CAUSES AND CONSEQUENCES OF ACCELERATING TREE GROWTH IN EUROPE

Proceedings of the International Seminar held in Nancy, France 14-16 May 1998

Timo Karjalainen, Heinrich Spiecker and Olivier Laroussinie (eds.)

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Effects of Environmental
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PREFACE

In 1996, European Forest Institute published the research report ‘Growth trends in European forests’[1] which presents the results of growth studies in 12 European countries including Northern, Central and Southern European sites. Most studies showed that site productivity has increased on numerous sites, in particular in many Central European countries. This may have been caused by a single factor or by a combination of factors. Kuusela[2] (1994) concluded that recorded growing stock in Europe has increased by 43% during the period 1950-1990. Net annual increment has exceeded annual fellings, and the difference has been increasing. Kuusela concludes further that if this trend continues, stand density as well as age and growing stock volume per hectare will increase thus posing a risk for increasing damage by insect, fungi and wind, and other natural losses. These are interesting observations and would definitely require further investigations in order to quantify possible causes and consequences of accelerating growth in European forests.

EFI and Forest Ecosystem Coordination Unit (ECOFOR) organised in cooperation with IUFRO Group 4.01.08 (Effects of environmental changes on forest growth) an international seminar in May 17-19, 1998 with the title “Causes and consequences of accelerating tree growth in Europe” in Nancy, France to learn to what extent the findings of increased tree growth and its consequences in Europe are identified, quantified and understood. Moreover, the sustainability of increased tree growth and the possible need for further research were discussed in the seminar which was attended by 75 participants from 18 countries. On the first day of the seminar, an excursion was organised in the vicinity of Nancy, related to functioning and long term survey of forest ecosystems. First visit was to a heavily instrumented experimental plot (*Fagus silvatica* stand) for forest ecosystem research in State Forest of Hesse. At this site was demonstrated how water, CO_2 and energy fluxes are monitored as part of a European project EUROFLUX. Measurements provide basis for calibration and validation of models simulating ecosystem functioning and impacts of climate change. Carbon cycle at tree and stand scales are analysed and modelled (relation between carbon balance and tree growth). Second visit was to State Forest of Abreschwiller, which is a plot (*Abies alba* stand) of the European network of permanent sample plots for monitoring of forest ecosystems. Data are collected on throughfall, soil solutions, and meteorology. At this site was demonstrated how to organise long term monitoring and how useful such monitoring is.

[1] Spiecker, H., Köhl, M., Mielikäinen, K. and Skovsgaard, J.P. (eds.). 1996. Growth trends in European forests. EFI Research Report 5. Springer-Verlag. 372 p.
[2] Kuusela, K. 1994. Forest resources in Europe. EFI Research Report 1. Cambridge University Press, Cambridge, UK. 154 p.

The seminar itself took place at the INRA (French National Institute for Agronomic Research) centre of Nancy. During two days, 21 oral presentations were given, in addition 17 posters were on display. Altogether 26 papers were submitted for the proceedings, and after review process, 21 have been included in these proceedings, providing an overview of recent findings and ongoing activities under the theme of the seminar. Contributions have been divided in two themes: 1) biological basis for understanding causes and consequences of increased forest growth and 2) possible consequences of the increased forest growth. The first paper of the proceedings deals with the policy consequences of accelerating tree growth and by nature it is not a research paper as such but contains important perspectives from a decision maker point of view.

In addition to the authors of oral and poster presentations, the authors of the papers in this volume and participants to the seminar, many people and institutions deserve thanks for helping the organisers to run the seminar and to publish the proceedings. In particular, we would like to thank the representatives from INRA and ONF (Office National des Forêts) for organising the excursion, Ms. Brita Pajari and Ms. Colette Defer for organising the seminar, and Ms. Minna Korhonen for her assistance with the proceedings.

December 1999

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EXECUTIVE SUMMARY

Based on the presentations of the seminar, it can be concluded that there is evidence of accelerated forest growth in Europe. The case studies are based on national forest inventory data, repeated measurements of permanent plots and tree analysis data. There is now a need for studies combining different approaches (utilisation of national forest inventory data, trials on permanent plots, tree analysis) with help of modelling. One of the objectives should be to provide end-users with relevant and regionalised information on the causes and consequences of accelerating forest growth. To be able to consider this, forest management for example should know about standing stock, wood quality, impact of changing practices and evolution of site fertility.

The possible causes identified are recovery from past intensive land-use, atmospheric deposition of nitrogen, increasing concentration of atmospheric carbon dioxide, and elevation of air temperature. Nevertheless, it is difficult to quantify each impact and even more difficult to separate the relative importance of factors.

Possible consequences of accelerating forest growth were also discussed. These are related first to economical aspects: what will be the quantity and quality of wood in future and how wood markets will react on possibly increasing supply of timber, as well as to socio-economic impacts (income and employment at regional and national level). Ecological aspect should not be neglected, since increased growth may involve risks. It was suspected that nutrient imbalances could occur and the forest ecosystem could be more sensitive to extreme events like drought, frost and storm. Since accelerating forest growth is a pan-European phenomenon, it requires contributions from scientists all over Europe and involvement of various stakeholders.

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ACCELERATING TREE GROWTH – POLICY CONSEQUENCES

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ABSTRACT

Accelerated tree growth in European forests may have an impact on wood supply, profitability of forestry, tree health, stability of forest ecosystems and biodiversity. Marketing strategies, promotion of the use of wood, sustainable forest management methods and management planning may have to be reviewed. There may also be links to other policy sectors like energy supply and climate change.

For evaluating the need and appropriateness of policy consequences to be drawn in a timely manner, decision-makers would like to know more about the underlying causes of accelerated tree growth and their trends, the future developments of increment and growing stock in European forests, wood supply and its regional distribution and, last but not least, wood quality in the future.

Keywords: tree growth, wood markets, forest health, forest policy

1 INTRODUCTION

According to Tim Peck (1997), member of the board of the European Forest Institute and former chairman, major challenges for world forestry are:

- to ensure that forests meet the future demands of an expanding world population respectively to squeeze out of a worldwide shrinking area of forest land more goods and services and a widening range of them,
- for that, to ensure sustainability of the global forest resource taking into account the economic, environmental and social aspects of sustainability and
- to limit to the greatest possible extent the pressures on forests arising from outside the sector.

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As far as forestry in Europe is concerned, we should also take note of challenges like

- the very large number of small-scale forest owners,
- reducing costs and raising efficiency in forestry,
- promoting the use of wood,
- identifying additional sources of income,
- the pressure to adopt close-to-nature silvicultural regimes and
- concerns about health and vitality of forests.

Given this scenario for forestry and forest policy in Europe, a question arises concerning the links to accelerated tree growth. In other words:

- Will there be an impact on forest policy, if trees are growing faster?
- How about the policy consequences?

My answer will not be: yes, there will be an impact. Before going so far I would very much like to know more about facts and figures. For the time being, my general answer will be: there may be an impact. To be more precise: there may be many impacts, some of which I would like to discuss in detail, mostly in the form of questions in order to indicate information needs of policy-makers (and their advisers) which EFI is always eager to learn about.

2. WOOD MARKETS

According to the growth trends study (Spiecker et al., 1996), trees are growing faster in European forests (except a few regions) and growing stock is increasing. So, in the long run, there will be more wood available in the future. However, can we tell the general public, the industry, the forest owners, that, in the long run, they will be blessed

- with much higher quantities of wood available than in the past?
- with much higher quantities of an abundant, renewable, versatile, environmentally benign raw material?

Also, will wood quality be affected by accelerated growth? E.g. will there be a negative impact from higher ring width (spruce/pine trees) or not (beech)? Can we tell the forest owners good news, e.g. that the poor record of profitability (as given in parts of the forests) will improve, that wood revenues will cover the costs of sustainable forest management, plus cover the costs of providing the general public with non-wood-goods and services?

That concerns the long-term viability of the forest sector, which, in my view, is of high political importance, because, for managing forests properly, forest owners need income. Forests will only be managed, if management in the long run is profitable. Otherwise a considerable number of owners might give up forestry or – even worse –

private ownership (which is a corner-stone of western democracies). Larger areas of unmanaged forests in densely populated countries like ours are not expected to fulfill all the needs of people.

Especially the conversion into stable close-to-nature forests, which the general public expects, mostly requires active management. On the other hand, forest owners will only be able to earn a higher income from selling timber if market conditions improve.

Already at present, there is no lack of timber available in Europe. Already at present, it is indispensable to promote the use of wood and wood products significantly.

However, the question is: do we need much more efforts in this regard in the future? Do we need more research (concerning new wood products, higher quality products, improved wood processing technologies), more funding for research (from the public as well as from the private sector, from national governments as well as from the European Union), more public relations campaigns (aiming at raising public awareness of the advantages of wood and wood products)?

Do we need any further changes in national legislation (e.g. for reducing legal restrictions concerning the use of wood in house-building)? Do we need the more than ever a CO_2/energy-tax on fossil fuels and materials (which is a policy related issue to be decided in Brussels)?

As far as market strategies are concerned, can we continue harvesting and selling timber as usual? In other words, how to address the continuing build-up of growing stock in European forests? Should wood supply be increased? Slowly, step by step, of course, however, starting early enough in order to avoid abrupt changes and disturbances on the timber markets in in the years to come?

Removals in European forests and other wooded land amount to 2.3 m^3 over bark/ hectare according to the most recent FAO/ECE forest resource assessment (unpublished yet). They are nearly three times the world average, however considerably less than the annual increment. The result has been a substantial increase in growing stock, which averages about 160 m^3/hectare on exploitable forests, in some countries like Switzerland, Austria and Slovenia nearly 300 m^3 and more.

The question will have to be faced, at least in Central Europe, how far is it desirable, from both the ecological and the economic points of view, to allow this trend to continue indefinitely.

Last, but not least let me mention links to some other policy sectors: if wood supply increases, can forests become a more important source of energy than today? Can forests play a stronger role in carbon sequestration, if trees are growing faster?

3. STABILITY OF FORESTS

There is another issue to be considered which is relevant for timber markets and for forest health as well, that is, the stability of trees and stands against wind and storm. This is an issue of importance not only for forest owners, but also for policy-makers. More detailed questions include the expected height of trees, diameter growth and heigth/diameter relationship.

How about the root system? Will trees grow under ground as fast as above ground? Will higher resp. heavier stems be balanced by an equally improved root system?

May stability be weakened, if the trend of root concentration in the humus layer continues, because some nutrients like nitrogen (which is expected to be a major cause of accelerated tree growth) more than ever come from outside the forests, from the air?

I would like to focus on the issue of stability of forests respectively forest health. If trees grow faster, may there arise nutrient imbalancies? On a number of sites high nitrogen input may lead to a lack of magnesium and to discolouration and loss of needles.

These trees cannot be regarded as healthy. So, it would be premature and too simple to draw any conclusions like ”Trees grow faster; forests now healthy”, as some media did, when reporting on the growth trend study. Some of them went even further: ”Forest dieback not true. Clean air policy no longer justified”, which immediately became a matter of political importance. In the context of forest health, policy-makers are also interested in information on possibly increasing funghi and insect attacks and on future forest management needs.

4. SUSTAINABLE FOREST MANAGEMENT

Forest owners in Europe have often managed their forests sustainably for a long time, in the private sector mostly in small family holdings (more than 12 million with an average size of less than 7 hectares), thus producing a great diversity in European forests, even biodiversity.

Due to a long tradition in sustainable forest management there exists a wide range of rather sophisticated, site-adapted silvicultural methods.

Nevertheless – nothing new – those methods must be permanently reviewed and adapted to a changing environment. Will this also be true, if trees are growing faster? In this case, also forest policy means to help the forest owners like grant systems, training and extension, tax relief, legislation may be affected.

Furthermore, close-to-nature forest management might become even more necessary than today. If offers a wide range of options for the future. Stands may become better prepared for an – as I see it – uncertain future.

Policy-makers may also ask questions concerning biodiversity. E.g., will there be impacts on biodiversity, negative or positive ones, from potentially modified silvicultural methods? Will accelerated growth as such have an impact on biodiversity in forests? How many nature reserves will we need in future for maintaining biodiversity? How about a proper gap analysis?

Quite recently at their conference in Lisbon, European ministers responsible for forests adopted a work programme for the enhancement of biological diversity in forests. Together with improved monitoring, research and protection of forests against pressures from outside its main elements are conservation and – following the decisions made at UNCED in Rio de Janeiro in 1992 – sustainable forest management.

5. CONCLUSIONS

- Within the wide range of challenges which forest policy makers in Europe have to face up to, there may arise some additional pressing issues due to accelerated tree growth.
- There may be effects on the goals of forest policy in the countries as well as on policy means and ways.
- The questions raised may partly be answered by the decision-makers themselves (governments, forest owners, forest industry, other stakeholders). However, to a significant extent, researchers of various disciplines are invited to clarify matters.
- If necessary, consequences must be drawn early enough.
- However, for evaluating the need and appropriateness of policy consequences in detail, first and above all, more and more precise information is needed on facts and figures.
- At the moment we know something about trends. However, it would be helpful, if trends could be translated into quantities. Trends, up to now, are based on most interesting studies on a number of permanent plots. However, to what extent are those results representative for larger areas?
- Furthermore, how about trends in other regions? Wood markets are global ones. Enhanced growth, as we have just learnt, is expected almost everywhere around the world at middle and high northern latitudes.
- Provided, nitrogen emission abatement strategies are successful and nitrogen deposition decreases, will the present growth trend slow down? Or is the rising CO_2 level in the air more relevant for stimulating growth and, so, the trend will continue?

More general questions would include: how about the underlying causes? Their relative importance? Their interaction? Their specific trends?

A better understanding of cause/effect relationships will (hopefully) enable scientists to develop scenarios of future growth trends in European forests.

Acknowledgements

Researchers need time for adequately studying a problem, for collecting necessary information, for identifying consequences, for developing options, for carefully examining pros and cons of the different options etc.

So, I would like to thank participants for having raised the topic of accelerated tree growth in time, i.e. early enough, for working in this field and for cooperating on a supra-national, i.e. European level.

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THEME I

BIOLOGICAL BASIS FOR UNDERSTANDING THE CAUSES AND CONSEQUENCES OF INCREASED FOREST GROWTH

EFFECTS OF ATMOSPHERIC NITROGEN DEPOSITION IN FOREST STANDS: RECOGNIZING THE CONSEQUENCES BY FOLIAR ANALYSIS

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ABSTRACT

A nitrogen (N) cycle model shows that only a part of the total deposition is useful for stand nutrition because a major part of the winter deposition is lost in the drainage water. Nitrogen deposition can be beneficial to forest nutrition only if nitrogen was a limiting element before the period of high deposition, as was the case in France between 1960 and 1970, or even more recently, in some forest stands. Several fertiliser experiments demonstrated that when major elements other than nitrogen are supplied in sufficient amounts by the soil, the effect of N fertilizer, and thus probably of N deposition, is positive. However, when the supply of an other element is limited too, the effects of nitrogen fertiliser or deposition may be noxious. Foliar analysis might be a good tool for recognizing effects of N deposition but this method is limited by the high interannual fluctuation of the N concentration in the leaves or needles. For this reason, it is necessary to perform foliar analysis every year in the same stands. In addition, this continuous analysis has to be performed in mature stands: in young stands, the effect of N deposition may be hidden by the evolution of the needle or leaf composition due to stand ageing.

Keywords: foliar analysis, increase of growth, nitrogen deposition, nitrogen nutrition

INTRODUCTION

Nitrogen deposition is one of the possible explanations of accelerating tree growth in Europe (Van Bremen and Van Dijk 1988; Thimonier 1994). A general model of the N cycle (Figure 1) shows that while a large proportion of the summer N deposition is taken up by trees, only a small part of the winter deposition, which is stored in the soil water as NO_3^- and on the soil colloids as NH_4^+ is transferred to the roots. The remaining part is lost in the drainage water. Thus only a part of the total deposition is useful for stand nutrition.

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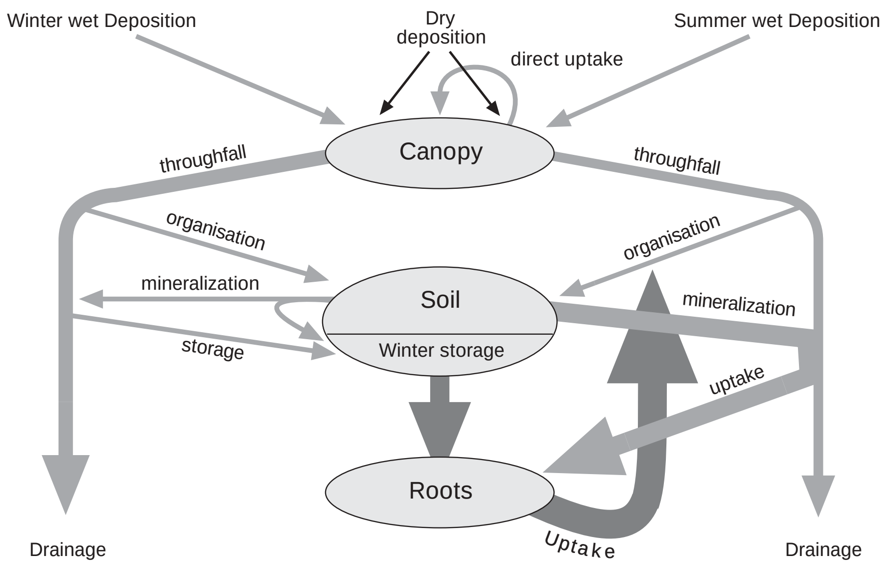

Figure 1. A N cycle model (Bonneau and Nys 1992).

Effects of N deposition from relations between stand production and N level in the leaves or from fertilization experiments

Nitrogen deposition can be beneficial to forest nutrition only if nitrogen was a limiting element before the period of high deposition. Numerous studies in France between 1960 and 1970, or even more recently, demonstrated that N nutrition was insufficient in some forest stands. This situation has been detected by foliar analysis in many studies. For instance, Leroy (1968) stated that sessile oak production in western France was positively related to nitrogen concentration in the leaves (Figure 2). In many afforestation areas in the Massif Central N nutrition was also limited (Le Tacon and Oswald 1969; Bonneau 1972a). Chichery (1972) stated that the nitrogen concentration of silver fir needles at high elevation in the Vosges was far below the normal concentration of 15 g/kg (Figure 3). N deposition has probably been useful in such conditions.

Fertilization experiments with different elements were also useful for detecting positive effects of N given in addition to natural deposition and soil supply. In some cases N fertilization without any other element may have a positive effect, as demonstrated by Nys (1981) in the Couturas experiment, in western Massif-Central on granitic soil: annual wood production of a 40-year old Norway spruce plantation was 2.5 m^3 higher in the N fertilized stand than in the control for five years after N addition. In such a situation, it is likely that atmospheric N deposition had a positive effect. In many other experiments in young (between 2 and 10 years) spruce or Douglas fir afforestations in the western part of the Massif-Central, N addition was not beneficial, with or without other elements (Bonneau 1972b, 1973).

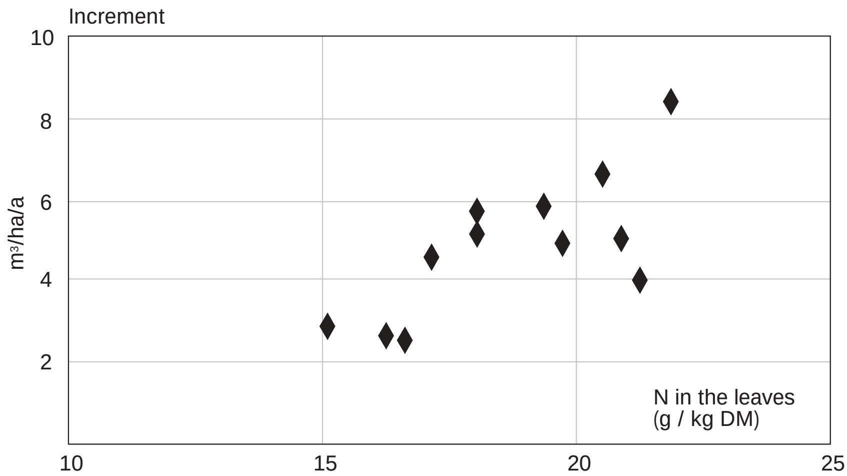

Figure 2. Relation between annual volume increment and N concentration in the leaves in sessile Oak forests in western France (Leroy 1968).

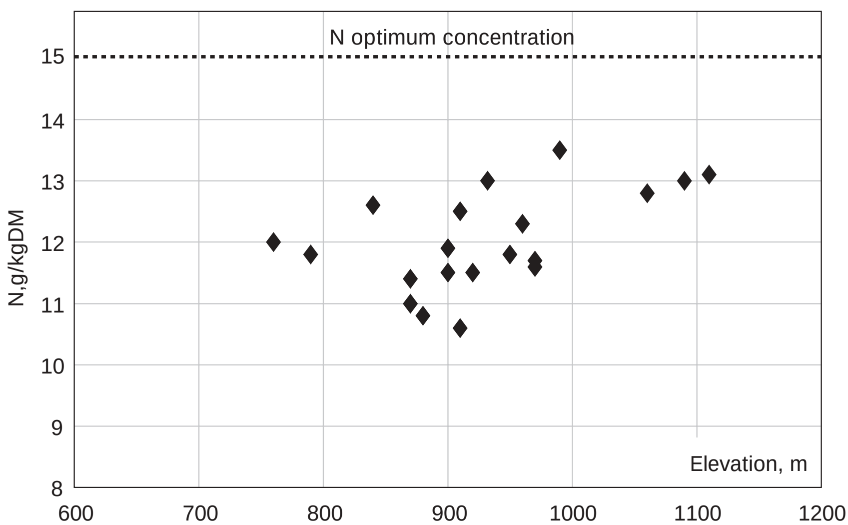

Figure 3. Nitrogen concentration in the current year needles of silver fir in the Vosges, at high elevation (Chichery 1972).

