al Ratio	1967/77	1991–1994
<1	0.00 %	0.00 %
1–10	21.97 %	60.14 %
10–50	30.95 %	12.72 %
50–100	13.33 %	7.69 %
100–500	21.72 %	12.35 %
>500	4.60 %	0.00 %
no data	7.42 %	7.10 %

Table 7. Changing of soil nitrogen content and nitrogen storage capacity depending on nitrogen saturation of the soil (Konopatzky & Freyer in press).

Nitrogen status of the soil		area 1967/77 (%)	area 1992 (%)	N % of total C	organic substance (t ha^{-1})	N-content (kg ha^{-1})	N-storage capacity (kg ha^{-1})
very poor	(n2)	0.14	0.00	2.3	73.1	1423	585
poor	(n3)	74.81	2.47	2.9	98.4	2008	629
optimum	(n4)	15.72	29.65	3.8	108.3	2637	194
maximum	(n5)	0.26	56.62	4.9	91.9	2831	-272
N-loss	(n6)	0.7	1.10	6.2	63.8	2559	–
no data		8.37	8.16				

whole East Germany was about 30 kg $ha^{-1}yr^{-1}$ (*Friedrich* et al. 1996). Direct effects of these diffuse emissions were estimated to affect a range of about 3 km into the forests (*Heinsdorf* & *Krauß* 1991).

At the beginning of the investigation period most of the sites had "low" or "optimum" nitrogen status whereas the "optimum" status is to be considered as "typical" in pine forest plantations of eastern Germany (Table 7). Afterwards the N-content of the soil increased in almost all of the stands (Table 7). As the result of the nitrogen input the area where soils are nitrogen saturated (nitrogen status "maximum") increased from 80 ha to 17, 100 ha, the area where N-losses have to be assumed increased from 212 ha to 303 ha within the investigation period.

3.2 Impacts on Forest Growth

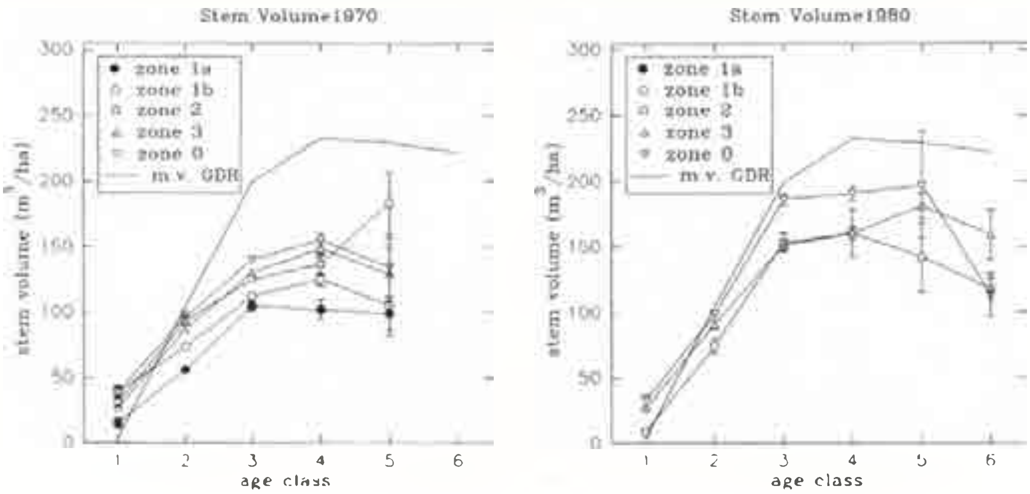
According to the damage zones (Fig. 3a) distinct differences in stem volume occurred in the investigation area in the year 1970 (Fig. 7a). Values were much lower than the average values in East Germany (*BMELF* 1994). Ten years later the growth conditions of the forests seemed to be improved in the nitrogen fertilised areas with low pollution stress (Fig. 7b), but even in the "undamaged" zones older stands had lower stem volumes per area than in average.

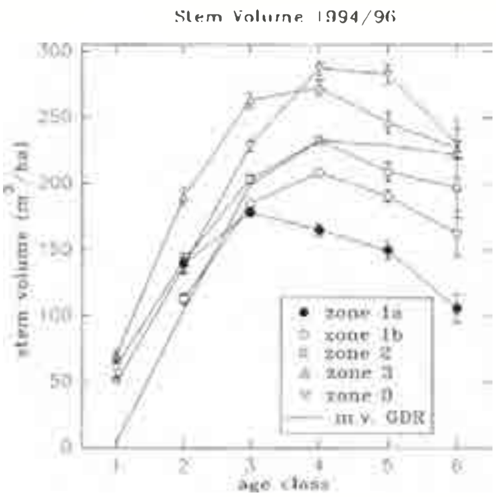
In the inventory data of the years 1994/1996 a tremendous increase in stem volume could be observed (Fig. 7c). ANOVA statistics were used to analyse the effects of SO_2-concentrations and nitrogen input on growth rates (Table 8). The results indicate, that the reduction of atmospheric SO_2-concentrations was the most important factor controlling tree growth. Only in younger stands with maximum growth rates (40–60 years) nitrogen had an significant effect on growth rate. Especially young forest stands in the areas with low pollution

Table 8. ANOVA analysis of variance of the growth rates between the years 1970/80 and 1994/96 depending on the damage zone (Fig.3a) and the changes in soil nitrogen status (Fig. 7).

age class	damage zone F-value	soil nitrogen F-value	two way interaction
1–2	1.867	1.280	–
2–3	15.492***	3.584**	yes
3–4	9.514***	1.559	yes
4–5	12.879***	0.203	yes
5–6	3.006*	1.169	yes

*p < 0.1; **p> 0.05; ***p < 0.01





age class	tree age (years)
1	1–20
2	21–40
3	41–60
4	61–80
5	81–100
6	>100

Fig. 7: Stem volume per hectare, age class, and damage zone in the year 1970 (Sachsen-Anhalt) 1980 (Sachsen) and 1994/96 (data: forest inventory data base).