Conversely, in young natural sessile oak seedlings, N fertilization was beneficial but was tested only after addition of other elements, namely phosphorus. Figure 4 gives an example from central France, where the silty soil with clay leaching was poor in phosphorus (0.01 g/kg extracted by the Duchaufour method) and limited in exchangeable K and Ca (0.08 cmol$^+$ /kg K and 0.2 cmol$^+$ /kg Ca in the E horizon).

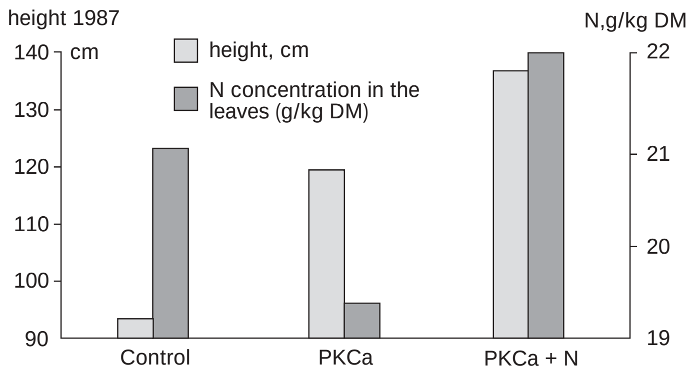

Figure 4. PKCa and PKCa+N effect of fertilization on sessile oak seedling height growth (Bonneau 1996). The control and both treatments (PKCa and PKCa + N) are represented by the pairs of bars.

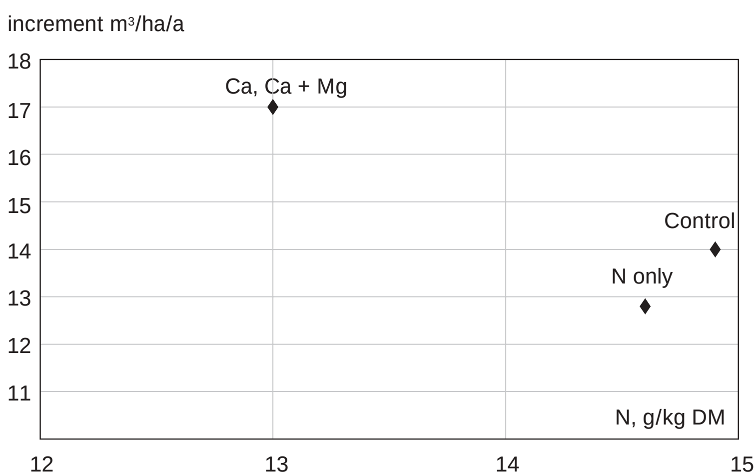

Figure 5. Monthermé experiment (Nys 1989).

The PKCa fertilization leads to a smaller growth increase than that with PKCa+N (Bonneau 1996). Fairly high N concentration in the leaves of the control and of the NPKCa fertilized seedlings and decrease after PKCa fertilization shows that N is a limiting factor after addition of elements other than N and therefore that N deposition was probably beneficial on the best soils of this region.

In very poor soils a high N deposition may be harmful, as demonstrated in the Monthermé experiment (Nys 1989) in a spruce forest where annual deposition was about 50 kg/ha under the stand canopy. In this experiment the annual wood production decreased by about 1.2 m^3 after N fertilization without other elements while it increased by 3 m^3 after Ca or CaMg fertilization (Figure 5). In this region, the French Ardennes, where the majority of the soils are poor in Ca or Mg, N deposition is certainly damaging as it causes strong acidification in soils which are already very acidic as they are developed on a poor parent material (Cambrian shales).

Possibility of recognizing N effects by series of foliar analyses

Comparison of nitrogen concentrations in leaves or needles over time would provide the possibility of recognizing positive effects of N deposition if there is an improvement of N concentration. In fact, it is only possible when several conditions are fulfilled. The first condition is that interannual variations of leaf or needle N concentration are taken into account. As an example, Figure 6 shows the mean N concentrations in needles of five mature silver fir stands in the Vosges from 1985 to 1993, which differ by more than 2 g/kg. Therefore foliar analysis might have to be performed every year for at least ten years in order to make the calculation of a significant mean concentration possible.

The second condition is to work in mature stands. When young stands are ageing, the N concentration of their leaves or needles decreases gradually, as illustrated in Figure 7 for two spruce afforestation sites in the Massif-Central. Consequently, an increase due to N atmospheric deposition might be hidden by this decrease.

There are two possibilities for detecting long term variations in foliage N concentration in mature stands. The first is by performing foliar analysis every year for 20 or 30 years and calculating a regression factor. The second is monitoring leaf or needle composition for two ten year periods separated by ten years or more and comparing the mean N concentrations of the two series.

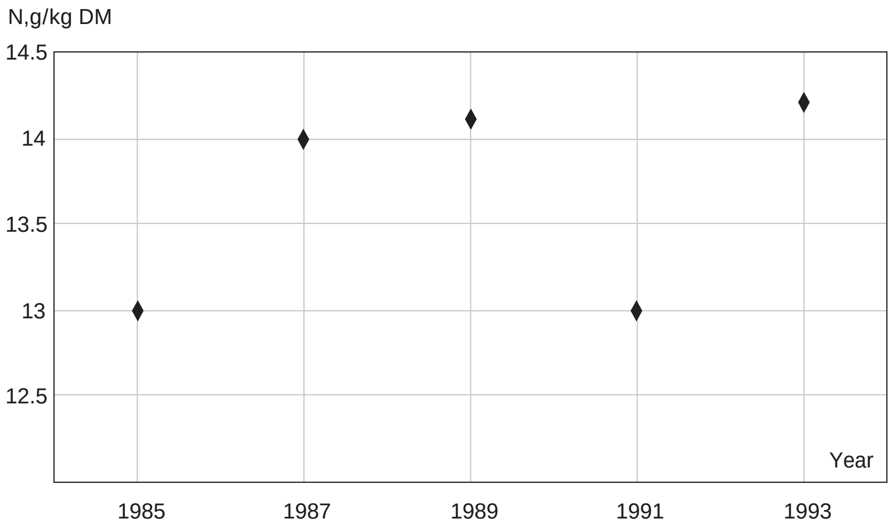

Figure 6. Interannual variation of N concentration in the needles of silver fir stands in the Vosges (mean values from six mature stands)(Bonneau 1993).

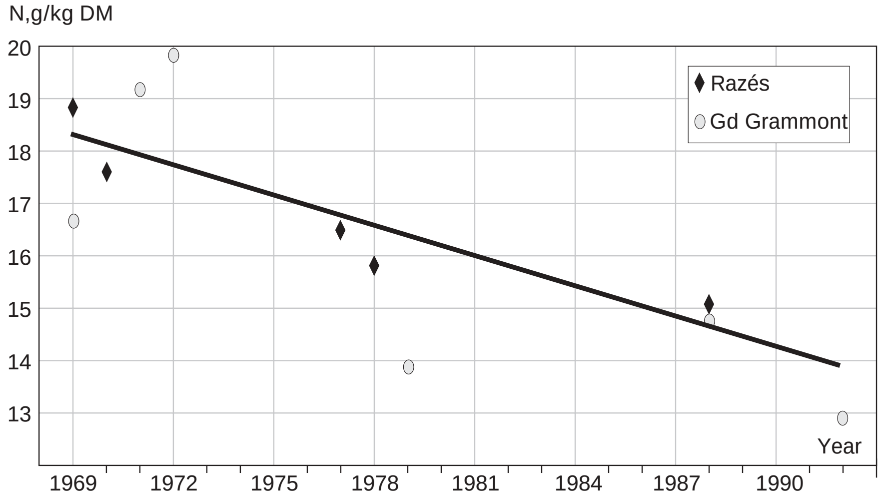

Figure 7. Development of N concentration in the needles of two Norway spruce stands in the Massif Central over 25 years since planting.

CONCLUSIONS

Several conditions are necessary for demonstrating the effects of atmospheric N deposition by foliar analysis. As in the past these conditions were not respected and research plans had other objectives, it is not easy to carry out foliar analysis afterwards. In the future, level 2 permanent plots for monitoring the state of health in European forests might provide good opportunities for creating valuable data series. For instance foliar analysis is performed every year in the 102 plots of RENECOFOR (Rèseau National de suivi des Ecosystémes Forestiers) in France. Unfortunately such networks are recent and it is unlikely that atmospheric N deposition will increase in the future. On the contrary, we hope that N deposition will decrease as a result of a pollution reduction policy (for instance catalytic silencers). If continuous monitoring of N concentration in the foliage shows a significant decrease, we can consider this evolution as an indirect argument of a positive effect of N deposition on the tree nitrogen nutrition in the past years. If, at the same time, production is decreasing, we could conclude that atmospheric N deposition was useful.

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RELATIVE IMPORTANCE OF INCREASING ATMOSPHERIC CO_2, N DEPOSITION AND TEMPERATURE IN PROMOTING EUROPEAN FOREST GROWTH

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ABSTRACT

This paper sets out some of the arguments and counter-arguments for and against increasing atmospheric CO_2, N deposition and temperature as potential drivers of the observed increase in growth rate of European forests. Some of the arguments are summarized in Tables 1, 2 and 3. The author's evaluation of the evidence is that there has been a positive, non-zero effect of increasing CO_2 on the growth of European forest this century, possible increasing NPP by as much as 10-15%. It is also highly likely that N deposition has amplified the CO_2 effect (or vice versa) in areas where forest growth is N-limited, although N deposition on its own is unlikely to have accounted for more than 10-15% increases in forest growth. Increasing temperatures may have had a smaller effect than might be deduced from site studies. But all three factors will not account for the 50%+ increases in forest growth observed in some parts of Europe, which must also be due to changes in land use practices and improvements in forest management.

Keywords: carbon dioxide, nitrogen deposition, warming, forest growth

1. INTRODUCTION

The main purpose of this paper is not to answer the question implied by the title, but rather to identify and discuss the main arguments that have been put forward for and against CO_2, N deposition and temperature as drivers of increased European forest growth.

There are two starting points for this discussion. The first is that the growth rates of many European forests have accelerated substantially during this century. Growth increases have been of the order 40% in southern Sweden, commonly 50% and exceptionally 250% in southern Germany, 24-80% in Austria and 50-160% in France

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(Spiecker et al. 1996). In northern Britain, there appears to have been a mean increase in the General Yield Class of spruce of about 1.0 m^3 ha^{-1} a^{-1} per decade, comparing forests planted in the 1930s and 1970s, and an increase of 1.2-1.6 m^3 ha^{-1} a^{-1} per decade on better quality land in Scotland, representing 20-40% increases (Cannell et al. 1998).

The second starting point is that (i) atmospheric CO_2 concentrations have risen from about 290 ppm in 1900 to 360 ppm now and is currently increasing at 1.5-2.0 ppm a^{-1}, (ii) before 1940 most European forests probably received about 5 kgN $ha^{-1}a^{-1}$ from the atmosphere, but many areas now receive 15-30 kgN $ha^{-1}a^{-1}$ – reflected in a post-War leap in sulphate and nitrate concentrations in Alpine ice cores (Wagenbach and Preunkert 1996) and in long term records of atmospheric deposition (Pitcairn et al. 1995; Mylona 1996), and (iii) mean annual temperatures over much of Europe rose by about 0.5°C during the first half of this century, with more recent warming reflected in 1989, 1990 and 1995 being three of the four warmest years since records began.

The question of whether CO_2, N deposition or rising temperatures have been important contributors to the increase in European forest growth rates is not academic. If CO_2 has been important, then Europe is witnessing an effect that is widespread in the world and is likely to continue for many decades to come. If N deposition has been important, the effect will be regional and will diminish if N deposition rates decrease and/or forest ecosystems reach saturation and adverse effects become manifest. If temperature has been important then future accelerated warming is likely to have major effects.

2. IS INCREASING ATMOSPHERIC CO_2 ACCELERATING FOREST GROWTH?

Table 1 summarizes four arguments for the proposition with their counter-arguments (1-4, arrows going left to right) and two arguments against the proposition with their counter-arguments (5-6, arrows going right to left).

2.1. Forest models predict increased growth in response to elevated CO_2

As far as I am aware, all process-based, mathematical models of forest growth which represent photosynthesis and the carbon, nitrogen and water cycles within forest ecosystems, predict that rising CO_2, without climatic change, increases forest net primary productivity (NPP) and total carbon storage (e.g. Melillo et al. 1996; Thornley and Cannell 1996, 1997; McMurtrie and Comins 1996; Medlyn and Dewar 1996; McGuire et al. 1997). Notably, Kellomäki et al. (1997) estimated that timber production in Scots pine forests in southern Finland could increase by 20% within a rotation in which CO_2 levels increased by 3.3 ppmv a^{-1} and Cannell et al. (1998a and b) predicted that forest NPP in many parts of Europe has increased by 5-14 % during this century as a result of increasing CO_2 alone.

Could all the models be wrong? All models have uncertainties associated with each process and parameter values and the accumulated errors associated with predictions of NPP are potentially very large (see Monteith 1996). Forest and crop model

Table 1. Is increasing atmospheric CO_2 accelerating forest growth?

Arguments for		Arguments against
1. *Forest models predict increased growth and C storage.*	→	Models have unquantified uncertainties and may omit or misrepresent critical processes.
2. *Forest CO_2 response needed to account for northern latitude terrestrial C sink required to balance global budget.*	→	Northern sink could also be due to N enrichment, warming, forest recovery and management.
3. *Tree seedling growth is enhanced in elevated CO_2.*	→	May not apply to mature trees in forest / soil ecosystems.
4. *Observations of faster tree growth in some parts of the world.*	→	Most interpretations implying that increasing CO_2 is responsible could be challenged (see text).
5. No consistent evidence for downregulation; photosynthesis higher at elevated CO_2; quantum efficiency does not downregulate.	←	*Light-saturated photosynthesis down regulates in elevated CO_2.*
6. In the long term, plants may use excess carbon to acquire more nutrients; existing nutrients are used more efficiently (see text).	←	*Response of some forests to elevated CO_2 may be limited by nutrient supply.*

intercomparisons have revealed large discrepancies indicating the high level of uncertainty (e.g. Ryan et al. 1993). Also, most models represent photosynthesis in great detail, but they may omit or misrepresent other critical processes affecting sinks and mineral nutrient supplies from the soil which prevent the potential response to CO_2 being realized (see Korner 1996).

2.2. A forest growth response to CO_2 must be invoked to account for the northern terrestrial sink that is required to balance the global carbon budget

A global terrestrial carbon sink of 0.5-2.5 GtC a^{-1} is required to balance the perturbed global carbon budget (Houghton et al. 1998). The evidence considered by the IPCC suggested that CO_2 enhancement of terrestrial plant growth, and especially forest growth, is currently contributing a sink of 0.5-2.0 GtC a^{-1} (Melillo et al. 1996). The land between 30 and 60°N has been identified as a strong contributor to this sink, based on forest inventories (regardless of land use change, Houghton 1996), ‘forward’ modelling (Denning et al. 1995), variations in atmospheric CO_2 and $^{13}CO_2$ (Ciais et al. 1995) and O_2/N_2 (Keeling et al. 1996). Forests, because of their large biomass and its high C: N ratio, must account for a large part of the sink (Houghton et al. 1998). Lloyd and Farquhar (1996) pointed out that the sink may be the inevitable result of a lag between the rapid response of photosynthesis and NPP to increasing CO_2 and the delayed response of soil respiration as it takes time for increased litter input to increase soil organic matter pools.

The problem is that, at present, it is impossible to separate the effects of CO_2-fertilization, N-fertilization, possible warming-enhanced mineralization and the recovery of forests from previous disturbance (Houghton et al. 1998). Also, King et al. (1995) showed that ecosystem models which predict the terrestrial sink are sensitive to assumptions about relationships between NPP and biomass. Their model is one of the few which suggests that CO_2 enhanced carbon fixation does not explain the missing sink. Thus, the terrestrial CO_2-fertilization sink is still a hypothesis, although, if it is dismissed, it leaves a serious problem to balance the global carbon budget.

2.3. Tree seedling growth is enhanced in elevated CO_2

Young, pot-grown trees usually grow faster in elevated CO_2. Wullschleger et al. (1995), reviewing 58 studies on 73 tree species found a mean response in biomass production to double ambient CO_2 of 32%. Curtis and Wang (1998), reviewing 102 measurements of tree biomass in response to elevated CO_2, found an average weight gain of 29% (averaged over all growth conditions). These reviewers found average increases in net photosynthesis of 44-54%. More recent data are consistent with this conclusion, including the EU-ECOCRAFT studies, which show that responses are especially large in tree species with indeterminate shoot growth i.e. many broadleaved trees, compared with conifers (Jarvis 1998).

There is, however, persistent doubt about whether mature trees respond the same way as seedlings and saplings. Bagged branches photosynthesize faster in elevated CO_2 (e.g. Dufrene et al. 1993; Teskey 1995) and semi-mature trees grown in an open-air exposure experiment have photosynthesized faster for 2 years (Ellsworth et al. 1997) but some argue that we need to wait longer to be absolutely sure that mature trees will respond in the long term.

2.4. Elevated CO_2 is a plausible explanation for observations of faster tree growth in some parts of the world

There is evidence for increasing forest growth rates in areas of the world where there is little N deposition and where increasing CO_2 seems a plausible explanation. Increasing ring widths in recent decades in subalpine pines in New Mexico, Colorado and California (LaMarche et al. 1984) in *Pinus uncinata* at the tree line in the Pyrenees (Badeau et al. 1996) and in subalpine *Pinus cembra* in the central Alps (Nicolussi et al. 1995) have been cited as evidence of possible CO_2 enhanced growth. Forests in remote areas of Quebec, where there is little N deposition, are growing faster in height than previously (J-L Dupouey, pers. comm.). Across northern latitudes, ring width analyses suggest that forests started growing faster after 1850, well before the warming that occurred in the first half of the 20th century, but when CO_2 levels first started to increase (Briffa et al. 1998). Another intriguing observation is that the NPP (as measured by rates of tree mortality and recruitment – the turnover rates) of humid tropical forests throughout the world seem to have increased in recent decades (Phillips and Gentry 1994). Finally, strong evidence for CO_2-growth enhancement comes form tree ring analyses of *Quercus ilex* continuously exposed to about 650 ppm CO_2 near natural CO_2 vents in Italy. These trees have grown about 12% faster than those growing in ambient CO_2 nearby, especially when the trees were young and during dry seasons (Hattenschwiler et al. 1997).

With the exception of the observations near natural CO_2 vents, all of the other interpretations could be challenged. Thus, atmospheric N deposition is spreading worldwide, owing to fertilizer use and biomass burning as much as to fossil fuel combustion (Matthews 1994; Townsend et al. 1996). Consequently, it may be unsafe to assume that N deposition is not contributing to accelerated forest growth in many remote areas in the northern hemisphere or in the tropics, especially bearing in mind that N deposition itself is enhanced by the roughness of forest canopies (Fowler et al. 1989) and even small inputs will be important for N-deficient forests.

2.5. Light-saturated photosynthesis downregulates so that there is little growth response to elevated CO_2

In many experiments on trees and other plants, some of the gain in photosynthesis created by reduced photorespiration in elevated CO_2 is lost by downward adjustment or acclimation of photosynthesis – due to a reduction in %N in leaves and carboxylase levels, a depression of carbonic anhydrase activity and/or stomatal restriction (Stitt 1991). Downregulation is manifest as a depression in light-saturated photosynthesis by leaves grown in elevated CO_2, when measured at ambient CO_2 and is especially severe in nutrient-limiting conditions and in plants grown in small pots (Jarvis 1998). Some reviewers have argued that downregulation is a general phenomenon (Ceulemans and Mousseau 1994; McGuire et al. 1995) and Gunderson and Wullschleger (1994) reported an overall 21% acclimation response across 20 studies. Could downregulation seriously limit the response of forests in the field?

There are three reasons why it may not. First, the latest review of the literature (Curtis and Wang 1998) shows no consistent evidence for downregulation except for plants grown in small pots. Studies in which plants are grown in large containers are evenly divided among those showing downregulation and those showing none or, indeed, upregulation. According to Curtis and Wang (1998), it is premature to conclude that downregulation is a universal phenomenon. Second, although downregulation often occurs in trees grown at elevated CO_2, the rate of light-saturated photosynthesis *measured at elevated* CO_2 is almost always higher than that of trees grown in ambient CO_2 (McGuire et al. 1995). Thus, trees experiencing increasing CO_2 levels in the field may be expected to have increasing light-saturated photosynthetic rates despite downregulation. Third, most foliage in forests canopies is not light saturated for much of the time, so the rate of photosynthesis is determined by the maximum quantum efficiency of photosynthesis. Even if light-saturated photosynthesis downregulated, the quantum efficiency can only be adjusted by using a different pathway of carbon metabolism. This seems highly improbable, given the constancy of all stages of the pathway in all eukaryotic photosynthetic organisms. Consequently, an increase in quantum efficiency of photosynthesis seems inevitable in response to elevated CO_2. It follows that there will be an increase in canopy photosynthesis at the high leaf area indices which exists in most forests (Long and Hutchin 1991).

2.6. The response of some forests to elevated CO_2 may be severely limited by nutrient supplies

Some studies on plants or whole plant communities growing in soils with natural low fertility show an increase in canopy photosynthesis in response to CO_2 doubling but no significant increase in plant biomass aboveground nor sometimes total biomass (Norby et al. 1992; Hattenschwiler et al. 1996; Murray et al. 1996; see Korner 1996). If there is no increase in total biomass, the additional carbon fixed in high CO_2 is presumably transferred to the soil or respired. The conclusion from such studies has been that some communities, including forests, may not respond much to elevated CO_2 when growth is severely constrained by nutrient supplies.