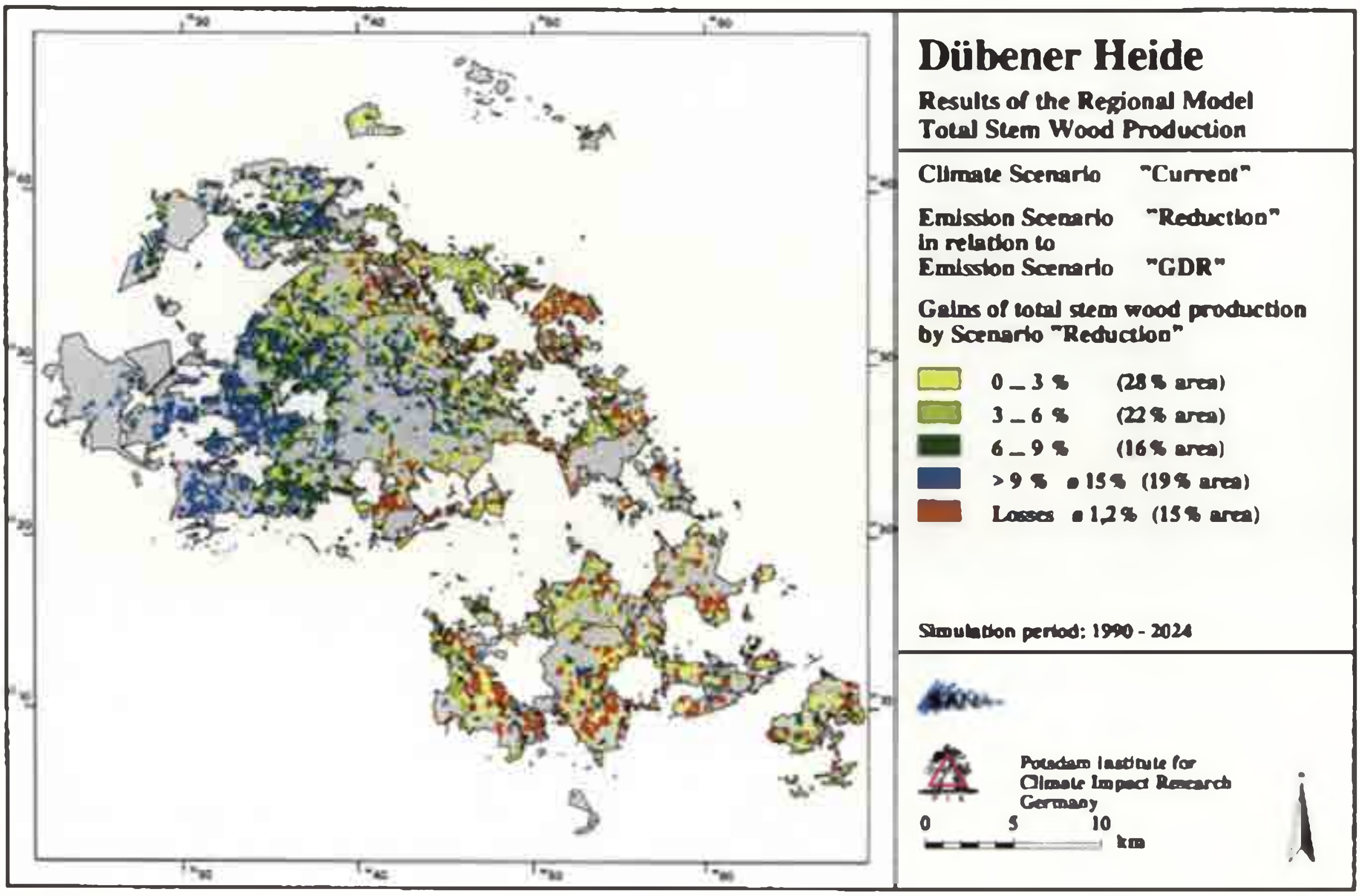


Fig. 8: Spatial pattern of changes in total wood growth as difference between the scenario "worst case" and the scenario "emission reduction" under "recent" climate conditions.

stress (zone 3) profited from nitrogen input. Therefore the growth rates were higher at these sites than in stands without pollution stress. The positive interactions between the impact of SO_2 and nitrogen indicated that both effects on tree growth could not be regarded as independent from each other.

Further investigation showed that tree height seemed to be more affected by pollution stress than diameter. Only small effects of stand density on yield, tree height, and diameter could be found (*Grote & Erhard* 1999).

The correlations between forest growth and stand characteristics like field capacity, soil fertility or depth of groundwater table were very weak only (Erhard in prep.). It seemed that the SO_2-concentrations and the nitrogen input have clearly dominated the forest growth rates in the investigated time period.

Table 9. Mean differences and correlation coefficients between simulated and measured stand dimensions (Grote & Erhard 1999).

	+N+S	+N–S	–N–S	–N+S	Total
Mean differences					
Diameter (cm)	2.9	0.7	2.5	0.8	1.6
Height (m)	1.4	0.4	2.1	1.2	0.9
Stemwood volume ($m^3\ ha^{-1}$)	10	2	29	14	4
Korrelation coefficients					
Diameter (cm)	0.80	0.74	0.79	0.86	0.79
Height (m)	0.64	0.68	0.67	0.74	0.72
Stemwood volume ($m^3\ ha^{-1}$)	0.76	0.75	0.70	0.57	0.78

3.3 Forest Growth Simulations

The growth module of FORSANA was calibrated with data sets of three pine forest stands with high, medium and low pollution. The data was measured between the years 1993 and 1995.

Simulated forest stand dynamics were then tested against data of 288 forest stands with different combinations of nitrogen loads and SO_2-concentration levels. This was performed using forest inventory data of the year 1970 as initial values for the model and comparing the simulation results of 1992 with forest inventory data of the same year as described in *Grote & Erhard* (1999). The correlation between simulated and measured parameters (Table 9) indicated that stand properties of the four investigated forest groups (+N+S, +N–S, –N+S, –N–S) were well reproduced. Height, diameter growth, and stemwood volume were slightly underestimated, indicating that mortality in the forest stands was smaller than assumed in the simulation. The development of

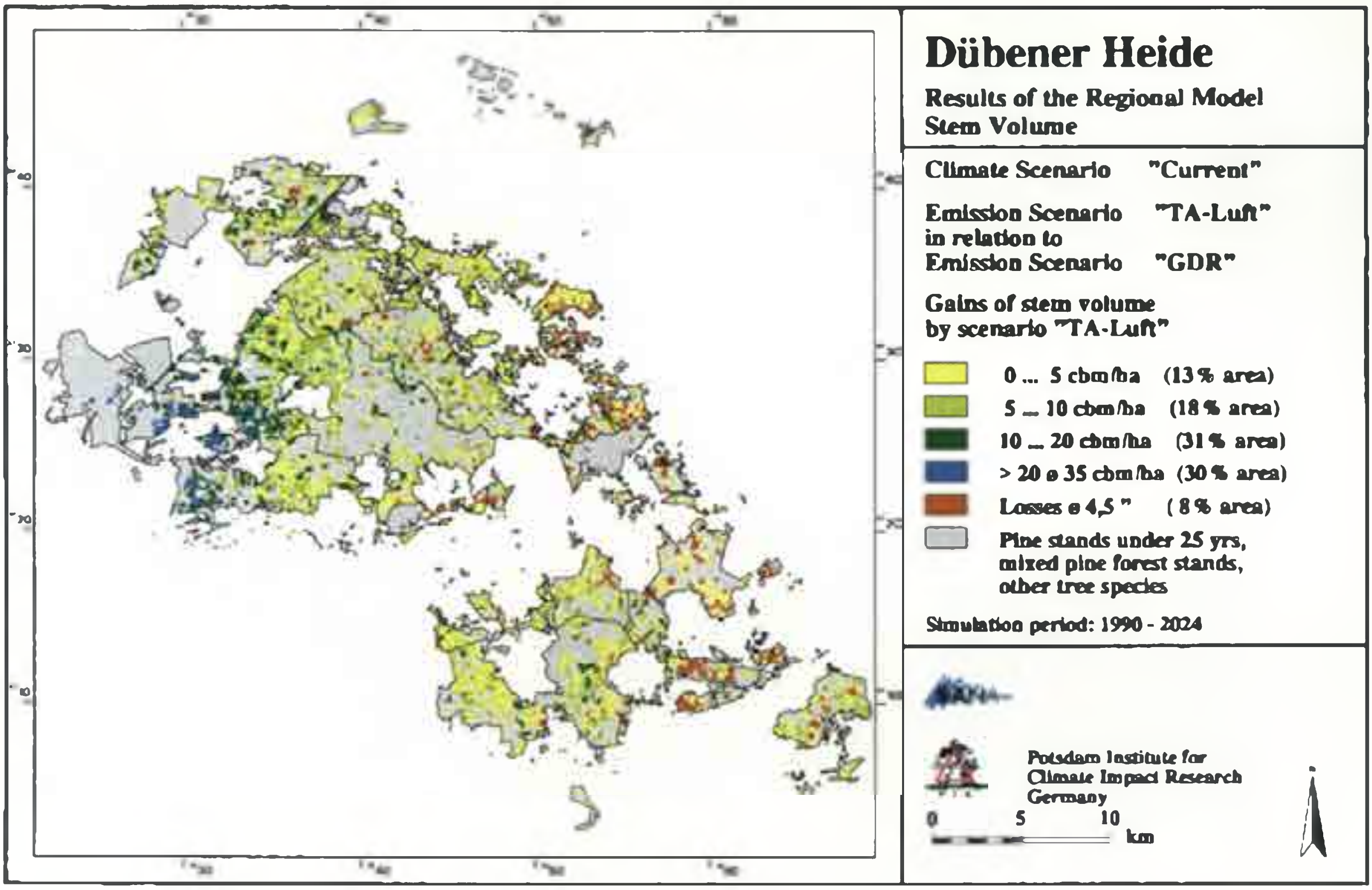


Fig. 9: Spatial pattern of changes in stem wood production as difference between the scenario "worst case" and the scenario "emission reduction" under "recent" climate conditions.

diameter and stemwood volume were better represented than height growth. In fertilised stands which were exposed to only low levels of SO_2, simulated values were very close to measurements, whereas they were somewhat smaller than the inventory data in stands exposed to high SO_2 levels.

Scenario calculations were carried out considering climate, nitrogen budget and SO_2 effects on forest stand growth. For the analysis of the results, the state variables total wood growth, stem growth and foliation were considered.

As shown in Table 10, increase of needle biomass was directly related to the reduction of SO_2-pollution and was only limited by water supply. Therefore the former highly polluted areas profited mostly from pollution reduction. Further reductions of SO_2 emission have only a small effect on this parameter.

The development of total wood growth, an indicator for the productivity of the forests, calculated as yield (2024) – yield (1990) + [harvest (1990–2024) according to "common management practice"] showed the same trend. Comparing the "worst case" with the "best" emission scenario, total wood growth increased at an average rate of 6 %. The largest increase, 15 %, was simulated for the western part of the area, above all in the damage zones 1 and 2 (see also Figs. 3a, b). In the other zones growth remained more or less constant.

The spatial pattern of the growth trends is shown in Figure 8. The heterogeneity of changes in production within short distances seemed to be primarily caused by the diversity of the initial values for the simulation run, which are normally a consequence of management. In most cases the year of the last stand treatment by management measures could explain the variations in the results of the simulations. Of course this effect was relatively more important if the calculated changes in growth rate were only small (± 3%).