When the nutrient supply is *very low*, so that tissue contents of limiting nutrients (especially N) are near their minimum and cannot be further reduced by internal redistribution within the plant, then *in the short term* elevated CO_2 may result only in an accumulation of non-structural carbohydrates followed by down-regulation of photosynthesis and no increase in growth (e.g. Jarvis, 1998; Arp et al. 1998). But *in the long term* and perhaps on the timescale of actual CO_2 rise, some plant communities may be able to allocated the 'excess' carbon to roots and root exudates and effectively use it to increase nutrient availability, nutrient capture, reducing leaching and gaseous losses and/or increase both symbiotic and nonsymbiotic N_2 fixation (Idso and Idso 1994; Rogers et al. 1994; Gifford 1996). If this occurs ecosystem models show that the response of nutrient-poor ecosystems may, in the long term, be proportionately larger than that of nutrient-rich ones (Cannell and Thornley 1998)

When nutrient are limiting, but not severely so, plants respond to elevated CO_2 by reallocating mobile nutrients, especially N, away from Rubisco to light-harvesting compounds, from foliage to other plant parts, increasing retranslocation from senescing leaves and increasing the C: N ratio of the foliage (Thornley and Cannell 1996; Lloyd and Farquhar 1996). The decrease in %N in the foliage will decrease rates of leaf light-saturated photosynthesis, but the *proportionate* increase in photosynthesis with increase in atmospheric CO_2 concentration is predicted to be similar at a wide range of foliage %N levels. At double CO_2 an average C_3 leaf can probably lose 30-40% of its Rubisco activity before its light-saturated rate of photosynthesis is reduced (Long et al. 1996). Thus, even if plants do *not* use the 'excess' carbon to acquire or retain more nutrients, they may well allocate the *existing* nutrients more efficiently, allowing an increase in total plant biomass and decrease in total plant C: N ratio without a drop in plant or canopy photosynthesis. Consequently, several reviewers have found that the CO_2 growth responses of nutrient-rich and nutrient-limited plants are *proportionately similar* (Ceulemans and Mousseau 1994; Wullschleger et al. 1995; Lloyd and Farquhar 1996).

A number of growth models support this observation (e.g. Kirschbaum et al. 1994; Medlyn and Dewar 1996; McMurtrie and Comins 1996).

3. IS ATMOSPHERIC N DEPOSITION ACCELERATING FOREST GROWTH?

Table 2 summarizes four arguments for the proposition with their counter-arguments (1-4, arrows going left to right) and one argument against the proposition with its counter-argument (5, arrows going right to left).

3.1. An N-fertilization sink must be invoked to balance the global carbon budget

Models constructed by Kohlmaier et al. (1988), Schindler and Bayley (1993) and Hudson et al. (1994) suggest that N-fertilization is responsible for a global carbon sink of at least 0.7 GtC/yr. Hudson et al. (1994) argued that the hypothesized N-fertilization sink is consistent with the spatial and temporal pattern of N deposition in the northern hemisphere. Recently, this finding was supported by Townsend et al. (1996) and Holland et al. (1997) who modelled the global distribution of N deposition and concluded that it was responsible for a carbon sink of 0.7-1.3 GtC/yr, largely due to the promotion of forest growth, although globally forests receive less than 10% of the N deposited.

Houghton et al. (1998) have challenged the assumption made in most models that a substantial fraction of the N deposited on forests is taken up by the trees. Townsend et al. (1996) showed that the N-fertilization sink was only 0.4 GtC/yr in their model if they assumed that the fraction of deposited N lost (by leaching and gaseous loss) increased

Table 2. Is atmospheric N deposition accelerating forest growth?

Arguments for		Arguments against
1. *An N-fertilization sink must be invoked to balance the global carbon budget.*	→	Could be small, depending on the fraction of N taken up by forests.
2. *N enrichment is amplifying the CO_2 enhancement of forest growth.*	→	None.
3. *Positive relationship between N mineralization and forest NPP.*	→	Suggests only moderate effect of N deposition.
4. *Many forests respond to N fertilizer application.*	→	Quantities required suggest only moderate effect of N deposition (see text).
5. Many contentious issues (see text).	←	*N deposition may be having harmful effects on some European forests.*

from 20% in areas of low deposition to 100% in areas of high deposition. Houghton et al. (1998) pointed out that a large fraction of the deposited N could, in fact, be immobilized by microbes in the soil, especially as the world warms, because microbial biomass makes up a larger fraction of soil carbon in warmer soils (Insam et al. 1989). Their conclusion was that N deposition has probably stimulated a carbon sink of some kind, but its magnitude cannot be reliably estimated.

3.2. N enrichment is amplifying the CO_2 enhancement of forest growth

In many parts of Europe where there is high N deposition, foliar N concentrations have increased in recent decades (e.g. Spiecker et al. 1992; Prietzel et al. 1997; Uebel and Heidsdorf 1997). Where foliar N concentrations have risen from suboptimal towards optimal levels, we can expect that potential light-saturated photosynthetic rates have also increased. Also, foliar N enrichment will have amplified the CO_2 response to photosynthesis. In a review of 42 experiments, McGuire et al. (1995) found a linear relationship between the extent to which light-saturated photosynthesis was enhanced and the changes in CO_2 and leaf %N concentration that occurred. In other words, elevated CO_2 increased absolute rates of photosynthesis much more when leaf %N was maintained or increased as a result of N fertilization. Downregulation of photosynthesis is much less pronounced, or non-existent, when N is applied, with less reduction in Rubisco activity and less accumulation of starch and sugars in the leaves (e.g. Gunderson and Wullschleger 1994; Jarvis, 1998).

The evidence that N enrichment increases the absolute and possibly also the proportionate increase in growth of trees in response to elevated CO_2 is very strong, both from experiments on tree seedlings (see reviews by Ceulemans and Mousseau 1994; Idso and Idso 1994; Lloyd and Farquhar 1996; Curtis and Wang 1998) and from models (e.g. McGuire et al. 1995; McMurtrie and Comins 1996; Medlyn and Dewar 1996; Thornley and Cannell 1996). Besides increasing gross photosynthesis, N enrichment may lessen carbon export belowground, maintain lower C: N ratio litter and reduce N immobilization by soil microbes (e.g. Diaz et al. 1993).

3.3. Positive relationship between annual N mineralization and forest NPP suggests an N deposition effect

The aboveground productivity of forests in many temperate regions has been shown to be closely and positively related to annual N mineralization in the soil (Nadelhoffer et al. 1985), both among forest types (Pastor et al. 1984) and among soil types within a forest type (Zak et al. 1989). In a recent study of 16 conifer and 34 broadleaved stands in Wisconsin and Minnesota, Reich et al. (1997) found linear relationships between aboveground productivity and N availability for all sites taken together and for subsets grouped by forest type, soil type and land history type. It is only in single-location studies, in areas where there might be N-saturation or where only a few closed-canopy stands are studied, that no such relationship is found (Gower et al. 1993; Grigal and Hofmann 1994). Thus, if annual N mineralization was a major factor limiting the growth of European forests in preindustrial times and is still a limitation in the less polluted areas (Binkley and Hogberg 1997) then we might use N mineralization-productivity relationships to indicate how much productivity may have been increased by N deposition.

The relationships found by Reich et al. (1997) are unarguable, but it does suggest that N deposition in Europe may have promoted growth by much less than the 40-50% observed in many areas (Spiecker et al. 1996). The overall relationship shows an increase of 0.53 t ha^{-1} a^{-1} in aboveground productivity for an increase in N mineralization of 10 kgN ha^{-1} a^{-1}, over the range of 5-11 t ha^{-1} a^{-1} in productivity and 30-130 kgN ha^{-1} a^{-1}. Thus, an increase in N availability of 20 kgN ha^{-1} a^{-1} from atmospheric deposition (which would require total deposition to be greater than 20 kgN ha^{-1} a^{-1}, given the expected losses) would increase aboveground productivity by about 20% at the lower end of the range (at poor sites) and about 10% at the upper end of the range. Reich et al. (1997) found that the slope of the relationship was similar in different soil types, but was significantly less steep for planted stand, suggesting that a 20 kgN increase in annual N availability would increase aboveground productivity in these stands by a maximum of about 8%. Also, it should be noted that the slope of the relationships are probably less for *total* NPP, because of greater allocation belowground at N-poor sites. Since annual N mineralization cannot be less than annual N uptake (unless there is substantial foliar uptake) it is reasonable to assume that European forest soils, like those in the USA, mineralize 20-120 kgN ha^{-1} a^{-1} (Miller 1978; Tamm 1991; Binkley and Hogberg 1997). Thus, if Reich et al's (1997) relationships apply in Europe, N deposition is increasing aboveground productivity by no more than 10-15% except in the very highly polluted areas – where adverse effects may come into play.

3.4. The growth of many European forests is increased by N fertilizer addition

The most compelling argument supporting the contention that N deposition has increased European forest growth is that many forests respond positively to the addition of N fertilizers (Binkley and Hogberg 1997). The question then is not *whether* N deposition has promoted growth but *by how much*. Below, are a few points arguing that atmospheric N deposition may have increased growth by only a small amount.

First, where European forests respond to N fertilization, it is commonly necessary to apply very large amounts of N to obtain a 30-50% increase in productivity. Thus, applications of 150 kgN ha^{-1} *per year* are needed to increase growth by 30-50% in much of Sweden (Hinkley and Hogberg 1997). Very large amounts of N (500-2000 kgN ha^{-1} a^{-1}) must be applied to bring about substantial *long-term* increases in N mineralization at most sites, because there has to be an appreciable fractional increase in soil N. For instance, a moderately poor soil which has 2000 kgN ha^{-1} of soil N ‘capital’ and a mineralization rate of 3%, mineralizes 60 kgN ha^{-1} a^{-1}. If 300 kgN ha^{-1} is added – and only half of this remains in the soil after a period of years – then the soil N capital rises to 2150 kgN ha^{-1} and annual mineralization to 64.5 kgN ha^{-1} a^{-1}, a rise of only 7.5%. We should note that annual deposition of 15 kgN ha^{-1} a^{-1} over 20 years totals only 300 kgN ha^{-1}.

Expectations of large responses to increased N deposition may arise from the extraordinary growth responses obtained in ‘optimum nutrition experiments’ conducted in Sweden on *Pinus sylvestris* (the SWECON project, Linder 1987) and *Picea abies* (Linder 1995; the Skogaby experiment, Nilsson and Wiklund 1992; Nilsson 1997), Australia on *Pinus radiata* (Linder et al. 1987) and Portugal on *Eucalyptus globulus* (Pereira et al. 1989) in which N or all nutrients have been supplied according to demand usually with and without irrigation. In many of these experiments, growth rates have been doubled, but only *with irrigation* and an optimum supply of *all* nutrients, including at least 100 kgN $ha^{-1}a^{-1}$ for several years. At Skogaby, an increase in aboveground productivity of 31% was obtained without irrigation, but required 300 kgN ha^{-1} in 6 small applications over 3 years (Nilsson and Wiklund 1992). The growth response over 6 years to 600 kgN ha^{-1} *with irrigation* was equivalent to about 300 kg stemwood ha^{-1} per kg N applied (Nilsson 1997). Thus, deposition enhanced by 15 kgN $ha^{-1}a^{-1}$ over 20 years (300 kgN $ha^{-1,}$ without irrigation) is likely to have increased growth by considerably less than half that observed at Skogaby.

Second, conifer *plantation* forests may not take up much of the N which is deposited during that part of the rotation after canopy closure, when there is efficient internal recycling of N and/or efficient N cycling through the litter and soil. This point has been made most elegantly by Miller (1981, 1986) supported by fertilizer experiments (Miller et al. 1992) and by the fact that there has been no consistent or predictable response of *Picea sitchensis* plantations in Britain to N fertilization during the ‘pole stage’ – after canopy closure, before full maturity (McIntosh 1984). At this stage most of the N required for growth is met by recycling from senescing foliage (typically 75% of the N is recycled, depending on the N status of the trees; Zhang and Allen 1996) and by mineralization of litter, which recycles much of the N with a turnover time of 3-6 years (Thornley and Cannell 1992). Also, the aerodynamically rough forest canopy becomes more efficient at capturing atmospheric N pollutants such as HNO_3 and NH_3 (which are absorbed on leaf surfaces) and NO_3 in cloud droplets – although roughness does not alter N deposition in rain or as NO_2 (Fowler et al. 1989) – but the forest has a low demand for this N. It is therefore not surprising that, during this stage, a greater fraction of the deposited N may be leached and the ‘critical load’ for N deposition may be quite small (Emmett et al. 1993). Of course, many forests in Europe are mature, grow on poor soils, have deep humus layers and so do respond to N-fertilization (Tamm 1991; Hinkley and Hogberg 1997). However, there are many new plantations which may fail to respond, like those in Britain.

Third, in the most polluted areas of Europe, forests may already be well-supplied with N, close to the point of N saturation – when N outputs equal or exceed N inputs (Binkley and Hogberg 1997). The NITREX consortium manipulated N inputs in whole catchments or large forest stands at 7 sites spanning the gradient of N deposition across Europe. With annual inputs of about 10 kgN ha^{-1} a^{-1} nearly all the N was retained and outputs were very small. As inputs were increased from 10 to 25 kgN ha^{-1} a^{-1} there was a transition to increased leaching loss. Above 25 kgN ha^{-1} a^{-1} the forests approached N-saturation (Wright 1995). If this is true across Europe, then most forest areas in Scandinavia are well below N saturation and will respond to N addition with little risk of serious eutrophication and acidification, as concluded for Sweden by Binkley and Hogberg (1997). However, substantial areas in the more polluted areas of central Europe have received 25 kgN ha^{-1} a^{-1} or more (NOx and NHx) for several decades and so may be close to N-saturation. Emmett and Reynolds

(1996) estimated that 45% of the plantation forests in Wales receive 10-25 kgN/ha/yr and that nitrate leaching from mature forests (with least demand on soil N) may already be depleting soil base cations.

3.5. N deposition may be having harmful effects on some European forests

Contrary to the arguments for accelerated growth are all those for increased stress, a fall in NPP and eventual forest decline in response to heavy N deposition and associated pollutants in the most polluted areas (Aber et al. 1989). It is beyond the scope of this paper to cover this subject in detail. However, we may note that, in some forest regions of Europe, N, S and H^+ deposition have been accompanied by (i) decreased pH in topsoils and release of aluminium ions, especially under coniferous forests (Hallbacken and Tamm 1986; Rehfuss 1990), (ii) decreased base saturation (e.g. Falkengren-Grerup and Eriksson 1990; Prietzel et al. 1997), (iii) accumulation of soil organic carbon S and N (Meiwes et al. 1980) and (iv) widening of foliar N/P and Mg/N ratios, and disruption in Ca and Mg tree nutrition on base-poor soils (e.g. Landmann and Bonneau 1995). Aber et al. (1989) hypothesized that continued N deposition beyond the point of N saturation (exacerbated by S deposition and exposure to ozone) could lead to a drop in NPP and forest decline.

There are, however, many points of contention. In most cases, trends in soil acidity due to atmospheric deposition have not been separated from the acidifying effect of increasing stand age (Hallenbacken and Tamm 1986) and some changes in the cation exchange complex could be due in part to tree nutrient uptake and changes in species and humus composition (Miller 1990). Binkley and Hogberg (1997) concluded that, although some of the above changes are occurring in Swedish forests, there is no evidence that N deposition has reduced the health or productivity of the forests in any region – in fact Swedish forests are growing about 30% faster now than in the 1950s.

4. ARE WARMING TEMPERATURES ACCELERATING FOREST GROWTH?

Below, two arguments are considered for the proposition with their counter-arguments.

Table 3. Is warming accelerating forest growth?

Arguments for		Arguments against
1. *Strong spatial correlations between forest growth and temperature.*	➔	Confounds effects of solar radiation, soils, exposure etc. Photoperiod. Adaptation.
2. *Faster photosynthesis, sink activity, mineralization, longer season etc.*	➔	Faster respiration, leaf senescence, higher vpd, water stress etc.

4.1. Strong spatial correlations exist between forest growth and temperature in Northern Europe

At a regional scale, the growth of forests in northern Europe is positively related to temperature, or more precisely to temperature sum above a threshold (e.g. Beuker 1994). Even at the scale of northern Britain, there are strong positive relationships between temperature and the General Yield Class of conifer plantations, equivalent to an increase of 2-4 $m^3 ha^{-1}a^{-1}$ per 1°C (Worrell and Malcolm 1990; Allison et al. 1994; Proe et al. 1996). It is tempting to apply these relationships to predict effects of warming over time.

There are two reasons why spatially-derived correlations may not apply over time. First, other spatially-variable quantities are likely to be correlated with temperature, such as solar radiation, soil characteristics, 'exposure' and vapour pressure deficit. Secondly, tree responses to rising temperatures over time may be constrained by adaptations to photoperiod and temperature-response functions adapted to cooler conditions. Overall, regressions based on spatial analyses are likely to over-estimate the effects of warming, as shown by modelling studies (Cannell et al. 1998a, 1998b).

4.2. Warming accelerates many plant and soil processes which may be expected to enhance forest growth

Temperature affects almost all plant and soil processes. Warming will increase gross photosynthesis (in most of Europe), sink activity, the foliated period (length of growing season) and rates of soil mineralization, all of which could be translated into faster growth. However, warming will also accelerate maintenance respiration rates, leaf senescence rates, rates of loss of N as gases from the soil and possibly immobilization of N by microbes (Insam et al. 1989). Also, most importantly, vapour pressure deficits and evaporation rates increase with temperature, increasing periods of stomatal closure and the likelihood of plant water stress. The overall net effect may or may not be an increase in growth (see Thornley and Cannell 1996, 1997).

5. CONCLUSIONS

Conclusions on the relative importance of increasing CO_2, N deposition and temperature on the growth of European forests has to based on an evaluation of the evidence presented above – much of it conflicting. There is no simple answer. European regions and forests types differ and responses will have changed over time. A modelling analysis of forest plantation growth in northern Britain suggested that up to half of the observed increase in growth this century was due to a combination of increasing CO_2, N deposition and temperature, the other half being due to improved management practices (Cannell et al. 1998b). But some analyses of N-limited forests in Sweden suggest that most of the increase in growth this century may be due to N deposition alone (Agren in Cannell et al. 1998b).

Overall, the author's conclusion is that there has been a positive, non-zero effect of increasing CO_2 on the growth of European forest this century, possible increasing NPP by as much as 10-15%. It is also highly likely that N deposition has amplified the CO_2 effect (or vice versa) in areas where forest growth is N-limited, although N deposition on its own is unlikely to have accounted for more than 10-15% increases in forest growth. Increasing temperatures may have had a smaller effect than might be deduced from site studies. But all three factors will not account for the 50%+ increases in forest growth observed in some parts of Europe, which must also be due to changes in land use practices and improved forest management.

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CHANGES IN PHENOLOGY OF TREES IN EUROPE

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ABSTRACT

Observational data of the International Phenological Gardens (IPG), a European network established with clones of trees and shrubs, were analysed for the period of 1959 to 1993. Statistical analyses and model studies demonstrate that more than 70% of the observed variance of spring phases is explained by temperature variations. Synthetic phenological maps derived from temperature data match those based on observations surprisingly well. Thus, changes of phenological phases induced by future warming can be investigated. During the past 30 years of IPG observations, phase shifts are clearly noticeable: while spring phenophases have advanced by at least 6 days, autumn phases have gradually delayed by more than 4.5 days, yielding an average lengthening of the annual growth period of at least 10.5 days as compared to the early 1960s. Thus, accelerating tree growth is likely to be partly due to increased biomass produced during a lengthening annual vegetation period. Vegetation index variations observed from space platforms, as well as the increased amplitudes and phase shifts of the annual cycle of atmospheric CO_2, indicate that enhanced growth rates are not confined to Europe and suggest that climate changes are reflected in accelerated biomass formation almost everywhere at middle and high northern latitudes.