As consequence of the pollution reduction the production of harvestable stem wood (yield 2024 – yield 1990) in-

Table 10. Average needle percentage (%) in the damage zones and needle development under different emission scenarios with "recent" climate.

damage zone	1961	1981	emission scenarios 2024		
	· Lux 1965	forest inventory data 1992	"worst case"	"unification"	"emission reduction"
1a	25–50	54	60.0	84.4	93.0
1b	50–60	61	70.3	90.0	96.0
2	60–67	67	73.0	91.5	97.4
3	67–75	69	74.1	90.0	96.3
0	75–90	76	79.3	91.1	96.2

***Table 11.** Changes in wood production under different scenarios. The spatial distribution of changes in growth are shown in Fig. 8 and 9.*

total wood growth emission scenario "best" - "worst", climate "present"		stem wood growth emission scenario "best" - "worst" climate "present"		total wood growth emission scenario "best", climate "present" - "dry"	
growth in % (average value)	percent of investigated area	growth in % (average value)	percent of investigated area	reduction in % (average value)	percent of investigated area
<0.0 (1.2)	15	<0(1.1)	8	>-3.0 (3.5)	40
0.0-3.0	28	0-5	51	-3.0 - -2.0	19
3.0-6.0	22	5-10	27	-2.0 - -1.0	8
6.0-9.0	16	10-20	11	-1.0-0.0	7
>9.0 (15)	19	>20 (29)	3	>0.0 (0.8)	26

creased significantly on 79 % of the investigated area (Fig. 9). It seems that especially stem wood production has profited from emission reduction. In contrast to the total wood growth distinct increases of stem wood production were also simulated in the eastern parts of the area.

The effect of drought stress was analysed with a combination of the climate scenario "dry" and the emission scenario "best". The impact of a moderate reduction of water availability on stand growth seemed to be quite weak (Table 11). Transpiration was reduced by about 25 % in the dry years, but this did not affect assimilation in the same order of magnitude. To a certain degree the reduction in water availability seemed to be compensated by an increase in the water use efficiency of the trees (*Fischer & Turner* 1978, *Schulze* 1986). Furthermore periods of water stress were observed in almost all of the years, so that the reduction in growth was less than may be expected from the precipitation data (*Grote & Suckow* 1998).

4. Discussion

The quality of the forest growth simulations is not only restricted by the probability of the scenarios but also by the knowledge of the processes and interactions between forest growth, pollution stress and site conditions.

Until the year 1989 the dominant factor controlling forest growth within the area was obviously the atmospheric SO_2-concentration. The coherency between SO_2-concentration, enhanced needle losses and reduced growth rates was caused mainly by the impact of SO_2, which led to direct inhibitions of photosynthesis in the needles (*Mohren* et al. 1992, *Meng* et al. 1994). There might have been further damages by HCl and other corrosive substances especially in the western part of the area but these effects could not be separated statistically from the SO_2 impacts.

The high immissions of fly ashes led to significant enrichments of base cations in the soils.

Therefore the acidifying effect of sulphate deposition was buffered by the alkaline components of the fly ashes especially in the vicinity of industrial facilities. As a side effect, the deposition of fly ashes also improved the base cation supply to the trees. This also may have compensated for some direct damages caused by the SO_2-concentrations.

A reduction of fly ash emissions during the investigation period in combination with a permanent high level of SO_2-emissions led to an increased potential of acidification through precipitation, and subsequently to a (re)acidification in the soils. This process already started in the 1980th. The leaching of sulphate from soils in the western part of the research area is mainly buffered by calcium, while in the eastern part, pedogeneous aluminium is already mobilised (*Schaaf* et al. 1995).

The effects of low pH-values and high concentrations of aluminium in the soil solution on tree growth are only documented as empirical relationships in the literature. The BC/Al ratio and the pH-value are used as indicators for estimating the risk of forest damages caused by soil acidification (*Sverdrup & Warfvinge* 1993). Below the BC/Al ratio of 1 or the pH-value of 4.2, an enhanced mobilisation of aluminium has to be expected, which may lead to nutrient imbalances and root damages (*Ulrich* 1987).

Despite a clear increase of the area with pH-values less than 4.2, cation supply of the soils seems to be still sufficient as can be seen from the BC/Al-values (Figs. 5a, b and Table 6). Moreover, no indication of yield losses or damages could be found in the investigated pine stands. Despite the strong decrease of sulphate immissions after 1989 it is nonetheless to be expected that the tendency of acidification in the soils will continue. This is caused by the ratio between the acidifying and basic compounds in precipitation, and the still high amounts of soluble sulphur in the soils as a consequence of the accumulation of sulphate over decades.

With the strong reduction of SO_2-emissions after the year 1989 the ongoing high nitrogen input led to a strong increase in growth rates. This is why stem volumes in the research area are somewhat higher now than the average values in eastern Germany. The positive effect of enhanced nitrogen supply on tree growth is well known (e.g. *Mälkönen* et al. 1990). As long as high SO_2-concentrations have severely affected tree growth this has more improved the survival rate of the trees than the growth (*Erhard* in prep.) and therefore stem volumes had been much lower than the average values in eastern Germany.

Due to high rates of nitrogen input the nitrogen status of the soil has changed drastically within the investigated time period. A substantial amount of the soils in the research area is almost saturated with nitrogen now. The input of nitrogen into the ecosystems is still high. Reductions in emissions are not foreseen in the near future. For that reason an ongoing process of saturation must be assumed. There are first indications of humus disintegration and subsequent nitrogen release from soil at several sites with high nitrogen concentrations (see Table 7). The most probable effect of this process is an increased leaching of nitrogen into the groundwater. A direct negative effect of enhanced nitrogen concentrations on tree growth and survival is related to the mineralization rate and therefore to the base cation supply (*Killham* 1990). For this reason the further trend in soil acidification may also influence forest growth by controlling nitrogen mineralization. High rates of inorganic nitrogen in the soil solution may lead to an overoptimal supply of the trees with the consequence of an increase in tree mortality (*Hofmann* et al. 1990).

The pattern of changes in soil nitrogen content indicates that nitrogen input was dominated by the N-emissions from nearby agricultural areas. This means that short range gaseous nitrogen immissions were more important under these conditions than medium and long range wet and particle bounded dry deposition and the fertilisation of the stands. For this reason the further development of agriculture will be of essential significance for forest growth in the research area especially at its margins.

Comparing the different data sets of nitrogen input and regarding the principal problems in quantifying gaseous nitrogen immission into forests, the nitrogen content of the soil seems to be the most reliable indicator for quantifying the nitrogen status of pine forest ecosystems especially over long time periods (decades). One of the major problems by using this approach are the large differences between the classes (see Table 7) which allows several hundreds of kilograms of nitrogen to be incorporated into the system without any visible changes in the nitrogen status of the soil.

With increasing nitrogen content the response time of the ecosystem to an ongoing N-deposition is becoming shorter and shorter (see Table 7). According to the classification high amounts of nitrogen in the soil also affect the carbon storage capacity and reduce the sink function of the forest ecosystem for carbon.

Taking into account the current annual N-surplus of the pine forest ecosystems the balance between deposition, gaseous and net uptake of the forest stands and losses by nitrate leaching and gaseous emissions from the soils indicates that the saturated soils will most likely loose nitrogen within the next 20 years (*Erhard & Flechsig* in press). Changes in biomass and species composition of the ground vegetation as observed in some parts of the area seem to be able to buffer some of the nitrogen surplus and improve the storage capacity of the ecosystem. The most auspicious measure for the maintenance of the nitrogen storage capacity and the protection of base cation levels in soils is the planting of deciduous species into the pure pine stands (*Kreutzer* et al. 1986).

According to the nitrogen status of the soil at the beginning of the investigation period, the high nitrogen storage capacity of the soils is probably a consequence of an earlier extensive use of the forests which led to a very strong reduction of the nitrogen content. This demonstrates the influence of the former management of the stands on the present and future status of the forest ecosystems (*Magill* et al. 1997).

The process oriented, dynamic forest growth model FORSANA was used to evaluate the future development of the sites in the research area. It was tested at sites with different combinations of tree age and pollution load. The model reproduced the growth of pine stands very well for a large range of site conditions, although only simplified driving forces and a small data set for initialisation were available. However the model slightly underestimated growth.

Under present conditions growth factors which are not described in the model sufficiently are getting more and more important. Especially the physiological mechanism of soil acidification and the impacts of high levels of plant available nitrogen in the soil on tree growth are still not well understood.

In this context the direct nitrogen uptake through the canopy is very important for the calculation of the total nitrogen input into the ecosystem. These fluxes can not be calculated sufficiently yet. Therefore these important factors affecting forest growth can only be evaluated using empirical risk factors.

The results of the simulation runs with FORSANA show positive effects with respect to the growth of the stands. In general stemwood seems to benefit relatively more than total growth rate. The reduction of the SO_2-immissions also has a specific effect on the foliation of the trees.

The effect of a moderate reduction in precipitation on the growth of Scots pine was lower than might have been expected. But the combination of enhanced growth rates, nitrogen saturation and soil acidification may increase the sensitivity of the forest stands to potential changes in precipitation in future. Furthermore an enhanced risk of drought stress may affect also the efforts in changing forest structures from pure to mixed forest stands as well as the groundwater recharge.

5. Conclusions

The changes of the pollution pattern in the research area from high SO_2-immissions and high nitrogen inputs linked with a good base cation supply, to low SO_2-immissions with ongoing high nitrogen loads and an increasing soil acidification led to drastic changes in the growth conditions of the investigated forests.

The positive effects of immission reductions could be proofed statistically as well as by the simulations with a process based forest growth model. The scenario based calculations indicated, that growth rates will increase also in future, if the expected trends in emission reduction will be maintained.

The decrease in pollution impact is opposed to some other risks. The simulation runs demonstrated the potential vulnerability of the ecosystems to drought stress, if climate conditions will change. Further risks that will affect future stand development are rising from the nitrogen saturation of the soils and the soil acidification. The combination of enhanced nitrogen input with decreasing cation supply, and an increasing concentration of aluminium compounds in the soil solution will lead to a higher risk for tree growth and may increase tree mortality in the subsequence of nutrient imbalances and toxic effects of aluminium in future. These kinds of problems are expected to start in the eastern part of the area, at sites which presently are nitrogen saturated and close to the critical values of pH and BC/Al ratios. It seems that in the near future the former high polluted areas will be less sensitive to the expected changes than the areas where pollution stress was less severe in the last decades.

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Microclimate Studies in an Altitudinal Gradient in the Western Ghat Mountain Ranges of Peninsular India

Jose Kallarackal & C. K. Somen

Abstract

This paper describes the studies on microclimate at four altitudes in the mountain ranges of the Western Ghats in peninsular India. The locations and their elevations are as follows: Peechi-Vazhani Wildlife Sanctuary (105 m), Chinnar Wildlife Sanctuary (450 m), Silent Valley National Park (1000 m) and Eravikulam National Park (1800 m). All the sites were protected forests. Parameters measured were atmospheric temperature, atmospheric relative humidity, soil temperature at 15 cm and 30 cm depths, rainfall, wind velocity and direction, and total solar radiation. Using automated stations, the data on the above parameters were logged at 30 seconds interval and averaged over every hour.