Keywords: phenology, phenophases, vegetation period, climate change

1. INTRODUCTION

Forests of temperate and cool climate zones are closely adapted to the seasonal cycle, with growth during spring and summer and rest during winter. This adaptation of natural populations to environmental conditions is governed by the seasonal variation of photosynthetic active radiation (PAR) and air temperature, aiming at long growth periods with minimal risk of frost. Climate changes may disturb this synchronization:

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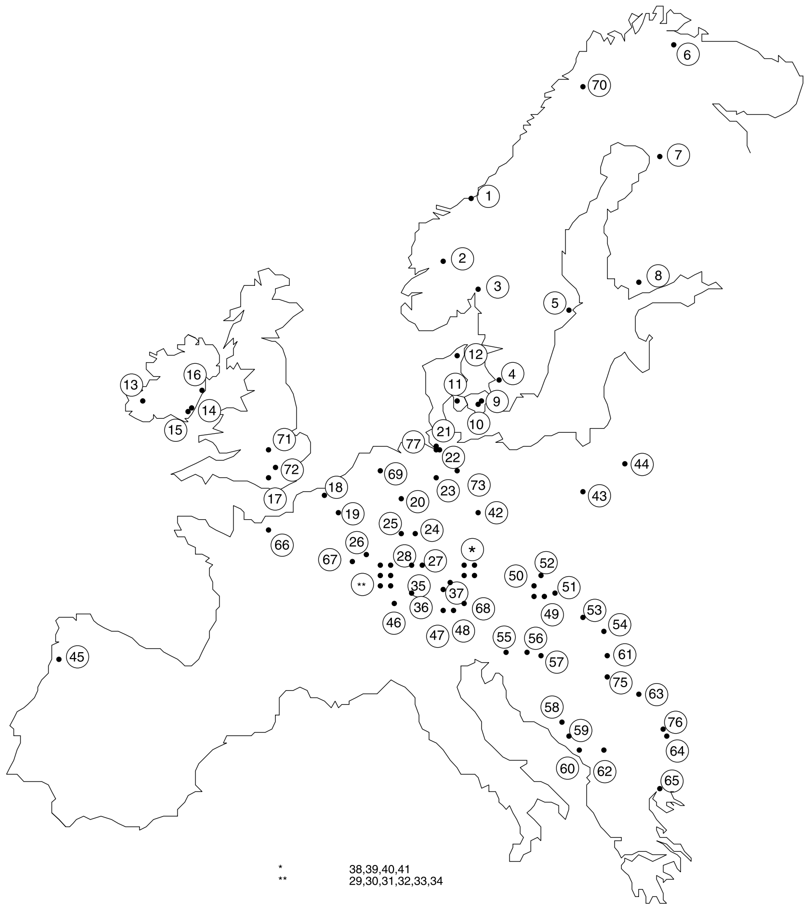


1 Trondhjem-Stjordal-Kvithamar
2 Bergen-Fana
3 Oslo As-Vollebekk
4 Lund-Svalöf-Ekebo
5 Stockholm-Bogesund
6 Utsjoki-Kevo
7 Oulu-Pelsonsuo
8 Turku-Piikiö-Yltöinen
9 Kobenhavn-Horsholm
10 Kobenhavn-Taastrup-Hojbakkegard
11 Odense-Hofmansgave
12 Aalborg-Tylstrup
13 Kerry-Valentia Observatory
14 Co-Wexford-J.F. Kennedy Park
15 Wexford-Johnstown Castle
16 Dublin-Nation.Botan.Gardens
17 London-Farnham-Headly Park
18 Gent-Melle
19 Bastogne-Mitchamps
20 Münster
21 Hamburg-Schmalenbeck
22 Hamburg-Wulfsdorf
23 Hannoversch-Münden-Steinberg
24 Offenbach
25 Wiesbaden-Geisenheim
26 Trier
27 Stuttgart-Hohenheim
28 Stuttgart-Weilimdorf
29 Kaiserstuhl-Blankenhornsberg
30 Kaiserstuhl-Lilienthal
31 Freiburg-Stadt
32 Freiburg-Eschbach
33 Freiburg-Schauinsland
34 Freiburg-Feldberg
35 Donaueschingen
36 München-Grafrath
37 Freising-Weihenstephan
38 Freyung-Schönbrunn
39 Freyung-Klingenbrunn
40 Freyung-Waldhäuser
41 Freyung-Lusen
42 Tharandt-Hartha
43 Posnan-Kornik
44 Mikolajki
45 Porto
46 Zürich-Birmensdorf
47 Innsbruck-Stadt
48 Innsbruck-Rinn
49 Wien-Stadt-Hohe-Warte
50 Wien-Obersiebenbrunn
51 Slepcany-Mlynany
52 Zvolen-Kysihybel-Vulh
53 Budapest-Gödöllö
54 Debreczin-Püspökladany
55 Ljubljana
56 Zagreb-Krizevci
57 Sombor
58 Sarajevo-Ivan Sedlo
59 Dubrovnik-Trsteno
60 Bar
61 Beograd-Smederevska-Palanka
62 Skopje
63 Vidin-Bojuritza
64 Veningrad-Yundola
65 Saloniki-Serres-Lailia
66 Lieury-St. Pierre sur Dieves
67 Nancy-Champenoux
68 Salzburg
69 Wageningen
70 Harstadt-Kvaefjord
71 Oxford-Kennington
72 London-Farnham-Alice Holt
73 Quedlinburg
74 Wien-Koblenzl
75 Beograd-Zeleno-Brdo
76 Sofia
77 Hamburg-Quickborn

Figure 1. Map showing sites of International Phenological Gardens.

warmer springs may cause earlier onset of growth with perhaps higher risk of late frost events. On the other hand, warmer winters may delay or reduce the chilling stimulus necessary to overcome dormancy, thus perhaps even delaying bud burst or leaf unfolding (Murray et al. 1989).

For a given site phenology is mainly determined by climate and weather (Schnelle 1955). Phenophases, however, such as bud burst, leaf unfolding, flowering, leaf colouring or leaf fall, are depending on genetic factors, too. In order to separate environmental and genetic factors, observations are needed based on species of the same genetic origin. Following a proposal by Schnelle, then director of the agrometeorological department of the German Weather Service, the network “International Phenological Gardens“ (IPG) was established beginning in 1959. Genetically identical clones of *Larix*, *Picea*, *Pinus*, *Betula*, *Fagus*, *Populus*, *Prunus*, *Quercus*, *Robinia*, *Sorbus*, *Tilia*, *Ribes*, *Salix* and *Sambucus* were planted in a European network covering wide areas spanning a latitude range of 28 degrees between Scandinavia and Macedonia and a longitude range of 37 degrees from Ireland and Portugal to Finland and Macedonia, respectively (Figure 1). A total of up to 77 stations were operating carrying out observations with 37 clones, not all of which represented throughout the entire network. The following 8 phenophases were observed: leaf unfolding, May shoot, begin flowering, full flowering, St. John’s shoot, first fruits, leaf colouring and leaf fall.

The IPG network was supervised by the respective coordinators F. Schnelle, E. Volkert, A. Baumgartner and W. Lieth, observational details and first results were published in Arboreta Phaenologica (Schnelle 1986 and references given therein). Many papers on phenophases and their relation to climate and weather are documented. It is, however, beyond the scope of this paper to review these here, instead we refer to Menzel (1997) and references given therein.

2. IPG DATA ANALYSIS AND MODELLING

A comprehensive analysis of IPG data, for the 1959 to 1993 period, was carried out by Menzel (1997). This work also includes quality control of the data and model studies relating phenological phases to climate parameters from adjacent weather stations. Here we refer to this paper containing all pertinent details and confine ourselves to reporting some of the main results only.

Figure 2 shows typical examples of two of the longest series of the IPG network. The left panel shows a spring phase, the appearance of the May shoot of *Picea abies*, at IPG 26 (Trier). Days are counted beginning January 1. The lower panel shows a fall phase, the beginning of leaf colouring of *Betula pubescens*, at IPG 58 (Sarajevo). One can notice year-to-year variations of both phases as well as a negative trend of the spring phase and a positive trend of the fall phase which will be discussed in the next section.

Stepwise linear regression was carried out between phenological phases and various climatological parameters. The influence of the photoperiod and relations to longer weather period was investigated, too. It turned out that temperature is the dominating parameter for modelling spring phases. This was applied in our model with a

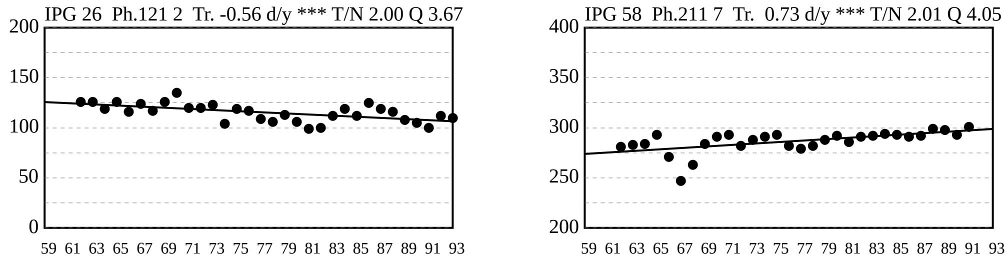
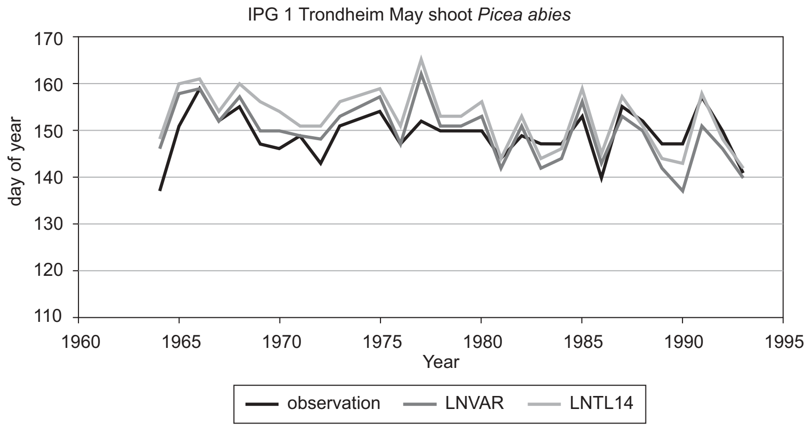


Figure 2. An example illustrating changes in phenological phases at two sites.
Left panel: IPG 26 (Trier) *Picea abies*.
Appearance of first May shoot (day of year) 1961-1993.
Right panel: IPG 58 (Sarajevo) *Betula pubescens*
Leaf colouring (Julian days) 1961-1993.
Tr = linear trend (days/year)
T/N = trend/noise ratio
Q = significance level Mann-Kendall trend test.
Trends of both series are highly significant (***)

logarithmic function and variable temperature threshold limits (LNVAR, for details see Menzel 1997). Two typical results are displayed in Figure 3. The upper panel shows the phase of May shoot of *Picea abies* at IPG 1 (Trondhjem), one of the poorest model fits, with 70% of the observed variance reproduced by the model (LNVAR). The lower panel shows the phase of flowering for *Prunus avium* at IPG 24 (Offenbach), one of the best model fits, with even 90% of the observed variance reproduced by the model.

LNVAR model experiments were carried out using 30-year model runs with the ECHAM-T42 climate model of the German Climate Center Hamburg performed under 1 × CO_2, 2 × CO_2 and 3 × CO_2 conditions. Phenophases were computed using temperature distributions of these time-slice experiments. A typical result is displayed in Figure 4 for the phase of flowering of *Salix smithiana*. In a latitude/longitude grid covering Europe this phase is shown in days (beginning Jan. 1) for present conditions (1 × CO_2, upper left). The middle and lower left panels show phase shifts for 2 × CO_2 and 3 × CO_2 conditions. It should be noted that, due to the cold start characteristics of these experiments, 3 × CO_2 represents conditions close to real CO_2 doubling. The right panels display late frost risk probability for present (upper), 2 × CO_2 (middle) and 3 × CO_2 (lower) conditions. These experiments showed, without exception, that the risk of late frost does not increase for increasing CO_2 levels. In most cases, despite earlier onset of spring phases, the risk of late frost events becomes smaller, compared to present conditions.

Model LNVAR was successfully applied on adapted wild plants and forest trees as well. Phenological phases observed within the Bavarian phenological network, about 1000 stations operated by the German Weather Service, were compared with those computed with LNVAR based on climate data. Synthetic maps thereby produced showing the geographic distribution of various phenophases for Bavaria based on climate data are almost identical with real maps of phenophases based on observations (30-year averages) as shown in the new Climate Atlas for Bavaria (Bayerischer



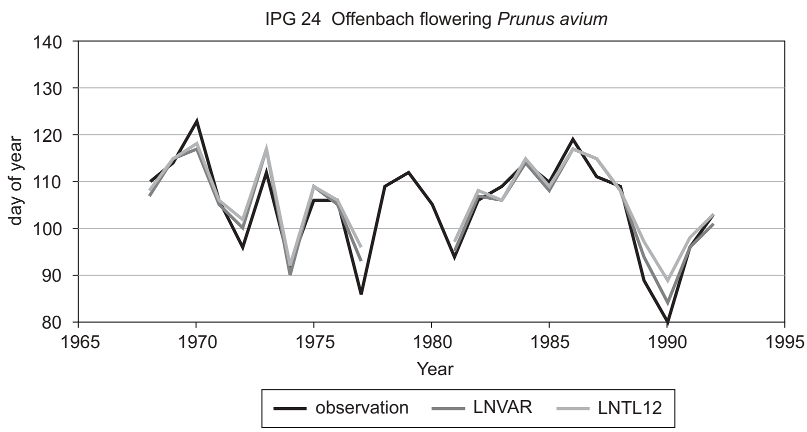


Figure 3. Comparison of observed phenological phases in days beginning Jan. 1 and model results. Observations are shown by heavy lines without symbols. LNVAR shows results of model with optimized temperature thresholds within 3° - 9°C (see text). LNTL 14 and LNTL 12 include correction for 14 and 12 hours daylight, respectively, not discussed her (see Menzel 1997). Upper panel: IPG 1 (Trondhjem), beginning of May shoot of *Picea abies*. Lower panel: IPG 24 (Offenbach), flowering of *Prunus avium*.

Klimaforschungsverbund 1996). It is obvious that the model developed for single clones is suitable for adapted plants as well.

3. TRENDS IN PHENOPHASES OBSERVED FROM IPG DATA

Figure 2 shows two examples of time series which clearly reveal trends of phenophases within about 30 years of IPG observations. While the spring phase of *Picea abies*

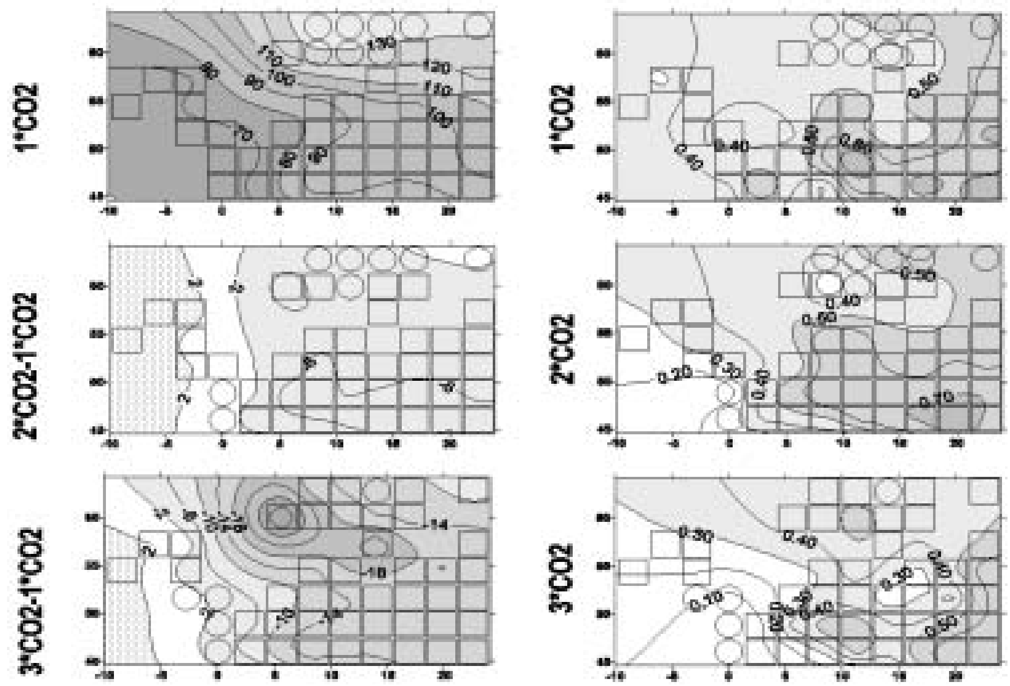


Figure 4. Flowering of *Salix smithiana*, displayed in a latitude/longitude grid covering Europe. Left panels: phase for present conditions (1 × CO_2) and phase shifts for 2 × CO_2 and 3 × CO_2, respectively. Right panels: Late frost risk probability for present conditions (1 × CO_2, 2 × CO_2 and 3 × CO_2, respectively. For further details see text.

displayed in the left panel shows a negative trend of –0.56 days/year or –18 days for the whole period, the fall phase of *Betula pubescens* shown in the right panel reveals a positive trend of +0.73 days/year or +23 days for the whole period. In the left case spring onset is gradually advancing with time, while the beginning of fall is gradually delayed over the years, as shown in the right panel. These trends are highly significant according to the F-test, trend/noise ratio and Q (Figure 2) determined for the Mann-Kendall trend test (Rapp and Schönwiese 1995).

Not all phases of the observed IPG clones show significant trends, and many show no trend at all. Trends observed at some stations of the IPG network are not necessarily consistent for all stations. In general, however, there is a tendency of negative trends for the spring phases and, although less consistently, of a positive trend for the autumn phases. Significant trends of spring phases (Leaf unfolding, May shoot, flowering) are displayed in Figure 5. Only those trends are shown which are significant on the 1% and 5% level, respectively, and which base on observational periods of at least 20 years. The majority of the 148 points is negative showing that spring onset is advancing over the years. The Slovak stations and some of the Balkan stations show significant positive trends, which are likely to result from the regional pattern of climate changes (Menzel 1997). Taking an average over all data points of Figure 5, a negative trend of -0.5 days/

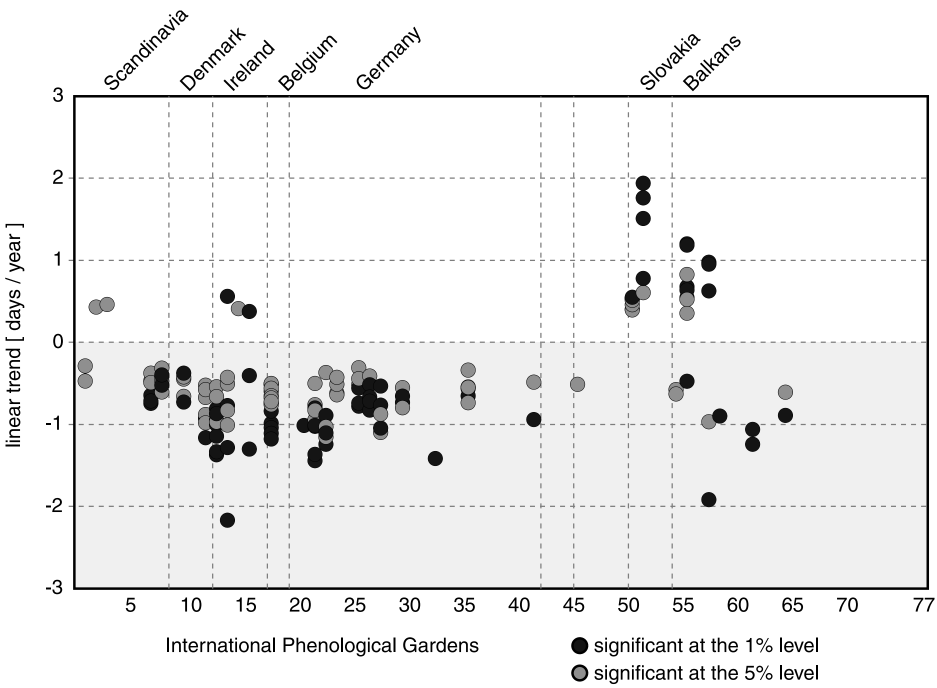


Figure 5. Significant trends of spring phases for long observational series in 1959-1993.

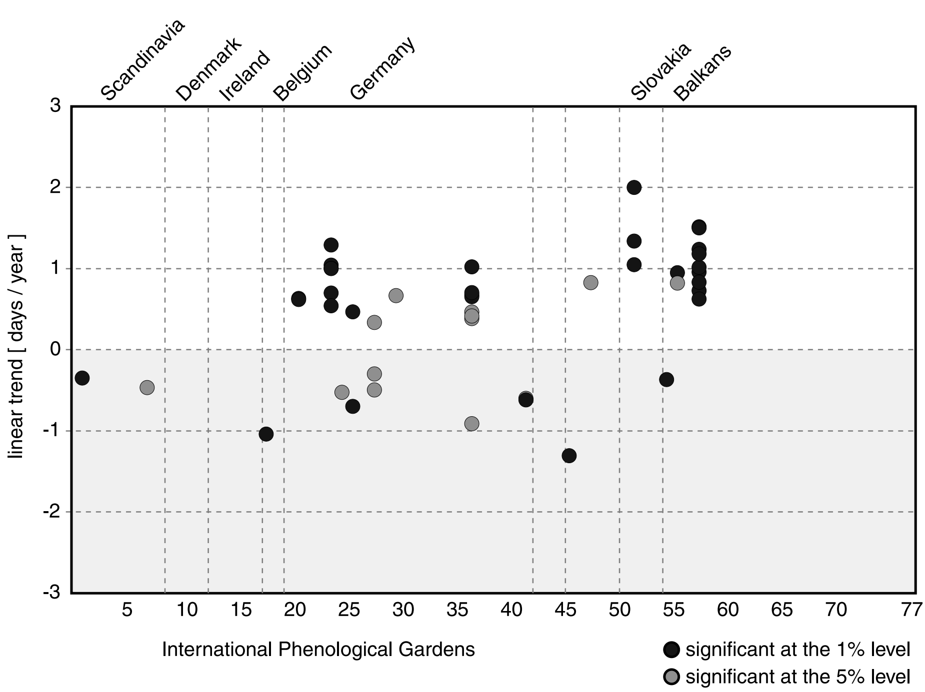


Figure 6. Significant trends of autumn phases for long observational series (≥ 20 years) in 1959-1993.

year or - 10 days for the 20 year observational period would result. Averaging over the entire set taking into account trends of all 615 spring phase data series, each covering more than 20 years, however, yields - 0.2 days/year. As these data series as a whole cover the entire 30-year IPG observational period, an average advance of spring phases of 6 days is likely.

Significant trends of autumn phases (leaf colouring and leaf fall) are displayed in Figure 6. Like for the spring phases, only observational periods longer than 20 years are considered. It is obvious that autumn phases are subject to a more complicated interplay of climatic parameters, and thus, so far our modelling is confined to spring phases only. Compared to Figure 5 much less data points of significant trends are shown in Figure 6. Nevertheless a tendency towards dominating positive trends is obvious. If an average over all data points of Figure 6 is taken, a positive trend of +0.3 days/year or 6 days for 20 years is obtained. In a similar way as compared to the spring phases, a delay of only 4.5 days is calculated averaging all 178 trends of autumn phase series covering more than 20 years.

Thus, if these average trends are considered representative for the whole IPG network, an advance of spring and a delay of fall results in a lengthening of the annual growth period. Considering significant trends only, an advance of spring by 10 days and a delay of autumn by 6 days would suggest 16 days lengthening of the vegetation period. Although this appears to be a conservative estimate since many of the observational series are longer than 20 years, we prefer to stick to the results obtained by averaging all data series. With 6 days advance of spring and 4.5 days delay of autumn phases we thus obtain 10.5 days for the average lengthening of the annual growth period, which is likely to be a lower limit. Thus compared to the early sixties, the average annual growth period in Europe has most likely become longer by more than 10.5 days. Considering the modelling results described in the previous section, there is no doubt that this observed lengthening of the vegetation period is due to climate changes. The regional dependency of climate changes is certainly reflected in phenological observations as well. We are presently working on the regional dependencies of phenological trends noticeable in Figures 5 and 6.