The temperature along the altitudinal gradients show the general pattern of reduction as the altitude increases. But the reduction in Chinnar Wildlife Sanctuary does not follow the same pattern of reduction as the other three stations. This is because Chinnar was comparatively dry. Like in many other tropical areas of the world, the relative humidity shows condensing levels during the night time during most parts of the year. However, the lower values of humidity shows the relatively high atmospheric demand in the forest areas even in the wet tropics. The solar radiation follows a pattern of reduction as the elevation increases. This is because of the higher frequency of overcast days as the elevation increases and also the presence of fog. The winds are monsoonal in all the four stations. In three of the stations, there are two monsoonal winds operating, the South-West Monsoon and the North-East Monsoon. In one of the stations, Chinnar, only the North-East Monsoon is operational. The wind velocities increased as the elevation increased. The rainfall in all but one of the four locations were very high going to more than 3000 mm annually. The Chinnar Sanctuary being situated on the leeward side of the Western Ghat mountain ranges experienced much less rainfall, approx. 500 mm annually. Data on the evapotranspiration in all the locations have been also worked out. The study stresses the need for maintaining the microclimate data in the face of global climate change and the threat to biodiversity especially in the tropics where the forests are highly fragmented.

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Isotope Analysis of Soil Water to Investigate Seepage Processes at Hartheim Pine Forest

Karin Lautenschlager

Abstract

The aim of this study was to investigate the unsaturated soil zone at the climatological site Hartheim of the Department of Meteorology of Freiburg University by means of Isotope Hydrology. Water movement in the unsaturated zone is often applied to study groundwater recharge mechanisms. The concentrations of stable environment isotopes oxygen-18 (^{18}O) and deuterium (^{2}H) in rain, soil and percolation water were used to find out whether water movement takes place at all at the Hartheim pine forest – and if it does – how such a movement is performed. The experimental site is located in the relict, holocene plain of the upper Rhine valley 20 km south-west of Freiburg. With an average yearly temperature of 11 °C and annual means of precipitation of about 500–600 mm, the region is considered to be a dry region with almost semi-arid character. Due to river regulation in the past and the sealed Rhine bypass channel, flooding does not occur any longer. As a consequence, the groundwater table has dropped to ca. 7 m below the surface.

In order to extract water from soils, the method of azeotropic distillation with toluene has been used for stable isotope analysis. So called laboratory "doping experiments", in which water of known isotopic content is added to ovendried soil material of Hartheim, helped to determine the method's variation. Almost every test experiment has shown, that azeotropic distillation technique results in lower isotopic concentrations due to incomplete extraction. The accuracy of this method declines when water content is low. In contrast to the results in relevant literature, an influence of isotopic content was observed. Therefore, the variation of the stable isotopic composition of extracted water must be differentiated during the annual sampling cycle: Low water contents in summer are responsible for variations of –1 ‰ for oxygen-18 and –12 ‰ for deuterium. Under saturated conditions, the isotopic compositions varied only up to 0,6 ‰ for oxygen-18 and to –6,5 ‰ for deuterium.

Assuming both a rather horizontal and vertical homogenous situation at the experimental site makes it possible to trace soil water movement through the unsaturated zone in the area only in a simplified way. Soil water movement could be traced by using natural isotopically (^{18}O and ^{2}H) labelled rain water. The infiltration input is built by the isotope's seasonal and local fluctuations. Temporal differences in isotopic content in soil water could be interpreted as a reaction to the precipitation input. The study indicates both, soil water moves downward layer by layer and it is temporal displaced, especially when the upper soil layers are saturated to field capacity (25–30 vol% water content) in autumn and winter time. The fact that percolation water has been collected in conduits installed in the soil is an indicator for direct vertical water movement. Particularly heavy rains will cause water transport through macropores. The mechanism of soil water movement is dominated by preferential flow as well as by diffuse piston flow.

The saturated water movement velocities were estimated according to field infiltration tests. The distribution of the soil's and substrate's representative grain sizes was carried out to determine the saturated hydraulic conductivities kf. The average kf ranges from 10^{-4} to 10^{-7} m/s in the soil layers, and 10^{-4} m/s in the gravely substrate.

The oxygen-18/deuterium relationship in the extracted soil water have information about evaporation effects. It was found out, that due to dense soil vegetation evaporation could only dominate the upper soil layer of 2–5 cm.

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Some Effects of N on Ectomycorrhizal Diversity of Scots Pine (*Pinus sylvestris* L.) in Northeastern Germany

J. Wöllecke, B. Münzenberger & R.F. Hüttl

Introduction

During evolution nitrogen (N) was always limiting in terrestrial ecosystems (*Raven & Yin* 1998). Therefore, forest communities are adapted to low N availability (*Ellenberg* 1986). Since the beginning of industrialization levels of atmospheric N have been increasing. Over the last two decades two Scots pine forest stands of the northeastern lowlands of Germany have been exposed to different N-deposition regimes (low and high N input). At the high N site the large N load stems from intensive livestock emissions, fertilizer application and fertilizer factories. As ectomycorrhizal morphotypes react sensitively to altered ecological parameters such as soil chemistry and moisture we investigated the mycorrhizal coenosis (i.e. composition and abundance of morphotypes) as part of the "Forest Ecosystem Research Project Eberswalde".

Materials and methods

Both sites represent *Pinus sylvestris* forests located in the continental lowlands of northeastern Germany. The dis-

Table 1: Characteristics of the investigation sites.

	low N site	high N site
area status	Biosphere reserve	industrial area – Schwedt
association[1)]	*Rubo-Avenello-Cultopinetum sylvestris*	*Calamagrostio Cultopinetum sylvestris*
soil type	Dystic Cambisol	Dystic Cambisol
humus form	raw humus like moder	raw humus like moder
pH-value (H_2O)	3.4	3.6
stock rate [trees ha^{-1}][2)]	673	395
stand age [a][2)]	73	76
annual precipitation [mm][2)]	507–683	487–630
bulk-deposition [kg ha^{-1}a^{-1}]		
1985–1988: N[3)]	10–20	>35
1996:[4)] NO_3-N	3.6	4.5
NH_4-N	4	9
SO_4-S	4	8
atmospheric NH_3 [µg m^{-3}][4)]	0.5	10.3
soil solution NH_4-N [mg l^{-1}][5)]	0.16	0.93
NO_3-N [mg l^{-1}][5)]	1.28	17.95
net-N-mineralisation[6)]		
[mg N kg^{-1} soil d]	6	10
net-nitrification[6)]	0.2	1.3
N-concentration [%][5)]		
needles	1.4–1.6	1.6–2.0
fine roots	1.4	1.8

[1)] determination following Hofmann (1997); [2)] Müller J. - BFH - Inst. f. Forstökologie u. Walderfassung (pers. comm.); [3)] Simon & Westendorff (1991); [4)] mean value of 1996–1998 – Zimmerling R. - FAL – Inst. f. Agrarökologie (pers. comm.); [5)] Steiner, A. – BTU Cottbus (pers. comm.); [6)] Papen H. – IFU – Fraunhofer-Inst. f. Atmosphärische Umweltforschung (pers. comm.).

tance between the low N site and the high N site is about 40 km. Soil conditions, stocking rate and forest floor vegetation were comparable before one site was exposed to higher N deposition.

For each sampling date, twelve randomly distributed soil cores (8 cm int. diam.) were collected from each site. These samples were divided into the organic and the mineral soil layer (0–10 cm). The mycorrhizae were sorted and counted in water under a stereomicroscope. The determination of mycorrhizae followed *Agerer & Rambold* (1998). To quantify the below-ground fungal mycelium (mycorrhizal and saprotrophic fungi) we measured the hyphal length according to *Söderström* (1977) by using a vital stain (FDA) and fluorescence microscopy.

Results and discussion

At the low N site *fine root dry mass* was significantly higher in the organic than in the mineral soil layer and also higher compared to the high N site. The differences between both soil layers were not present at the high N site. Also, the percentage of vital root tips was reduced at this latter site.

The *mycorrhizal frequency* (percentage of mycorrhizae on total amount of vital root tips) differed significantly between both sites (Fig. 1). Striking were the high seasonal fluctuations at the high N site. Also at this site mycorrhizal frequency decreased (<35 %) after longer periods of dryness in summer or of hard frost during winter. Such drastic decreases are only known from fertilizer experiments with very high N input (3000 kg N ha^{-1} a^{-1}; *Ritter & Tölle* 1978).

The marked decrease in hyphal length of the *below ground fungal mycelium* at the high N site in late summer (Fig. 2) corresponds well with the decreases of mycorrhizal frequency.

The *absolute mycorrhizal frequency* was highest in the organic layer of the low N site. The differences between both sites were highly significant. At the high N site several times the amount of mycorrhizae was higher in the mineral than in the organic soil layer, which is uncommon for forests in Central Europe (*Wallenda & Kottke* 1998).

Altogether we differentiated 23 *ectomycorrhizal types* at the low N site. Of these, only 15 types were found at the high N site. There were no differential species at the high N site. *Fruitbodies* of 14 potentially mycorrhizal fungal species were collected at the low N site compared to 7 species at the high N site.

Being aware of the difficulties determining critical loads, *Wallenda & Kottke* (1998) postulated that a possible critical load of 20–30 kg N ha^{-1}a^{-1} could still be too high for some ectomycorrhizal communities. In our investigation drastic changes in mycorrhizal parame-

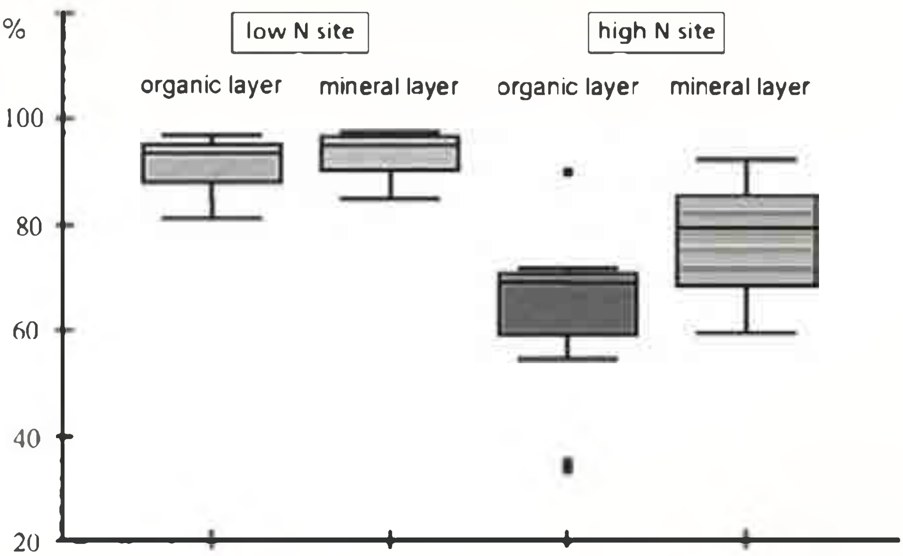

Fig. 1: Boxplot of the mycorrhizal frequency summarizing three investigation periods.

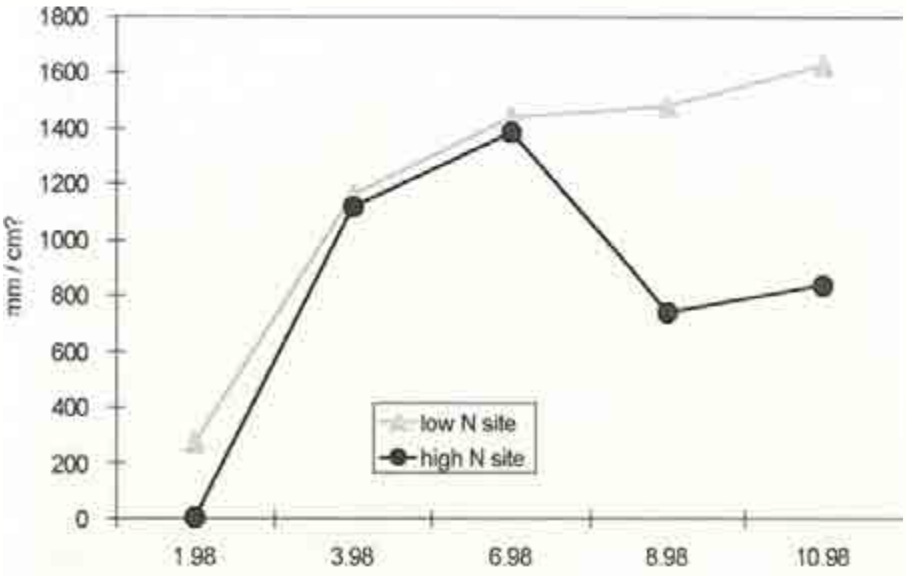

Fig. 2: Hyphal length of the below ground fungal mycelium.