4. ACCELERATED TREE GROWTH AND CLIMATE CHANGE

Accelerated tree growth observed in wide areas of Europe has been attributed to fertilization by nitrogen compounds and CO_2 (Spiecker et al. 1996). The observed lengthening of the annual growing season, by at least 10.5 days on average compared to the early 1960s, is likely to contribute to this enhanced biomass formation. At present it is not possible to quantify this contribution, but global observations show that climate change has a considerable effect on vegetation. In fact, accelerated tree growth is not confined to Europe: observations from space-borne platforms indicate that the vegetation index over most middle and high latitude land areas has increased remarkably during the 1980s (Myneni et al. 1997). Moreover, the increasing annual amplitude of atmospheric CO_2 and its shifting phase are indicative of increasing amount of biomass and a lengthening of the annual vegetation period at middle and high northern latitudes (Keeling et al. 1996). Accelerated tree growth in Europe is just part of a global increase of biospheric activity. There is no doubt that climate has changed already and that this climate change is manifested in accelerated growth. Computations applying global carbon and vegetation models are needed to quantify this effect.

Acknowledgments

We wish to acknowledge the work of late F. Schnelle and E. Volkert who initiated the IPG network. We also thank the numerous anonymous observers without whose efforts no IPG would exist. We are grateful to the German Weather Service for providing IPG and climatological data. Last but not least we gratefully acknowledge the kind assistance of many individuals and authorities in various countries for making climatological data available to us. Some financial support provided by the Bavarian State Ministry of Agriculture and Forestry is gratefully acknowledged.

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FLORISTICAL CHANGES IN CENTRAL EUROPEAN FOREST ECOSYSTEMS DURING THE PAST DECADES AS AN EXPRESSION OF CHANGING SITE CONDITIONS

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ABSTRACT

Changing floristical composition of vegetation stands can be used as an indication of changing site conditions. Phytosociological relevés are documents of vegetation stands at a given place and a given time. Repeated relevés (e.g. permanent plot or quasi-permanent plot analysis) allow to draw conclusions concerning changes of floristical and site conditions in the course of time. Three case studies from both central and southern Germany are used to discuss the potentials and limitations of the interpretation of such results.

Based upon that the results of such studies from all over Central Europe are reviewed briefly. The most essential results are: (1) Increasing nitrogen availability is the driving factor of floristical change in the forests of Central Europe. (2) In most cases the floristical composition does not reflect the current soil acidification process; increasing representativity of acid indicator species is a rare event, restricted to areas which are/were intensively influenced by (acid) immissions. (3) A general trend of the representativity of light indicator species during the last decades cannot be seen; changing representativity of the light indicator species especially depends either on changing forest (land use) management practices (high forest management instead of coppicing, “Hochwald“ versus “Niederwald“, “Mittelwald“; expiring forest grazing management) or on reduced crown density e.g. as a consequence of the so-called “new type forest disease“. (4) Species number per relevé is depending on many different reasons, most of them of very local extension; therefore changes in species number in the course of time can neither be used as an indication of the direction nor the extent nor the reason of the current successional processes. (5) Successional change as an effect of “global change“ cannot be evidenced in the forests of Central Europe with phytosociological methods up to now.

Keywords: phytosociological method, vegetation change, nitrogen availability, acid rain

Timo Karjalainen, Heinrich Spiecker and Olivier Laroussinie (eds.)
Causes and Consequences of Accelerating Tree Growth in Europe
EFI Proceedings No. 27, 1999

1. INTRODUCTION

Increased tree growth is well documented in Central Europe since several decades (see e.g. Röhle 1995, Spiecker et al. 1996). This paper is not focused on trees or tree stands but on forest phytocoenoses in total, i.e. on all the plants (including trees) living together at distinct spots, interacting (1) among themselves and (2) with the abiotic environmental factors. As a consequence of the plant-environment-interactions as well as the plant-plant-interactions groups of plant species (plant communities) can be understood as expressions of environmental conditions. Therefore changing floristical composition of phytocoenoses can be used as indication of changing site conditions (changing environmental factors). The questions of interest are: (1) Which general floristical changes are indicated by the (changing) vegetation at present? (2) Which factors are responsible for such changes?

First the method of phytosociology, as it is used in studies on vegetation changes, will be described in short, second some main results of three case studies carried out in Germany will be presented, and third a survey on the prevailing trends of succession in Central European forest communities will be given.

2. PHYTOSOCIOLOGICAL METHOD AND VEGETATION DYNAMICS

Phytosociological relevés are documents of vegetation stands; each relevé contains a list of all the plant species growing on a reference area (in forests usually 100 to 400 square meters large) as well as cover/abundance estimates of each species. In the course of time such relevés will become documents of *past* vegetation conditions. Because the floristical composition of vegetation stands in particular depends on site conditions, old relevés can be used as sources of information about the environmental conditions influencing the ecosystem during past time.

Hundreds of thousands of relevés have been made during the last decades in Central Europe, but unfortunately the accurate localities of the old relevés usually are unknown. In few cases, however, the relevé areas were marked permanently (*permanent plots*), or the localities of the old relevés were documented exactly, so that a repetition of the relevés is possible on almost identical sites (*quasi-permanent plots*). Finally a set of relevés worked out in a special vegetation typ of a limited landscape area can be repeated several years or decades later, and the two sets of relevés can be compared.

3. THREE CASE STUDIES FROM GERMANY

In 1950, in the course of a forest survey, 110 phytosociological relevés were carried out in stands of the Luzulo-Fagetum (beech-forest community on acid soils) and in coniferous forest stands of comparable sites in the Rhön mountains in northern Bavaria (Ehrhardt and Klöck 1951); the localities were precisely documented in maps. 40 years later 54 relevés were repeated on almost identical places (Röder et al. 1996; see Figure 3 to 6, study area: nr. 7). The following results are of general importance:

1. According to the site factor preference of the plant species under field conditions Ellenberg (1974) established the ecological indicator value system (Ellenberg et al. 1992). On a relative scale from 1 to 9 the ecological preference of each Central European plant species was evaluated; most important ecological site factors are the soil acidity (R), the nitrogen availability (N), the soil water availability (F) and the light availabiliy (L). Using simple mathematical methods *mean ecological indicator values* (mR, mN, mF, mL; high values mean high degrees of availability of nitrogen, soil water and light, respectively, and high pH values) can be calculated. Applied to the data set of the Luzulo-Fagetum from the Rhön mountains it becomes obvious (Figure 1) , that during the last four decades the mean nitrogen indicator value increased strongly, and the mean acidity value increased moderately, that means *increasing* importance of the species with high nitrogen demands and *decreasing* (!) importance of acid indicating species. How to interprete these results? The soil pH is really decreasing since the past one to six decades in Central Europe, as it has been proved by a lot of studies in soil ecology (see literature survey in Rehfuess 1990, p. 243). But the driving factor of vegetation change is the increase of nitrogen availability, making it possible for plant species with high demands on N availability to get into sites which were poor in nitrogen in the past. N-demanding plant species are usually not restricted to acid substrat; on the other hand the well growing N-indicators outcompete a lot of the low-growing

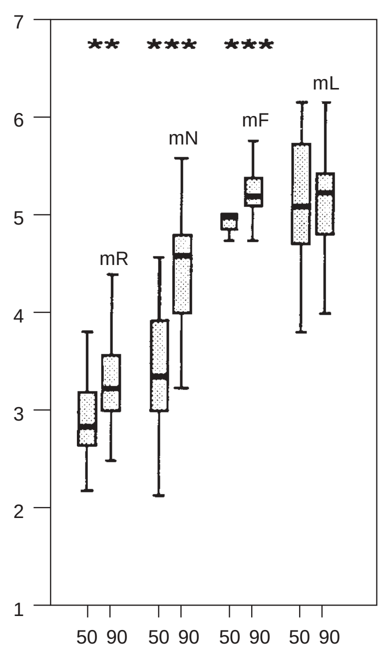

Figure 1. Boxplots of the mean ecological indicator values mR (mean soil reaction value), mN (mean nitrogen availability value), mF (mean moisture value) and mL (mean light value) 1950 (50) and 1990 (90), respectively, in unfertilized stands of Luzulo-Fagetum in the Rhön mountains/northern Bavaria (Röder et al. 1996, modified).

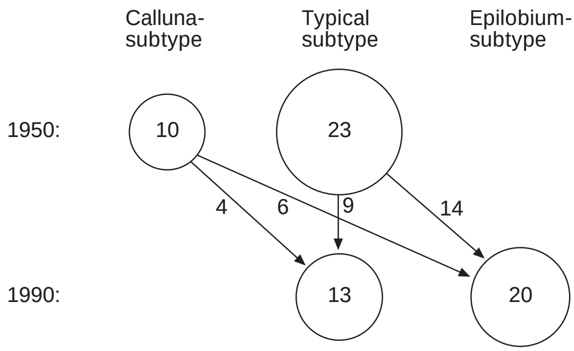

Figure 2. Subtypes of Luzulo-Fagetum in the Rhön mountains/Germany in 1950 and 1990 based on 33 quasi-permanent plots. Figures: numbers of phytosociological relevés (Röder et al. 1996, modified).

acid indicators. Indeed the mN and mR values are correlated positively at highly significant level (Röder et al. 1996). As a consequence the acid indicators may decrease (and the corresponding acid indicator values increase) although the soil pH is decreasing.

2. In 1950 the relevés represented two subtypes of the Luzulo-Fagetum, the "typical subtype" and the "*Calluna*-subtype", the latter characterized by acid indicator species like *Calluna vulgaris*, *Melampyrum pratense*, *Trientalis europaea* (Figure 2). As a consequence of the decline of acid indicator species up to 1990 the *Calluna*-subtype had almost disappeared; on the other hand a group of nitrogen indicator species like *Epilobium angustifolium* appeared, creating a new subtype. The general vegetation type, the association *Luzulo-Fagetum*, remained, but in detail there was a significant shift on the level of the subtype, indicating an increasing availability of nitrogen.

3. The water availability value had moderately increased; this also depends on the nitrogen availabilty: increased nitrogen availability reduces the need for water uptake. The light factor did not change significantly.

Summarizing the time sequence analysis shows that on the acid soils of the study area in northern Bavaria during the past four decades the most important environmental factor influencing the floristical composition of the forest vegetation was the increasing nitrogen availability.

A complementary result could be demonstrated in the forests of the vicinity of the Frankfurt airport (Fischer 1993, 1995; nr. 8 in Figure 3 to 6): In a ten years permanent plot study with vegetation records each year and with very detailed methods of vegetation recording and data analysis it became clear that in pine plantations on nutrient poor, acid, sandy soils the small-growing indicator species of nutrient deficiency were decreasing significantly during the short observation period (Table 1).

Table 1. Species with significant decrease (-) or increase (+) of cover degree during 1982 and 1990 on four unfenced permanent plots. Managed *Pinus sylvestris* stands on acid, sandy soils near Mörfelden/Germany. (Fischer 1993, modified). Symbols: Number of (-) resp. (+) characters: level of significance; (•) species present, but not any significant change; (×): year to year fluctuations.

permanent plot nr.	4	11	13	5
Rumex acetosella	--	---	---	×
Avenella flexuosa	•	---	---	---
Agrostis tenuis	•	---	•	---
Anthoxanthum odoratum		-	---	•
Lonicera periclymenum		---		
Festuca tenuifolia		-	•	•
Moerhingia trinervia	•	•	•	-
Molinia arundinacea	+++	+++	•	•
Dryopteris carthusiana	+	•	•	•

The situation can be quite different in areas with calcareous subsoil. In the surroundings of Lake Starnberg (Southern Bavaria with soils derived from calcareous moraine material) 71 relevés from 1949 of elder, ash as well as beech forests had been repeated nearly 5 decades later (in 1997; Fischer, Frielingdorf and Klöck, unpublished research report; see map 3 to 6, nr. 13). Using the floristical method it was not possible to detect any significant hints on changes of floristics which could have been interpreted as depending on changing environmental conditions like nitrogen availability or soil acidification.

4. THE GENERAL SITUATION IN CENTRAL EUROPE

Several studies of the type mentioned above have been carried out between Southern Sweden and Switzerland and between Eastern France and Southern Poland in the 1980s and 1990s (Table 2; Figure 3 to 6). The conclusions of these case studies shall be reviewed qualitatively and briefly.

1. All over Central Europe the representativity (that means: species number, frequency, cover/abundance, and/or mean ecological indicator value) of nitrogen indicating species increased more or less intensively (Figure 3; Table 2: publications of van der Werf, 1987/the Netherlands and Nieppola 1992/Finland were not included, because the original data as well as the indices of interest were not presented). This is the most homogeneous trend in vegetation dynamics realized in recent Central European forest stands. Increase of representativity of N-indicating species takes place on acid soils (e.g. nr. 1, 6, 11) as well as on calcareous soils (e.g. nr. 15). Nevertheless there are a few cases without any significant change of representativity of these species, independent of the soil substrate (nr. 5: acid, nr. 13: calcareous soil).

Table 2. Phytosociological studies on floristical changes in Central European forest ecosystems.

Country / landscape	author(s)	period of time	
Sweden			
1. Skåne/S-Sweden	Falkengren-Grerup 1986, 1989	1949/70	1987/88
2. E-Småland/S-Sweden	Brunet et al. 1997	1983	1993
Germany			
3. Holstein/N-Germany	Rost-Siebert & Jahn 1988	1935	1983/84
4. Westphalian Bight/NW-Germ.	Wittig et al. 1985	1976	1983
5. Osterzgebirge/ E-Germany	Schmidt 1993	1956	1991
6. Oberpfalz/E-Bavaria	Rodenkirchen 1993, 1998	2 to 4 decades	
7. Buntsandsteinröhn/N-Bavaria	Röder et al. 1996	1950	1990
8. Frankfurt/M.	Fischer 1993, 1995	1982	1991
9. Kirchheim/Teck (SE Stuttgart)	Buck-Feucht 1986	1951/53	1983/85
10. Schwäbische Alb/SW-Germany	Wilmanns 1989	1953	1988
11. Black Forest/SW-Germany	Bürger 1991 Bürger-Arndt 1994	1940	1985/86
12. Kaiserstuhl/SW-Germany	Wilmanns et al. 1986 a, b	1942/44	1985
13. Lake Starnberg/S-Bavaria	Fischer, Frielingsdorf & Klöck, unpubl. res. report	1949	1997
Poland			
14. Ojcow Nat. Park/ S-Poland	Medwecka-Kornas & Gawronski 1991	1958/59	1987/88
Austria			
15. Virgin forests Rothwald & Neuwald/NO-Austria	Zukrigl et al. 1993	1958/65	1989/90
Switzerland			
16/17. N-Switzerl. & Lake Geneve	Kuhn et al. 1987	1935/39	1984
France			
18. Lorrain Plain (Nancy)/ NE-Fr.	Thimonier et al. 1992	1970/71	1990

2. As a consequence of "acid rain" it had been expected earlier that the importance of acid indicator species should increase and the corresponding mean ecological indicator value decrease. Indeed such floristical change had been reported by Wittig et al. (1985; Westphalian Bight/NW-Germany, see Figure 4, nr. 4) and Schmidt (1993; Osterzgebirge/E-Germany; nr. 5); both areas were intensively affected by emissions for decades: NW-German industry complex ("Ruhrgebiet"), NO-German/Czech industry complex. But against all expectations in most of the forests studied the importance of acid indicator species did not change or it even

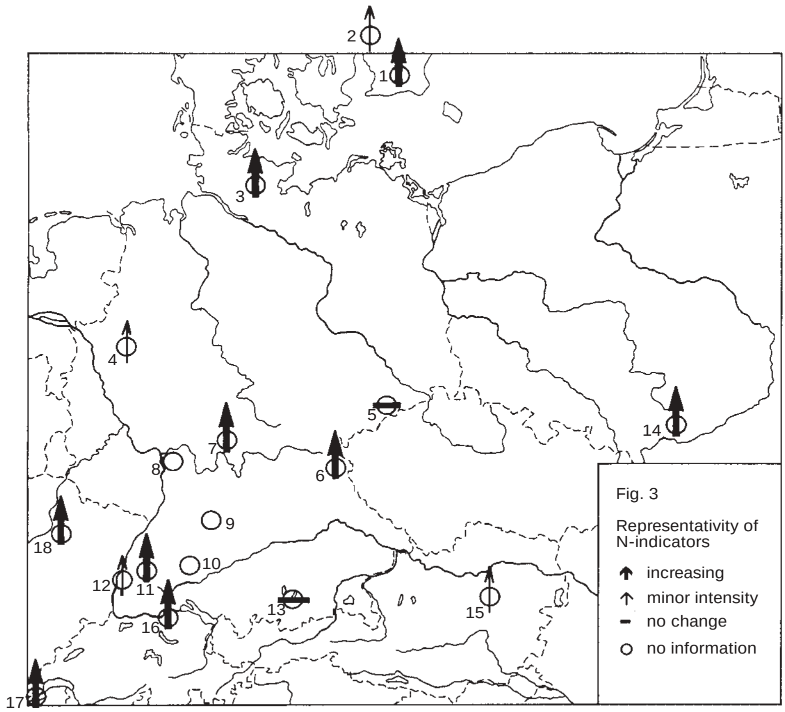

Figure 3. Representativity of N-indicators

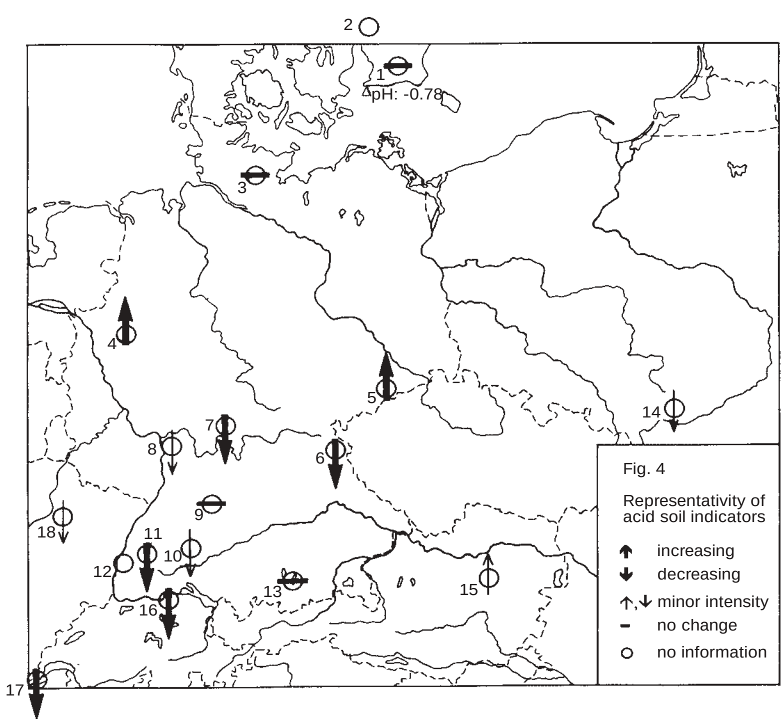

Figure 4. Representativity of acid soil indicators

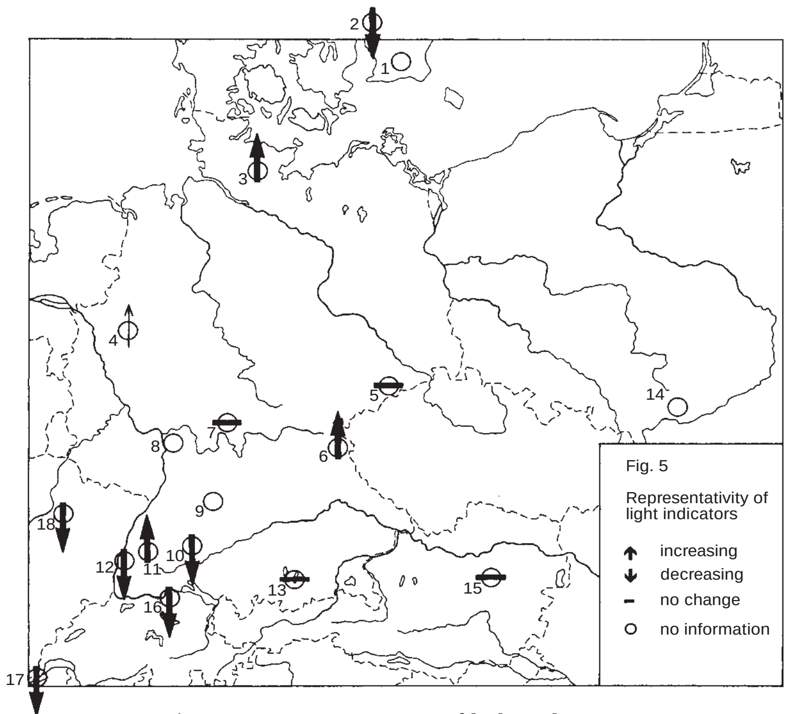

Figure 5. Representativity of light indicators

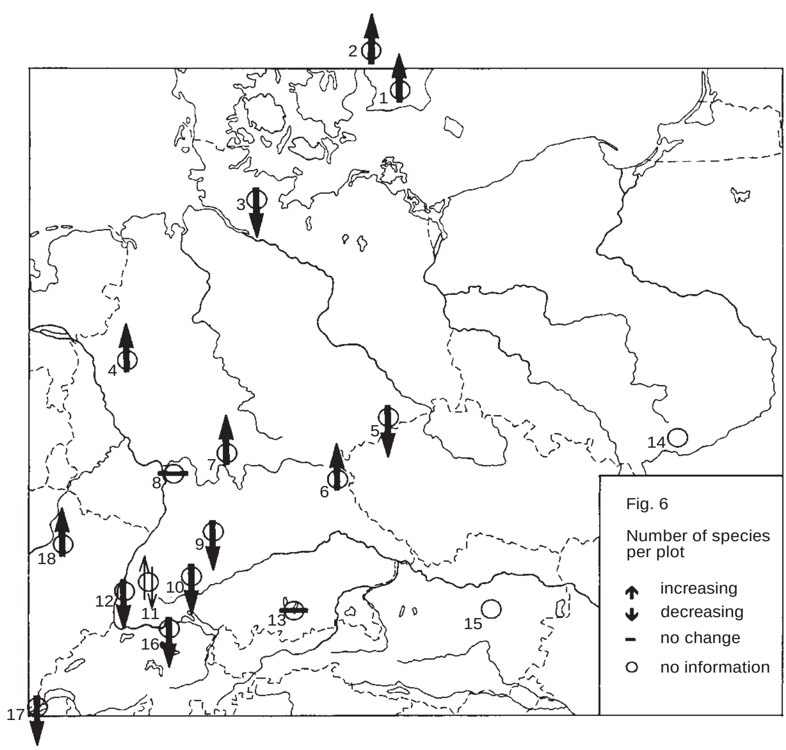

Figure 6. Number of species per plot

decreased (!) during the last decades (Figure 4). As it was explained previously this is not necessarily an indication of pH-increase; in contrast the pH of the humus layer could be proved to decrease on some of the study areas (e.g. nr. 1: -0.78 pH-units, see also Falkengren-Grerup 1995, Bjørnstad 1991).

Intensive emission of acid substances, therefore, may really stimulate an increase of acid indicator species, but that is more an exception than the rule; usually the effect of soil acidification is overcompensated by other ecological factors, especially by N-input.

3. The light indicator ability of vegetation seems to be rather obscure on the first glance (Figure 5). A general trend cannot be seen. The reason is that the light factor in a forest ecosystem in the first place is determined by the tree layer of the forest stand itself. Lot of Central European forests were managed in the past as coppice woods and coppice and standards (“Niederwald“, “Mittelwald“), and many were used as woodland pastures. Since these traditional forest utilisation methods fall out of use the forest canopy became more and more closed, and the light demanding species withdraw (see e.g. nr. 2, 12, 16, 17, 18). On the other hand a “forest decline“ (“Waldsterben“) leads to better light conditions near the soil surface, and light demanding species of the ground vegetation may increase (see e.g. nr. 11). In a 110 to 130 year old *Abies alba* forest in the Vosges mountains, eastern France, Becker et al. (1992) found the alteration of the light and temperature microclimate at ground level depending on the aging of the forest stand to be the most important factor of the floristical change. Bürger-Arndt (1994) pointed out that the light factor (either increasing or decreasing) is of high importance to the forest ground layer vegetation. As shown in Figure 1, an increase of nitrogen indicator species may also take place without any change of the light factor.

4. The total species number (per plot) changes very inconsistently (Figure 6). Replacement of historical forest utilisation methods by modern high forest management often drives species number to decrease because of a loss of open habitat species (see nr. 12, 16, 17), but species number may also increase because of invading forest species (nr. 18). Therefore changing species number in the course of time cannot be used as an indication neither of the direction nor of the extent nor of the causes of current successional processes in forest ecosystems.

5. DISCUSSION

The most important trend in forest vegetation succession corresponding to changing environmental conditions, actually indicated by vegetation, is a change in nitrogen availability. Several decades ago it was documented in the vicinity of industrial complexes (e.g. Trautmann et al. 1970); now it seems to take place all over Central Europe (Figure 3). The same holds true for many calcareous oligotrophic grassland communities, as it was analyzed e.g. by Hagen (1996), using a similar methodological approach as mentioned above. The N-fertilization is therefore of high ecological relevance all over Central Europe, far beyond the forest ecosystems: Ellenberg jun. (1985) pointed out that many of the Central European red data book species (endangered species) can be especially characterized as species of sites with nitrogen deficiency. Two reasons are of main importance: (1) recovery from former historical (devasting) land use practices, which were associated with the reduction of humus and nitrogen stocks and (2) direct fertilising effect by deposition of nitrogen compounds like NO_x and NH_x (the atmospheric N-inputs in The Netherlands are amongst the highest in the world: about 40 kg N ha^{-1} a^{-1}; van Breemen, 1988).

Acid emissions (“acid rain“), however, do not inevitably support species of acid soils. On the contrary the representativity of acid indicators in Central European forests is very often reducing. Acid deposition essentially consists of acid N- and S-compounds; actually only the (direct or indirect) fertilisation seems to have effect on the floristical composition of the forest vegetation.

Forest liming is triggering a very complex set of processes in the forest soil, including increasing pH as well as increasing nitrate concentration (Kreutzer 1995); Kreutzer pointed out that in the Höglwald-experiemnt “liming acted as a protection against acid irrigation“ (p. 447). Indeed in the *Luzulo-Fagetum*-stands of the Rhön mountains the mean acidity value increased more intensively in the stands with forest liming than in stands without liming (Röder et al. 1996). Therefore liming influences not only the soil but also the species composition of the vegetation.

According to Bürger-Arndt (1994) and Bücking (1993) it has to bear in mind that the forest flora and vegetation reflects changing environmental conditions only with retardation and with limited extent (“creeping“ according to Bürger-Arndt 1994). Therefore already small changes in the floristical composition of the vegetation are of prominent ecological importance.

Central European forests are in the process of directed change (succession), but up to now the community level of the “association“ is not affected; the subtypes of many forest associations, however, are changing recently (Röder et al. 1996, Wilmanns et al. 1986 b), and the diversity of vegetation subtypes may become reduced (van der Werf 1987). There are many factors driving change of floristical structure of forest communities (see Fischer in press). New forest management methods may influence the floristical composition of the forest stands significantly (see light factor), but on a very local scale; emissions are working on a regional to continental scale. On a global scale changes in CO_2-content, of mean near-surface temperature and of the atmosphere’s structure, summarized as "global change", may influence the floristical composition of Central European forest communities in the future (Fischer in press); up to now, however, successional trends of this type cannot be evidenced in forest phytocoenoses of Central Europe with phytosociological methods.

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HISTORIC FOREST USE AND ITS POSSIBLE IMPLICATIONS TO RECENTLY ACCELERATED TREE GROWTH IN CENTRAL EUROPE

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ABSTRACT

Before fossil fuels, mineral fertilisers and industrially produced goods came into use, forests were heavily exploited for energy, accumulated mineral nutrients and other non timber forest products. Intensive harvesting of biomass to supplement agriculture removed up to 20 kg nitrogen and up to almost 3 kmol acid neutralising capacity annually from forest ecosystems, in magnitude comparable to today's input from air pollution. Grazing on forest land and large clear-cuts favoured monocultures. After abandonment of most of these land use practices in the 20th century, recovery of forest ecosystems from degradation may explain accelerated tree growth on formerly abused land.

Keywords: historic forest use, soil acidification, nitrogen deficiency, litter raking, shredding

1. INTRODUCTION

Ever since forests had regained possession of much of Central Europe after the last ice age and replaced open savannahs, where prehistoric people hunted, forests were subject to human use and destruction. When agriculture and, later on, mining and smelting became known, forests were cleared for farming and pastoral use, but became at the same time indispensable resources of construction material, fuel and non timber forest products. Advance and decline of human civilisations, wars and epidemics were reflected in the extent of forest cover and forest degradation. The most recent climax of forest destruction at the turn of the 18th to the 19th century and thereafter, came in the wake of industrialisation and its insatiable demand for fuel and other forest resources. Before fossil fuels had come in use, dire forecasts about an impending collapse of industrialisation, as well as a dramatic increase of flood and avalanche catastrophes,

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had prompted governments to pass stringent forest laws and to found forest academies. Their job was to train professionals for the restoration of devastated forests and advance sustainable forestry. Forest science became an academic discipline and the first comprehensive textbooks on forest management were published. An outstanding example is J. Ch. Hundeshagen's "Forstliche Produktionslehre", published in Tübingen, Germany, in 1821. Its 4th edition, printed shortly after Hundeshagen's death in 1842, gives an excellent overview on the use of timber and non timber forest products at the time just before fossil fuels and chemical industries had started to release forests from destructive exploitation, which, in turn, allowed the evolution of modern forestry.

In the following, I will give an overview of historic forest use during the 19th century in Germany and in the Austrian Alps and discuss the degradation it has caused. In the context of recently observed accelerated tree growth in Europe, the potential for aggradation and its possible effects on site productivity are discussed.

2. FOREST USE IN THE 19TH CENTURY

Table 1 gives an overview of common uses of forests in the first half of the 19th century. This list is by far not complete, as Hundeshagen (1842) describes many more products, such as resinous torches, soot for painting and printing, wood tar for preservation of pilings, sap of trees for flavouring, sweetening or vinegar production.

In the early 19th century, when wood and peat where the only source of thermal energy in many regions, fuel wood harvesting was very intensive and in many forests no stick or stump remained in the forest. The huge demand of fuel for industrialisation was met by the harvesting of the last old growth forests in up to then inaccessible areas (Wessely 1853). Extensive chute and water transport systems were constructed for the transport of wood to industries and cities. In order to make such operations economically feasible, whole watersheds were clear-cut within a few years. Grazing of livestock on the clear cuts and planting of spruce or pine caused the decline of beech, fir and admixed broadleaf species, while spruce, pine and larch gained ground. Logging residue was converted to charcoal for easier transport to ironworks. Nutrient losses to forest ecosystems was therefore much more pronounced than in modern forestry.

In remote areas, where quartz and feldspar were available, glass works used forest biomass to produce potash and to melt the mixture of quartz, feldspar and potash into glass. Potash, potassium carbonate, obtained by leaching wood ashes and subsequent calcination in iron pots, consumed by far more biomass than melting, because of the low potassium content of forest biomass (less than 0.4% of dry matter on average). Often understory plants, such as ferns and ericaceous shrubs, were burned too, because of their higher potassium content (table in Hundeshagen 1842). In areas which lacked quartz and feldspar, potash was produced and sold to soap makers, tanneries, and many more industries, because the supply of ashes available from heating and cooking with wood in the cities was insufficient to meet the demand. Although diverse regeneration niches for pioneer tree species were created by the collection of herbaceous vegetation and tree stumps, as well as by scattered burning, nutrient losses, in particular nitrogen losses, were severe. Grazing on the harvested areas could quickly destroy an initially

Table 1. Common uses of forests in the first half of the 19^{th} century (after Hundeshagen 1842) and their ecological implications.

Forest Use	Description	Ecological Impact
Energy		
Charcoal	production of charcoal in the forest or at landings from woody biomass, often including branches and shrubs; it declined gradually after fossil fuels came in use around the middle of the 19^{th} century, but increased again during and after the world wars	loss of volatile nutrients in smoke (predominantly nitrogen); locally favourable seedbed for pioneer species
Fuel wood for local population	collection of dead woody biomass, branches, and often stumps; fuel wood coppicing; gradual decline in the 20^{th} century, but very intense during and after world wars	depletion of nutrients and soil acidification due to intensive removal of biomass; soil erosion after digging for stumps; seedbed for pioneer species after digging
Raw materials for trade & industry		
Potash	burning of woody and non woody biomass (ferns, Vaccinium sp.) for extraction of potassium carbonate from ash for glass making, and various other uses; declined when chemical industry offered alternatives (middle of the 19^{th} century)	severe depletion of nutrients and soil acidification due to intensive removal of biomass; seedbed for pioneer species at sites of burning; attraction of livestock to clear cut sites
Dyes	harvesting of shrubby and herbaceous vegetation	depletion of nutrients and soil acidification; loss of species diversity
Sap and resin	tapping of trees as well as distillation of branches and foliage; widespread into the 20^{th} century, in particular during the wars	increased susceptibility to pest and diseases; removal of understory to facilitate access for tapping results in loss of diversity, erosion and poor nutrient cycling
Bark for tanning, fibre, osiers	debarking of saplings and coppices (wood used as fuel wood); declined when chemical industry offered alternatives (middle to end of the 19^{th} century)	depletion of nutrients and soil acidification; monocultures of suitable trees
Digging for quartz and minerals	digging for quartz rocks to be used in glass making	soil erosion; increased seedbed diversity

Table 1. Continued.

Forest Use	Description	Ecological Impact
Harvesting of grass	*Carex brizoides*, a sedge growing in submontane forests on slightly stagnant, fine textured soils, was used for upholstery of furniture; abandoned when fibres from the tropics became available	depletion of nutrients and soil acidification; destruction of other understory species
Forests as resources for food production		
Litter raking	harvesting of litter and humus to be used as bedding for livestock and subsequent production of manure; very widespread well into the 20th century	severe depletion of nutrients and soil acidification due to repeated removal of biomass; favourable seedbed for establishment of ericaceous understory as well as spruce and pine
Lopping	use of leaves and twigs of deciduous broadleaf trees as fodder, often dried and stored for winter use; common in areas with sufficient broadleaf trees	depletion of nutrients and soil acidification; loss of timber quality
Shredding	Harvesting of conifer branches to be used like raked litter; very common well into the 20th century in the Alps where litter raking was impeded by rocky terrain	severe depletion of nutrients and soil acidification due to intensive removal of biomass; loss of broad leaf species; damage to trees attracted bark beetles; opening of forest attracted livestock
”Hackwald” (agro-forestry, shifting cultivation)	after harvesting of timber trees by clear-cutting, logging residue was burned and cereals or beets grown for two to three years, afterwards the area was used as pasture and for harvesting of fuel wood from coppices and shrubs until the canopy had closed; many regional systems; peasants had to provide labour to the landowners for compensation; declined in the second half of the 19th century	depletion of nutrients and soil acidification, immediately after burning of slash the pH of the topsoil is increased; soil erosion after burning and cultivation; favourable seedbed for pioneer species and shrubs; compacting of topsoil due to use as pasture; selective pressure on tree regeneration by grazing livestock
Forest pasture	pasture in forests, which were kept open to increase growth of herbaceous understory; still common in the Alps	depletion of nutrients and soil acidification due to removal of biomass; compacting of topsoil and formation of hydromorphic humus; loss of species diversity due to selective browsing; damage to tree roots by hooves facilitates root rot; horse and goat peel bark of young trees

diverse woody regeneration. Surviving pioneer species disappeared within few decades because of their short biological life span, resulting again in almost pure stands of pine or spruce.

The most devastating and longest lasting degradation resulted undoubtedly from the use of forest biomass to augment food production. Before chemical industry had invented methods to convert atmospheric dinitrogen into reduced or oxidised compounds, which can be taken up and assimilated by plants, nearly all nitrogen for the production of field crops and fodder for domestic animals was tapped from the pools terrestrial ecosystems had accumulated. Nitrogen recycled from the sea by seabirds and saltpetre, which was introduced as a fertiliser in intensive agriculture in the 19^{th} century, was beyond the reach of peasants living in forested areas. Over time, a great variety of methods had evolved to harvest nitrogen and mineral nutrients from forests for, ultimately, the production of food for human consumption.

Forest pasture and lopping of foliage and branches to feed livestock evolved, when hunter-gatherers advanced to pastoralism. Forest pasture has been practised for millennia in Europe and is still widespread in the Alps and in the Mediterranean region. When men had learned to grow crops, he soon grasped that leaf litter from forests and wood ash can be used to fertilise fields and to increase the yield of crops. When used as bedding for livestock, litter and other biomass from the forests scavenge urine and faeces and the mixture is transformed into manure, the indispensable and universal fertiliser before Justus von Liebig and the advent of agrochemistry. Frequently old and otherwise useless domestic animals (in German “Mistvieh“, literally “dung animals“) were kept to feed on land, which was not arable, and to extract nitrogen and nutrients from otherwise useless land. When not enough straw and leaf litter was available, trees were shredded to provide bedding. For shredding conifers (most often spruce and larch) were climbed and branches harvested with an axe or hatchet. The twigs with green needles were used as bedding, while the coarse parts of the branches were used as fuel wood. Sometimes chopped needles were admixed to hay in order to stretch winter fodder. Wood ash, which was not used for laundry or other domestic purposes, was used to fertilise the fields. In many areas owners of forest land allowed peasants to grow crops and to pasture livestock after timber harvesting by clear felling. The peasants in turn had to ensure a satisfactory regeneration of forest trees when use by peasants ended after between 10 to 25 years. Burning promoted the establishment of pioneer trees, which were harvested for fuel wood by the peasants. Coppices and root suckers were also cut for fuel wood. Regeneration of timber trees was by sowing or planting. Sometimes tree seeds were admixed to ray or oats, which were sown at less than usual density. In other cases, tree seeds were broadcast on snow to control even distribution. Nothing was known on forest genetics at that time and seeds of unknown geographic origin were frequently used. The resulting stands were often made up by genotypes, which were not adapted to the site. Repeated snow break in wide crowned spruce stands from lowland origin in regions with heavy snowfall was a much later recognised consequence of this practice.

In the context of the effects of historic forest use on tree growth, forest pasture, litter raking and shredding must be considered most significant. These uses were common in many parts of Europe and continued for a long time (150 to 200 years of regularly repeated litter raking in Bavaria, Kreutzer 1972, and nutrient depleted forest ecosystems of the Schwarzwald, Zoettl and Mies 1983, Feger 1993). The negative effects on forest were known long before intuition based on keen observation (Hausegger 1861) and scientific reasoning (Ebermayer 1876) linked biomass extraction to nutrient depletion and nutrient deficiency in trees. Forest owners tried to ban these practices or to get at least some income from selling litter and forest biomass. The maximum amounts to be harvested from an area were fixed and the method of litter collection defined (e.g. only wooden rakes were allowed to minimise damage to tree roots). In practice, these rules were often circumvented (Scholl 1997). In order to prevent excessive harvesting, yield tables for beech litter on three site classes were published for the province of Salzburg, Austria, by Tschermak (1926).

3. QUANTIFYING THE EFFECTS OF EXCESSIVE FOREST BIOMASS HARVESTING

In the first half of the 20^{th} century, scientific experiments demonstrated the negative effect of litter removal on soil properties, in particular content and quality of humus. As late as 1951 Wittich published a paper on the impact of litter raking on sandy forest soil, showing negative effects on humus content, exchangeable bases, biological activity, and water infiltration and storage. Quantitative information on nitrogen and nutrient harvesting is scarce, but some information is available. For the whole region of Tyrol and Vorarlberg data on the annual harvest of litter and green branches (in German "Hackstreu") in the middle of the 19^{th} century (census of 1846) can be found in Wessely's famous book on the Austrian Alps and their forests (Wessely 1853, p. 138 ff.). Based on his figures, nutrient exports from forest land, and, by balancing uptake of base cations and anions, the resulting soil acidification, can be estimated (Table 2).

Wessely (1853) gives no information on the percentage of forest land which was actually used for litter raking and shredding. The assumption of 60% is based on the rough topography and geology of Tyrol and Vorarlberg, which restricted litter harvesting in many areas. An annual biomass harvest of between 1.300 and 2.000 kg per hectare is much less than the annual litter yield of beech stands in Salzburg as determined by Tschermak (1926), which varies between 5.660 kg ha^{-1} air dry matter on good sites and 3.440 kg ha^{-1} on poor sites. Even if a 20% water loss from air dry to oven dry is assumed, Tschermak's figures, based an actual, repeated raking on sample plots are remarkably high. Assuming a nitrogen content of only 0.5%, nitrogen exports in excess of 30 kg N ha^{-1} a^{-1} must have been common in beech stands. Kreutzer (1972) estimated the annual nitrogen extraction from pine forests on sandy soil by litter raking at between 9 and 18 kg N ha^{-1} a^{-1}. Considering the lower leaf area index of pine forests on poor sites, this is plausible. Soil acidification due to biomass exports was, in many areas, for decades or even centuries of litter raking larger than today's acid deposition, including acidification due to oxidation of reduced nitrogen imports (Glatzel 1989).

Quantitative information on nitrogen depletion and soil acidification from forest pasture is even more scarce than on litter raking. Hager (Institute of Forest Ecology, UNI BOKU Vienna, personal communication) estimated nitrogen losses of between 2 and 8.5 kg N ha^{-1} a^{-1}. Acidification ranged between 0.16 and 0.67 kmol ha^{-1} a^{-1}. These

Table 2. Annual nitrogen losses and soil acidification due to litter raking in Tyrol and Vorarlberg in the middle of the 19th century.

Database / calculations	Estimates in SI-units
• in 1846 the forest area of Tyrol and Vorarlberg was 1.068.000 Joch (Wessely 1846)	614.000 ha
• area effected by litter raking (60 percent of total area, assumption by author, based on accessibility)	370.000 ha
• in 1846 a total of 1.469.000 Kubikklafter of raked litter and shreddings (green branches) was harvested per year in Tyrol and Vorarlberg (Wessely 1846)	4.850.000 m^3
• raked litter and shreddings harvested per hectare	13.1 m^3 ha^{-1} a^{-1}
• dry matter of 1 m^3 litter and shreddings (Dieterich 1925)	100-150 kg m^{-3}
• annual biomass harvest per hectare	1.300-2.000 kg ha^{-1}
• mean nitrogen content of harvested biomass (Glatzel 1991)	10-14 mg N g^{-1}
• acid neutralising capacity of harvested biomass (Glatzel 1991)	1.4 mmol g^{-1}
• annual export of nitrogen	13-27 kg N ha^{-1} a^{-1}
• annual loss of acid neutralising capacity (soil acidification)	1.8-2.8 kmol ha^{-1} a^{-1}

amounts are small in comparison to the losses due to litter raking, but add up to large quantities, if centuries of continuous forest pasture are considered.

The Tyrol Soil Survey of 1988 showed that base saturation of soils, which had experienced litter raking in the past, was about 25% less than of soils where presumably no litter raking took place. A difference of more than 35% was found, when stands with forest pasture were compared to stands without pasture.

Very few attempts have been made to quantify the effects of excessive biomass harvesting on tree growth. A particularly noteworthy exception are well designed experiments on the effect of a one time litter raking (50 and 100% litter removal) on the growth of pine, set up by H. Vater in 1912 in the district of Cottbus, Germany. After 50 years, Fiedler et al. (1962) were able to estimate growth by dendroecological methods. Total annual yield of wood with bark during the first 47 years after planting was 3.5 m^3 on plots where no litter had been removed, 3.2 m^3 where half the litter had been removed and only 2.6 m^3 where all litter had been removed. Nearly half a century after litter removal, the growth rates of the trees were still different and had not converged.

4. RECOVERY AFTER CESSATION OF EXPLOITATIVE USE OF FOREST BIOMASS

Excessive biomass export from forest ecosystems had in the past, undoubtedly, depleted the mineral nutrient pools of forest ecosystems beyond their capacity of compensation, had acidified the soil and had decreased biodiversity and tree growth. In the context of the discussion on recently accelerated tree growth, the question of autonomous restoration of soil function arises. Unfortunately this question has not been the subject of specific research so far and the discussion has to be based on deduction from basic knowledge on forest nutrition and forest fertilisation. In principle the pools of biologically accessible nutrients in forest ecosystems and the acid neutralising capacity of the soil can be amended and restored by several processes:

1. *Weathering of minerals in the soil*. If the pools of weatherable minerals in a soil are not exhausted, weathering releases base cations and mineral nutrients at a slow, but rather steady rate. This process will rebuild nutrient stores, if losses cease to be larger than release from weathering. In forest ecosystems mycorrhiza is a strong weathering agent in the rhizosphere (Gobran et al. 1998). Acid deposition or oxidation of reduced nitrogen to nitrate in the soil may, hypothetically, increase weathering.