ters were found at the high N site. Compared to the low N site the high N site was characterized by:

- a reduced fruitbody diversity
- a reduced number of ectomycorrhizal types
- a reduced amount of mycorrhizae per soil volume
- a reduced mycorrhizal frequency
- a reduced amount of vital root tips and fine root dry mass
- a reduced amount of the belowground fungal mycelium
- higher seasonal fluctuations of most of the mycorrhizal- and root parameters.

The high fluctuations and marked decreases of mycorrhizal parameters at the high N site correspond with periods of longer edaphic dryness. At the low N site correlations were found between mycorrhizal frequency and the content of nutrients (Ca, Mn, N, P, S) in the fine roots. At the high N site there was only a correlation between the mycorrhizal frequency and the elements P and S. No correlation was found between the mycorrhizal frequency and the content of N in the soil solution.

Many ectomycorrhizal fungal species produce fruitbodies only once or twice a decade. However, long term effects (>10 yr) of continuously increasing N deposition to ectomycorrhizal coenosis have so far not been investigated (*Wallenda & Kottke* 1998). N deposition experiments in the field have mostly shown minor changes of the belowground mycorrhizal root tips. These findings were derived from more or less humid climates or short term fertilization experiments. In our investigation the drastic differences between both sites can be explained by high N deposition (>35 kg N $ha^{-1}a^{-1}$) over a longer time period combined with climatic and edaphic dryness at the high N site (*Wöllecke* et al. 1999). We therefore hypothesize that the pine trees and their mycorrhizae react less flexibly at the high N site regarding their adaptation potential to natural stress factors such as summer drought or longer frost periods. This corresponds well with the observation of a 42 % higher natural reduction of the stock rate at the high N site compared to the low N site over the last two decades.

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Biotic Control of Organic Matter Decomposition under Climatic Changes

Sergey Trofimov

Abstract

The study was carried out in the Central Forest State Biosphere Reserve (56°30' N, 33°E, Tverskaya district, Russia). The territory represents the only place in Europe where virgin spruce south taiga ecosystems still exist. The main factor affecting spatial distribution of soil and vegetation types on the territory under study is hydrological regime, which, in turn, depends on drainage conditions. The objects of the present study were: *Piceetum sphagnoza* on fibric histosol located in gentle depression of watershed (waterlogged for the most part of a year), *P. vaccinoza* on stagnic podzoluvisol located on relatively flat part of the watershed (waterlogged for several months of a year) and *P. composita* on dystric cambisol developed on convex part of a slope (optimal drainage). Fibric histosol accumulated about 30 kg C/m² in organic horizons, 6 kg C/m² are typical for organic horizons of stagnic podzoluvisol while only 1,8 kg C/m² are stored in the forest floor of dystric cambisol. Thus, organic carbon stocks are in a good correspondence with the degree of soil overmoistening since the latter determines the rates of organic matter decomposition that are higher under optimal drainage conditions and vice versa . It has been initially presumed that lower rates of organic matter decomposition in waterlogged ecosystems (which are to a greater extent subjected to washing out of biogenic elements) are determined by "unfavourable" conditions (lower pH, N and P deficiency etc.) that, in turn may cause low diversity, biomass and potential activity of soil biota. However, only slight differences in the concentrations of biogenic elements in the organic horizons of the soils were found, while stocks of the elements in fibric histisol and stagnic podzoluvisol were even higher than in dystric cambisol due to higher organic matter stocks. Moreover, our results have shown that the diversity, abundance and microbial biomass in the first two soils were comparable or even higher than in dystric cambisol. In particular, concentration and stocks of microbial biomass in organic horizons of fibric histosol was much higher than those of dystric cambisol. That was the reason why unified spruce litter (25 replicates, 7 sampling times for three years) and unified labelled yeast biomass decomposed with the same intensity during field experiment in all soil types studied indicating that the potential biological activity of these soils is equal. However, distinct differences were found in the specific intensity of carbon mineralisation in native organic soil samples, incubated at 18°C under optimal moistening. The rates of mineralisation of comparable organic horizons were 0,011, 0,227 and 0,562 (in % of carbon loss per day) in fibric histosol, stagnic podzoluvisol and dystric cambisol correspondingly. It has been calculated that lower rate of decomposition in a bigger volume of organic substrate (that is the case with stagnic podzoluvisol) yields the same amount of annually released mineral elements as it is in dystric cambisol where decomposition proceeds with higher rates in smaller volume of organic substrate, but provides more effective use of mineral elements by plants. Proceeding from this data, one may come to the conclusion that the intensity of native organic matter decomposition in undisturbed ecosystems is strongly controlled by biotic mechanisms (including "litter quality" formation). Functional correspondence of vegetation and soil biota in natural ecosystems determines optimal rates of organic matter decomposition that ensure maximum possible plant biomass (at given drainage conditions) with minimum loss of nutrients. Proceeding from these data, one may conclude that the "strategy" of ecosystem functioning under climatic changes would be aimed at reducing the losses of biogenic elements thus hampering the accelerating effect of global warming on soil organic matter decomposition.

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