2. *Release from inaccessible organic pools.* In many degraded forest ecosystems, biological activity in the soil is depressed by low pH and the dominance of not easily degradable conifer and ericaceous litter. Under these conditions deep layers of inactive moor (raw humus) may form, which trap nutrients, in particular nitrogen. If conditions for litter decomposition improve by betterment of the nutrient situation and reestablishment of a richer herbaceous vegetation moor layers can be degraded, releasing formerly unavailable nutrients.

3. *Lateral nutrient import.* During the past decades most agricultural land in Central Europe has become highly saturated with mineral nutrients and nitrogen from intensive fertilisation. In the absence of directional mass flow, e.g. erosion of litter from higher to lower terrain, exchange of matter between adjacent ecosystems is analogous to diffusion. This means net transfer of nutrients from areas of higher concentration to areas of lower concentration, because chances of a nutrient rich particle being transported from an area of high nutrient content to a nutrient poor area are higher than vice versa. Transfer can be in form of aerosol (wind blown litter), interflow in the soil, or by animals, which feed on agricultural land and rest in the forest.

4. *Exploitation of formerly inaccessible soil horizons by deep rooting plant species*. Conversion of mixed deciduous forest to shallow rooted spruce monocultures decreased uptake of nutrients from lower soil horizons, which were no longer reached by plant roots. Restoration of more diverse herbaceous and tree vegetation can provide access to these soil horizons, transporting nutrients to the soil surface via litter fall.

5. *Atmospheric deposition.* Scavenging of dust and chemical compounds from the atmosphere has been an important mechanism in forest ecosystems, to compensate for inevitable losses of nutrients by leaching and litter erosion. In Central Europe, deposition of anthropogenic aerosols has significantly changed over time. Before industrialisation and modern agriculture, mainly mineral dust from open fields and ashes from fires were deposited. Nowadays, large amounts of plant accessible nitrogen are deposited to forest ecosystems, besides a wide spectrum of chemical air pollutants (van Breemen and van Dijk 1988).

Based on common knowledge on tree nutrition, any improvement of less than optimal nutrition must be expected to increase growth, until saturation is reached and other factors set a limit. Improvement may be slow and continuous over a long time span, but may be quite dramatic, if biological processes are involved. Establishment of a lush understory and the activity of a recovered earthworm population can quickly transform inactive moor into mull humus. This means that modelling of growth must consider such factors and not only the time at which damaging forest use ceased. Dendroecological research should be very useful for a better understanding of response of trees. It is also important to bear in mind that unsatisfactory forest stands are not in all cases a consequence of nutrient depletion and soil acidification. Loss of herbaceous and shrubby understory may be caused by grazing, high game populations or clearing of undergrowth to facilitate access to trees for tapping. In any of these cases, ecosystem functioning may be impaired. A mismatch between site conditions and genetic makeup of trees by indiscriminate use of seeds from unknown origin may lead to miserable stands too, with extremely poor growth rates, as demonstrated by many provenance trials.

5. CONCLUSION

It seems reasonable to hypothesise that nutrient depletion and soil acidification as well as conditions, which favoured the regeneration of spruce, pine, larch and an ericaceous understory, degraded forest ecosystems to a low level of productivity and plant diversity. This low level was often maintained for a long time by steady biomass exports, creating the impression of stability and predictability. When agriculture started to rely on mineral fertiliser and intensive pastures, rather than on biomass from the woods, forest ecosystems started to recover, a process enhanced by the deposition of atmospheric nitrogen from anthropogenic sources. This allows, in theory, for more varied ecosystem dynamics, return of nutrient demanding plants and increased growth. Unfortunately, our knowledge on restoration of degraded soils, and its implication to tree growth, is still sketchy. A joint European effort to document historic forest degradation and to study the response of forest ecosystems after the cessation of now obsolete forest use, would be much needed, for a better understanding of forest ecosystem dynamics in Central Europe.

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CLIMATE VARIATIONS AND TREE GROWTH BETWEEN 1961 AND 1995 IN AUSTRIA

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ABSTRACT

Using climate records from 20 weather stations, we investigated the changes in temperature, rainfall, and length of the growing season between 1961 and 1995. To establish a link between changes in climate and tree growth, we analyzed radial increment rates from tree rings over the same period. Our results indicate: (1) no change in precipitation over the period; (2) a highly significant increase (α=0.01) in average annual temperature (1.13°C), minimum temperature (1.23°C), winter temperature (2.70° C) as well as a significant (α=0.05) increase in the length of the growing season (14 days) since 1961. For the early 1990s, lower radial increment rates as well as a decrease in the temperature related climate parameters are detectable. To understand the importance of climate on tree growth we use the ecosystem model FOREST-BGC and predict the annual net primary production (NPP). The trends in NPP are consistent with observed diameter increment rates determined from 1179 increment cores for Norway spruce from all over Austria.

Keywords: growth trends, climate change, Norway spruce, Austria

1. INTRODUCTION

During the 1970s, researchers expected a forest decline in Europe due to air pollution (European Commission 1994). However, recent research suggests that vegetation productivity may have increased in certain areas of the northern hemisphere during the 1980s (Kauppi et al. 1992; Spiecker et al. 1996; Myneni et al. 1997). Among the three most logical causal factors (nitrogen, CO_2 and climate), CO_2 concentration has continuously increased (Keeling et al. 1995) and nitrogen deposition rates of up to 4 g/m^2/year (Katzensteiner and Glatzel 1997) have been evident in Austria since the early

1960s. Since the 1980s, the NO_x emission has continuously decreased from 230.7 thousand tons in 1980 to 176.5 thousand tons in 1990. During this time span (1980 to 1995), CO_2 emissions remained constant for Austria at about 60 million tons/year (Statistisches Jahrbuch 1996).

In the 1980s, however, only climate has been reported to have changed for northern high latitudes (Groisman et al. 1994). Similar findings have been reported for Austria (Auer and Böhm 1994), resulting in shorter periods of lake ice-cover for high mountain lakes in the Austrian Alps (Sommaruga-Wögrath et al. 1997). Therefore, it seems reasonable that in an alpine country like Austria, with maximum precipitation during the growing season (Auer 1993; Böhm 1992) lengthening of the growing season because of higher temperatures could have improved forest productivity.

The purpose of this study is to analyze the impact of climate on Austrian forest productivity between 1961 and 1995. We evaluate possible trends in climate parameters such as precipitation and temperature, and the length of the temperature controlled growing season. We use an ecosystem model, FOREST-BGC (Running and Coughlan 1988), to predict annual net primary production (NPP), a key terrestrial carbon cycle variable that is related to forest growth.

FOREST-BGC combines important interactions among plant growth and climate parameters such as minimum and maximum temperature, precipitation, changes in cloud cover etc., as well as possible changes in photosynthesis and respiration balance of plants. Therefore, the model can be used as a diagnostic tool to explain changes in forest growth. Finally, we compare our NPP simulations with observed diameter increment rates using 1179 increment cores of Norway spruce trees from all over Austria.

2. DATA

2.1 Climate Data

Daily climate records came from the National Weather Center in Vienna, Austria. We defined six growth regions according to Kilian et al. (1994) representing the major forest climatic conditions in Austria. We selected 20 weather stations across Austria, at least 2 stations in each of the six forest growth regions, with a full climate record of daily minimum and maximum temperature and precipitation between 1961 and 1995. Figure 1 gives an overview of the station distribution, including a brief description of the eco-climatic conditions of the six growth regions.

2.2 Forest Growth Data

Increment information was obtained from two independent data sources (Sample A and B) including 1179 increment cores of dominant Norway spruce (*Picea abies* L. Karst) trees across all age classes and site conditions. Norway spruce is the most important tree species in Austria with 61% timber growing stock (Schieler et al. 1995) and grows in all major forest areas.

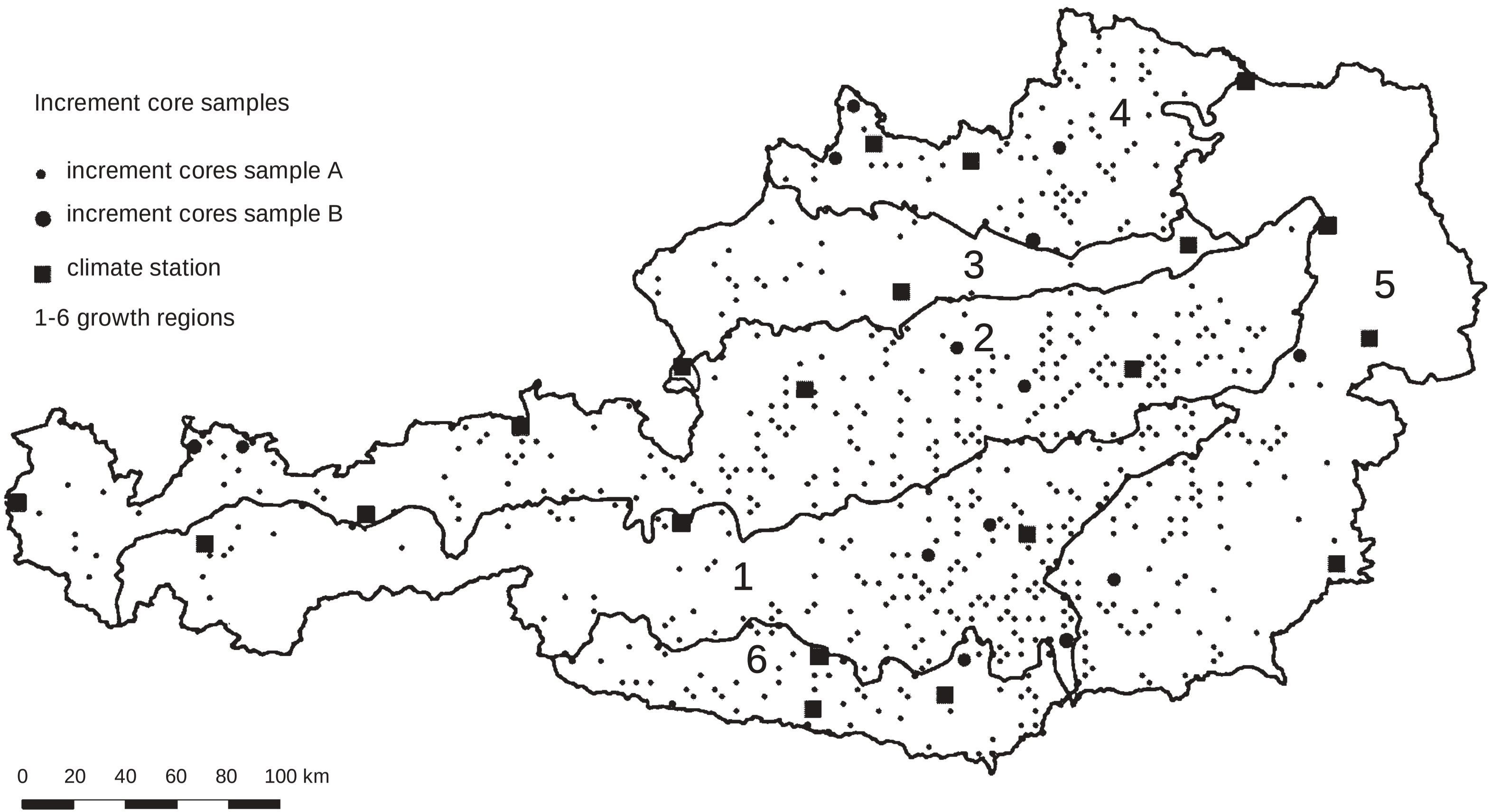


Figure 1. The growth regions of our study including the 20 weather stations with daily climate records between 1961 to 1995 and the 1179 increment cores for Norway spruce. The 6 growth regions represent a simplification of the 9 growth districts of Kilian et al. (1994) and characterize the major forest climatic conditions in Austria.

Sample A gives radial increment information until 1989 and was available from 614 systematically distributed permanent sample plots (grid size 3.89 km) established by the National Forest Inventory in Austria. Sample B represents increment information until 1994 from 565 cores from more than 40 Norway spruce stands distributed over 14 locations (Figure 1). With a large and representative sample size, the data are an excellent source for evaluating climate impacts on tree growth in Austria.

3 ANALYSES

3.1 Climate Parameters

For each of the 20 weather stations simple linear regression was applied to explore possible trends in the following climate parameters: (1) total precipitation (Figure 2), (2) average annual temperature ((max + min)/2) (Figure 3), (3) mean annual minimum and (4) mean annual maximum temperature, (5) winter temperature, (6) summer temperature and (7) length of the growing season (Figure 3). Winter temperature for each year was computed as the average temperature of the months which exhibited a monthly mean temperature of less than 0°C in 1961. All months with a mean temperature of greater than zero in 1961 were considered as summer months. The length of the growing season is defined as the number of days with a mean daily temperature greater than 5°C, an indication that on these days photosynthesis and carbon fixation may have taken place.

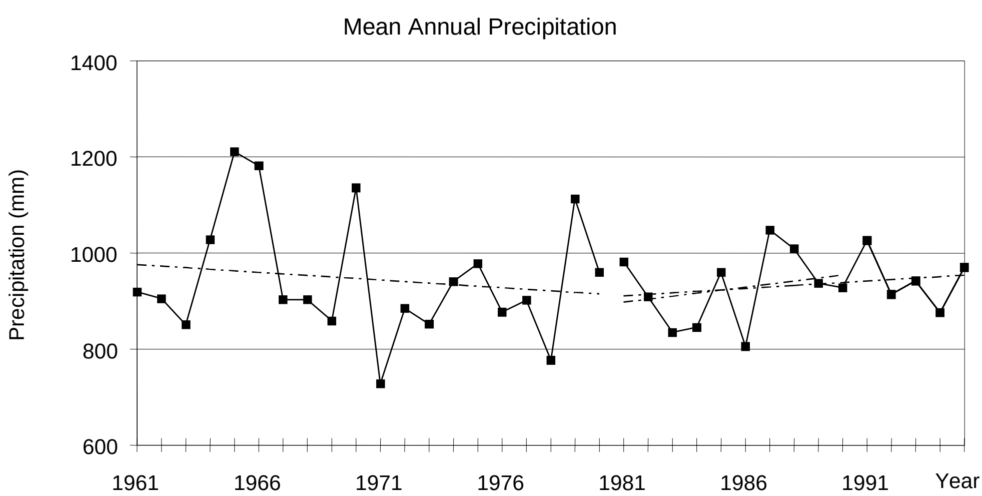


Figure 2. Mean annual precipitation including the corresponding regression lines for the time spans 1961-1980, 1981-1990, and 1981-1995 in Austria. The numbers represent the means from 20 weather stations.

In our analysis, we consider the whole time span between 1961 to 1995. Because recent research suggests that during the 1980s forest productivity may have increased by 11% for northern high latitudes (Myneni et al. 1997), we were specifically interested if our data confirmed these findings. Thus, we split the data in three time spans: 1961 to 1980, 1981 to 1990, and 1981 to 1995. The results are presented in Table 1. Note that

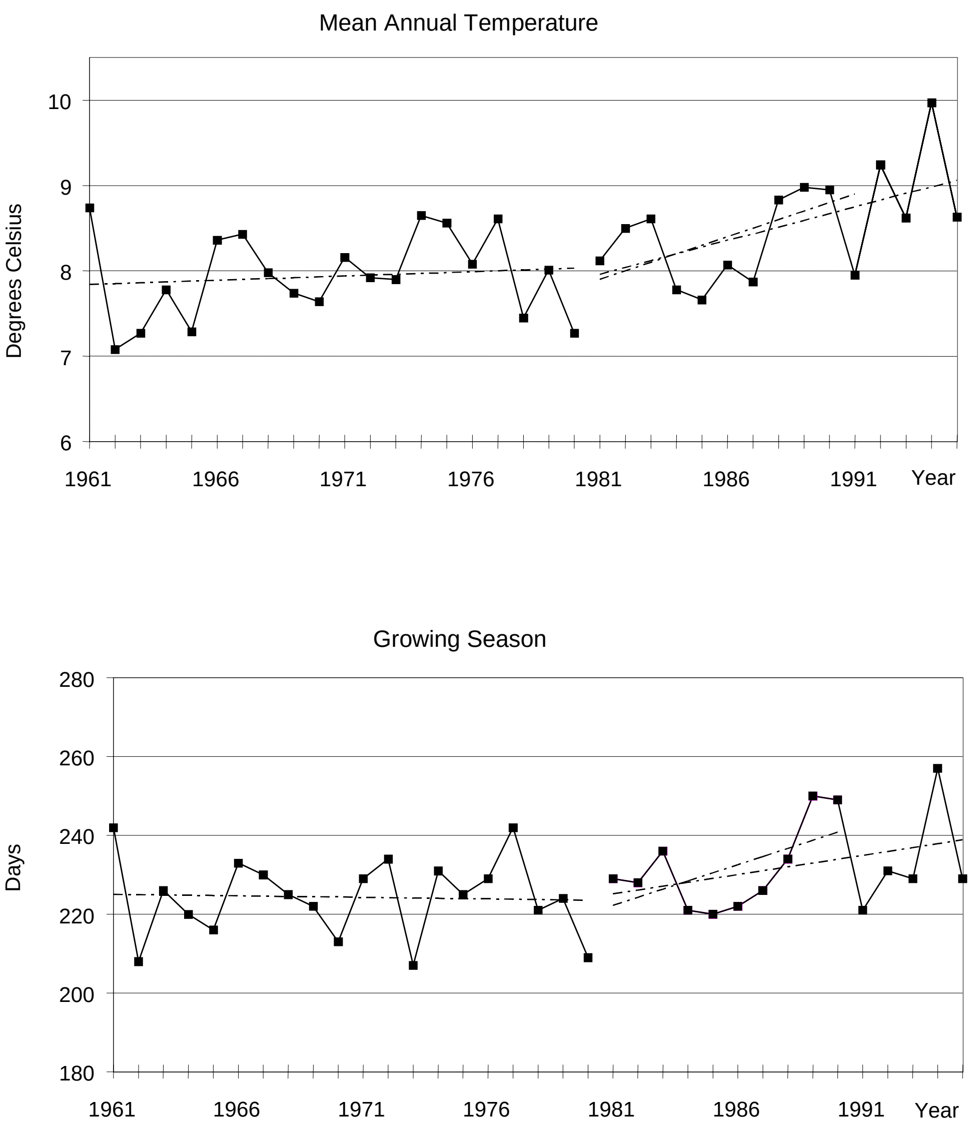
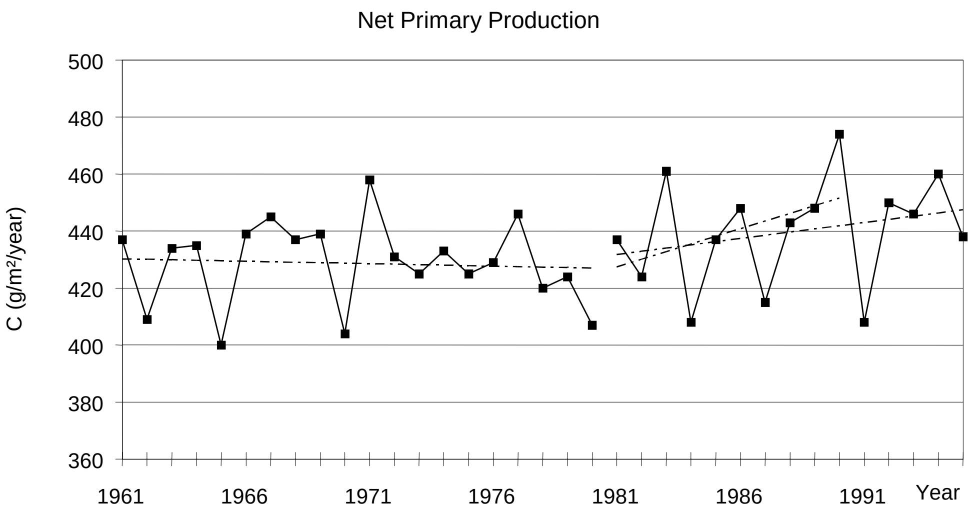


Figure 3. Average annual temperature and growing season length (defined as the sum of days with a daily temperature > 5°C) including the corresponding trend lines for the time spans 1961-1980, 1981-1990, and 1981-1995 in Austria. The numbers represent the means from 20 weather stations.



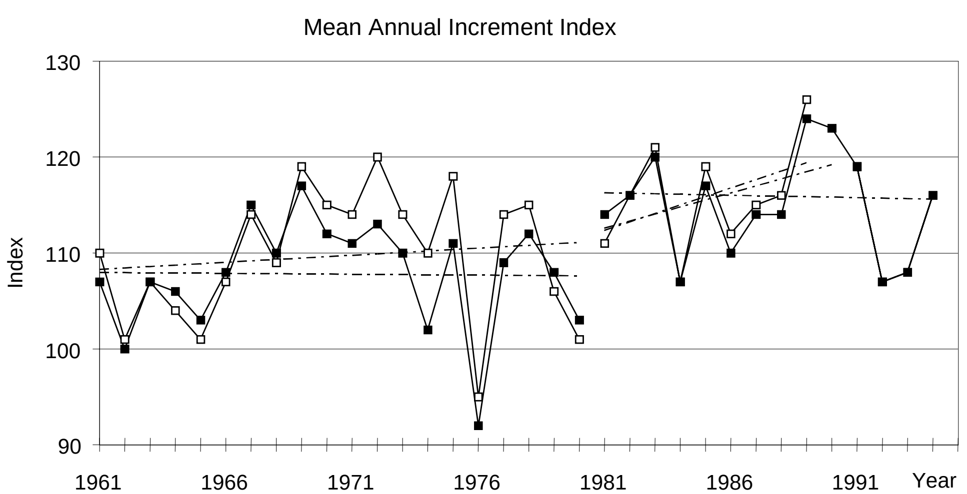


Figure 4. Mean annual net primary production (NPP) vs. the increment index development for Norway spruce plus the calculated regression lines for time spans 1961-1980, 1981-1990, and 1981-1995. The NPP is the average value simulated for 20 weather stations. Sample A gives the mean annual increment index until 1989 obtained from the 614 systematically distributed permanent plot data of the National Forest Inventory. Sample B summarizes the 565 increment cores from more than 40 stands across 14 locations until 1994.

Table 1. Trends in precipitation, average temperature, winter and summer temperature and the number of growing days in Austria for the growth period 1961 and 1995. The results show the magnitude in the detected change given by the calculated trend lines. The climate parameters represent the arithmetic mean of the 20 weather stations available for this study.

Trend in	1961 to 1995		1961 to 1980		1981 to 1995		1981 to 1990	
	Change	Standard error	Change	Standard error	Change	Standard error	Change	Standard error
Precipitation (mm)	- 31	107	- 62	131	46	72	62	80
Average annual temperature (°C)	1.13**	0.55	0.21	0.51	1.10*	0.55	0.68	0.50
Average annual minimum temperature (°C)	1.23**	0.45	0.42	0.47	1.17*	0.48	0.60	0.42
Average annual maximum temperature (°C)	1.04**	0.62	-0.01	0.59	1.03	0.65	0.74	0.62
Winter temperature (°C)[1]	2.70**	1.37	2.80*	1.41	1.89	1.28	1.57	1.34
Summer temperature (°C)[2]	0.82*	0.56	-0.33	0.52	0.92+	0.53	0.44	0.47
Change in the number of growing days[3]	14*	10.7	-2	10.4	21+	9.4	14	11.0
Net primary production – NPP (%)[4]	4.2+	4.0	-1.0	3.6	3.8	4.4	6.3	4.5
Mean annual increment index (%)[5] Sample A	9.5*	5.9	1.9	6.4	-	-	8.0	5.4
Mean annual increment index (%)[5] Sample B	9.6*	6.0	-0.9	5.4	-0.6	4.9	6.8	5.0

[1] defined as the mean annual temperature development of those month which exhibited an average monthly temperature of less than zero in 1961;
[2] temperature development of those month with an average monthly temperature of greater than zero in 1961;
[3] sum of the days with an average temperature > 5° C;
[4] based on the NPP production in 1961 and 1981, respectively;
[5] based on the mean annual increment index in 1961 and 1981, respectively;

+ significant with α=0.10;
* significant with α=0.05;
** significant with α=0.01;

throughout the study all presented variations refer to regression lines to avoid unreasonable findings due to randomly high starting or ending values within a certain observation period. Furthermore, the slope parameters of the linear regressions indicate the direction (increasing or decreasing) as well as the magnitude of changing climate parameters within a given time span.

3.2 The Ecosystem Model

To explore the complex interactions among climate and tree growth we use the ecosystem model FOREST-BGC (Running and Coughlan 1988) to predict annual net primary production (NPP), a key terrestrial carbon cycle variable that is related to forest growth. FOREST-BGC (Running and Coughlan 1988) is a mechanistic ecosystem model that calculates the cycling of carbon, water, and nitrogen through forest ecosystems. The model requires daily standard meteorological input data such as minimum and maximum and dew point temperature, precipitation and incident short wave radiation. Furthermore, Leaf Area Index (LAI) and the soil water holding capacity have to be initialized.

FOREST-BGC has a mixed time resolution: the hydrologic, photosynthetic, respiration processes are computed daily, while tree growth and nitrogen processes are computed yearly. The model calculates canopy interception and evaporation, transpiration, soil outflow of water, photosynthesis, growth and maintenance respiration, allocation, litter decomposition of carbon, deposition, uptake, litter-fall and finally the mineralization of nitrogen. The appropriateness of using this model to describe the carbon, water and nitrogen cycle within forest ecosystems has been tested extensively, as well as its applicability to describe the carbon balance response of forests as it may result from potential climate change (Running and Nemani 1991).

In this study we are interested in the response of the carbon balance expressed as net primary production (NPP). We assume a double sided LAI of 10 m^2/m^2 (closed timber stand) and a soil water holding capacity of 15 cm across all locations. Leaf nitrogen, stem nitrogen, soil nitrogen etc. are assumed to be constant across all locations and throughout the simulation period. Thus, differences in the annual NPP predictions can result only from varying daily climate records over time (Figure 4).

3.3 Terrestrial Tree Measurements

Tree age as well as annual tree ring widths of the 1179 cores were measured with the Digital Positiometer (Johann 1977). Age trends were eliminated using the method proposed by Becker (1989) which is based on the relationship between cambial age and the mean annual radial growth increment for all age classes and sites. After crossdating the increment cores to detect single missing values, we calculated the mean annual radial increment according to the ring age for the whole data set. This resulted in a mean radial growth curve or standard for both samples since 1870.

Next we calculated the deviations from the standard as growth indices in percent for each individual radial growth series. Essentially, we compared the relative change (increase/decrease) of a given increment core by dividing the actual ring width with the corresponding standard value of this age to eliminate the age trend. For example, indices greater than 100 indicate higher increments than expected from the age trend. Again, simple linear regression was applied for the different time spans (Figure 4).

4 RESULTS AND DISCUSSION

From 1961 to 1995, the length of growing season has increased by 14 days associated with an average annual temperature increase by 1.13°C. Although our results show that temperature related climate parameters may have improved in the 1980s (Table 1), we detected only for the temperature controlled growing season a significant change. The covariance analyses exhibited a significant increase in the slope parameter in the 1980s, the period for which the Austrian Forest Inventory reported higher timber volume growth (F-value = 4.2, α=0.05).

Our results suggest that the number of days with snow cover, one of the main limiting factors for plant growth in an Alpine country like Austria, has decreased in the 1980s (see also Koch and Rudel 1990). They report a strong correlation between the number of days with snow cover and the average winter temperature and conclude that a temperature increase of 1°C leads to a decrease of 25 days with snow cover. For the late 1980s similar tendencies of decreasing numbers of days with snow cover have been reported for the Alpine areas of Austria (Mohnl 1991). No changes in precipitation were evident (Figure 2, Table 1).

The simulations with FOREST-BGC indicate an increase in NPP of 6.3% for the 1980s and a decrease of -1.0% between 1961-1980. Combining both growth periods NPP increased by 4.2% which is not significant. The forest growth trend analysis exhibits a significant increase in the mean annual increment index of 9.5 (Sample A) and 9.6% (Sample B) since 1961, mainly because of the increasing trend during the late 1980s (Figure 4).

It is difficult to estimate how much of the NPP is allocated to stem wood as it depends on a number of biotic and abiotic factors. Therefore we restricted our analysis to see how well the NPP predictions correlated with the terrestrial tree measurements using a large and representative sample of increment data from all over Austria. The analysis of variance resulted in a significant (α=0.05) correlation for Sample A (F-value=7.4) and B (F-value=7.1) between the mean annual NPP predictions and the increment indices given in Figure 3, validating the use of FOREST-BGC as a diagnostic tool to search for possible causes of changing growth trends.

Most of the growth indices in Figure 4 are above the 100 level. Although we were only interested in the development since 1961, the data available would allow for a growth trend analysis since 1870 (Neumann and Schadauer 1995, Schadauer 1996). Our data indicated a slight increase in the mean annual increment index of about 1% per 10 year period before 1961. Thus, most of the growth indices since 1961 were greater than 100. The trends between the observed growth rates and the simulated NPP are fairly similar over the simulation period. This confirms that the carbon cycle has responded to an increase in the length of the growing season from warmer temperatures.

Although radial increment dropped in 1976 no similar signals were detectable for climate (temperature, growing season) and NPP. The reason for this discrepancy is probably that in spring 1976 during onset of tree growth dry weather conditions were evident for Austria. Because the climatic conditions for the rest of the year were not unusual, the extremes of spring 1976 were undetectable on an average annual basis.

Our analysis of climatic data shows that the largest changes in air temperature and the growing season length occurred between 1987-1990. Tree growth also responded strongly to these changes, evident from both NPP estimates as well as increment data (Figure 4). A first regional trend analyses of the data indicated that growth regions 1, 2, 3 and 4 of Austria (Figure 1) tend to exhibit a higher increase in average temperature, number of growing days as well as NPP in the 1980s vs. the time span 1961 to 1980. The highest increase in NPP was evident in growth region 4 (23% increase in NPP), the Austrian part of the Bohemian Massif (700 to 900 m), characterized by moderately wet and very cold climate during the winter months but dry and warm summers. The alpine parts of the country (growth regions 1 and 2) showed the highest increase in the number of growing days but the smallest improvement in NPP (about 5 to 10%).

Using the increment information of Sample A (n=614), the mean annual increment index across different elevation groups indicated an increase within the 1980s of about 20% for plots below 900 m (n=200), 7% between 900-1300 m (n=285) and of about 2% increase in the mean annual increment index for all cores from plots above 1300 m (n=129) altitude. Similar findings of diminishing growth in higher altitudes have been reported for Austria (Schadauer 1997) and for the Bavarain mountains in southern Germany, an area next to the north-western border of Austria (Pretzsch 1996).

5 CONCLUSIONS

Significant changes in the growing season length corroborate similar recent findings and can have profound effect on the functional aspects of ecosystems. While trees can respond by vigorous growth to such changes, the long term effects of such a stimulus are unknown. A comprehensive understanding is required to project the state of ecosystems into the future in response to changes in climate as well as in biogeochemistry. Simulation models, coupled with carefully planned field experiments, could help to understand the future course of ecosystems. Finally, it is important to note that 35 years represent a relatively short period of time to investigate climate trends and their long term impact on tree growth.

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SITE INDEX CHANGE IN THE 1950s-1990s ACCORDING TO ESTONIAN FOREST INVENTORY DATA

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ABSTRACT

Ocular estimations of mean height and age at total forest inventories in the 1950s and the 1990s were used in this study. Site indices for 21,409 subcompartments that mostly coincided at both occasions were calculated and compared ($H50_{1950}$ and $H50_{1990}$) using a difference equation of stand height depending on stand age, main species and site factors. The change in site index from the 1950s to the 1990s (the difference between $H50_{1990}$ and $H50_{1950}$) was calculated and used as a dependent variable to indicate and to analyse the actual change in forest growth.

On the basis of 21,409 sub-compartment data records, site index H50 was found to have increased on an average by 2.1 meters. Increase in site index depends on many factors, mostly on drainage, main species, change of stand generation and forest district. The average increase of site index H50 was 2.1 meters for pine stands, 1.6 meters for spruce stands and 2.5 meters for birch stands.

Keywords: forest inventory data, site index model, increase of forest growth.

1. INTRODUCTION

The first indications to the increasing growth trend of Estonian forests were found while analysing the forest inventory data in 1973-1977 (Nilson and Kiviste 1984). A hypothesis about the improvement of forest site properties was reported at the forest monitoring conference in Kaunas, Lithuania (Nilson and Kiviste 1986). However, we did not have any observation material to prove it. At the same time, it became evident that growth models based on traditional methods and temporary plot data give us a wrong picture of the actual forest growth under changing environmental conditions. Currently, a considerable amount of evidence about the forest growth trend in the recent decades has been published. These studies are mostly based on tree analysis data (Hari

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et al. 1984; Henttonen 1990; Untheim 1996; Badeau 1996), permanent research plot data (Eriksson and Johansson 1993; Elfving and Nyström 1996; Eriksson and Karlsson 1996) and National Forest Survey data (Elfving and Tegnhammar 1996; Elfving et al. 1996).

Forest growth data from permanent plots over a long period would provide the best material for forest growth modelling and detecting the growth trends (Gustavsen et al. 1988). Unfortunately, insufficient permanent plot data are available in Estonia. Forest inventory data, recorded for all forest stands at 10-year intervals, are the most reliable data about Estonian forest history which can be used to detect changes in forest growth. Maps and records of ocular estimates from the 1950s of mean height, diameter at breast height (DBH), volume etc. by sub-compartments were available in forest record books. Also, maps and records of ocular estimates of the same forest areas in the 1990s are available in database files. The aim of this study was to create a relationship between the forest inventory data of the 1950s and the 1990s, to compare the average growth rates of stands.

2. MATERIAL AND METHOD

2.1. Initial data

For this study 23 Estonian state forest districts (Järvselja, Vahastu, Peedu, Kambja, Alatskivi, Pühajärve, Otepää, Kärkna, Vesneri, Tähtvere, Erastvere, Kubja, Orava, Põlva, Rõuge, Vastseliina, Käsmu, Kunda, Loobu, Porkuni, Sagadi, Sõmera and Vihula) were selected. Two sets of forest inventory data of the selected forest districts were used – from the 1950s and the 1990s. Using forest inventory maps, a correspondence file was created to relate the data of both inventories. Very often a sub-compartment of the 1990s was divided between two or more sub-compartments in the 1950s. In that case, these sub-compartments were divided into plots. Comparing the maps of the forest inventories of the 1950s and the 1990s in order to compile the correspondence file was time-consuming hard work because of changes in sub-compartment borders after four consecutive forest inventories. In total, the forest inventory data of 56,958 plots on 71,206 hectares (3.6% of Estonian forest area) were prepared for analysis.

The forest inventory data of the 1950s and the 1990s are almost comparable. The technology of field work, including the rules of ocular estimation of the most important stand variables, has remained almost unchanged over the 40-year period. However, there are some differences between the forest inventory data of the 1950s and the 1990s relevant for this study:

1. In the 1950s the site type was not determined, while in the 1990s the forest site type classification by Lõhmus (1984) was used.
2. The forest inventory data of the 1990s that are recorded in database files include much more information than the data of the 1950s that are recorded in record books and entered in database files during this study.

3. Systematic errors in ocular estimations are not excluded. For example, in the 1970s, stand ages and volumes were tended to be underestimated to save Estonian forests from overexploitation by the Soviet planned economy.

2.2. Site index model

To detect the changes in forest growth, two site index estimates were calculated for each plot, on the basis of the 1950s forest inventory data and on the basis of the 1990s forest inventory data. The site index, determined as stand height at fixed reference age, is a commonly applied measure of forest site productivity. Thus, forest growth change is identified with site index change in this study.

In Estonian forest inventory data, the total age and mean height of the first storey of a stand are recorded as stand age and height. A difference equation (Cieszewski and Bella 1989) of stand height depending on dominating species and site factors has been elaborated on the basis of Estonian state forest inventory data in 1984-1993 (Kiviste 1997). As a basis for this equation forest inventory data from all Estonian state forests in 1984-1993 were used. Sub-compartment data were grouped by dominating species (pine, spruce, birch, aspen, common alder, grey alder, oak and ash) and by site type. Data from very young stands (age below 20 years for coniferous and hardwood, and 10 years for deciduous forests), from over-matured stands and outliers were excluded. On the basis of 511,514 sub-compartments data, the following difference equation was created:

$$H_2 = \frac{H_1 + d + r}{2 + \dfrac{4 \cdot \beta \cdot A_2^{-b_2}}{H_1 - d + r}}$$

where

H_1 = known stand height at any age A_1
H_2 = stand height prediction for desired age A_2
$\beta = b_1 - 493 \cdot \ln(OHOR + 1)$
$d = \beta / 50^{b_2}$

$$r = \sqrt{(H_1 - d)^2 + \frac{4 \cdot \beta \cdot H_1}{A_1^{b_2}}}$$

OHOR = a site-specific parameter, thickness of organic layer of site, cm (varies from 1 cm in best sites to 50 cm in bogs),
b_1, b_2 = model parameters depending on dominating species (Table 1).

Table 1. Parameter estimates for the height difference model.

Parameter	Pine	Spruce	Birch	Aspen	Common alder	Grey alder	Oak	Ash
b1	8319	12867	4990	3882	4228	2749	6742	3732
b2	1.58	1.71	1.48	1.3	1.41	1.38	1.61	1.35

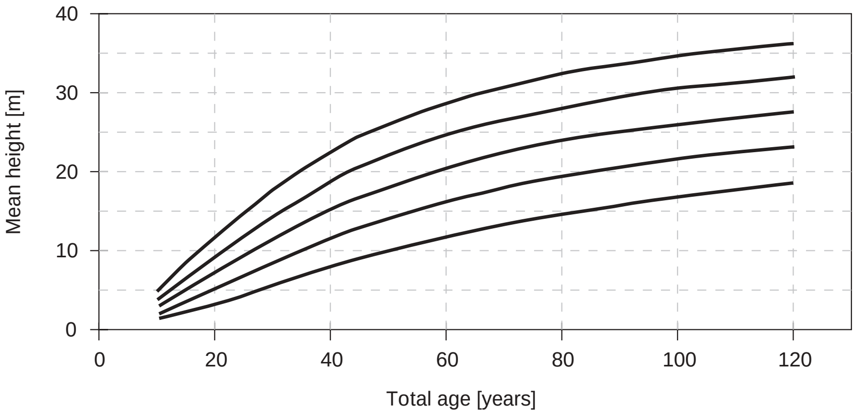

Figure 1. Estonian pine stands height growth example in *Myrtillus* site type (a special case of the difference model where thickness of organic layer OHOR = 12 cm).

2.3. Preliminary data analysis

While establishing relationships between the forest inventory data of the two inventories (in the 1950s and in the 1990s) by maps, remarkable changes in sub-compartment border, site type and stand composition were found. To give an overview of changes in dominant species, a distribution of analysed forest area by dominant species, generations and origin in the 1950s and in the 1990s is presented in Table 2.

In Table 2, in the case of the same forest generations, the change in dominant species may be caused by natural growth of trees and competition between them, although human activities like thinning and reconstruction of forest stands may also have taken place. In the case of artificial regeneration, stands dominated by deciduous species have been changed into coniferous stands as the result of Estonian forest policy. On the other hand, about half of coniferous forests have changed into deciduous forests after natural regeneration.

According to the site index definition in this study, not all plots could be used for site index change calculation. The following conditions were used to exclude the non-comparable plots:

Table 2. Distribution of analysed forest area by dominant species, generations and origin in the 1950s and in the 1990s (other species include mostly aspen and alder).

Dominant species in the1950s	Dominant species in the1990s				Area, ha
	Pine	Spruce	Birch	Other	
Same generations					
Pine	**91%**	4%	4%	0%	28744
Spruce	10%	**75%**	11%	4%	8966
Birch	12%	14%	**64%**	10%	10130
Other	3%	17%	35%	**46%**	2777
Different generations, plantations					
Pine	**83%**	15%	1%	0%	1868
Spruce	15%	**72%**	12%	1%	2356
Birch	5%	86%	**8%**	1%	1368
Other	2%	90%	4%	**4%**	285
Different generations, natural regeneration					
Pine	**42%**	14%	40%	4%	2065
Spruce	4%	**29%**	48%	19%	2057
Birch	1%	9%	**68%**	23%	2226
Other	0%	4%	48%	**48%**	709
Area, ha	31380	14360	13696	4116	63550

1. Stand age was too low for site index calculation (below 20 years for coniferous and hardwood and below 10 years for deciduous species) in the 1950s or in the 1990s.
2. Dominant species were different in the 1950s and in the 1990s.
3. Stand age has been estimated incorrectly – in the case of the same generations, the difference between ages in the 1950s and in the 1990s was not 40 years, in the case of different generations, the age of the new forest in the 1990s was more than 40 years.
4. Sub-compartment areas in the 1950s and in the 1990s differed more than twice.

After all exclusions, the data of 21,409 plots (39% of all plots) proved to be suitable for site index increase estimation in this analysis.

3. RESULTS

On the basis of 21,409 selected plots, basic statistics like arithmetical means, number of observations and standard deviations of site index increase in the 1950s-1990s ($H50_{1990} - H50_{1950}$) by dominating species, by drainage and by generations are presented in Table 3. On an average, site index was found to have increased by more than 2 meters from the 1950s to the 1990s. In spruce stands the increase in site index H50 was approximately half a meter lower (1.6 meters) and in deciduous forests half a meter higher (2.5 meters) than in pine stands (2.1 meters). In stands of the same generation the increase in site index is higher than in the case of different generations. The average increase in site index was 2.8 meters for ditched forests and 2.0 meters for unditched forests. However, very high variation was found in site index increase, with a standard deviation of 2.9 meters.

To analyse which factors influence the increase of site index, the general linear method (GLM) procedure of SAS statistical program package (SAS Institute 1989) was used. The main advantage of the GLM procedure over the classical regression analysis and variance analysis is its ability to include into the model classifications variables, which have discrete levels, as well as continuous variables, which measure quantities. In the GLM procedure site index increase $H50_{1990}$ - $H50_{1950}$ was used as a dependent variable. Dominating tree species, indicator of change of forest generation (same or different) in the 1950s and in the 1990s, forest district, drainage (ditched or not) in the 1950s and in the 1990s and stand origin (natural or planted) in the 1950s and in the

Table 3. Descriptive statistics of increase in site index ($H50_{1990}$-$H50_{1950}$) of stands by main species, drainage and generations.

	Unditched forests			Ditched forests			
Dominant species	Same generations	Different generations	Total	Same generations	Different generations	Total	Total
Average of site index increase $H50_{1990}$-$H50_{1950}$							
Pine	2.21	1.03	2.03	3.32	2.08	3.11	**2.13**
Spruce	1.84	1.33	1.66	1.62	1.46	1.55	**1.65**
Birch	2.72	1.27	2.40	2.96	2.01	2.64	**2.47**
Other	2.35	3.06	2.50	3.35	1.46	2.73	**2.54**
Total	**2.22**	**1.24**	**2.02**	**3.06**	**1.91**	**2.75**	**2.11**
Number of plots							
Pine	7908	3733	11641	1081	125	1206	**12847**
Spruce	2717	1349	4066	199	70	269	**4335**
Birch	2516	40	2556	1045	5	1050	**3606**
Other	524	11	535	86	0	86	**621**
Total	**13665**	**5133**	**18798**	**2411**	**200**	**2611**	**21409**
Standard deviation of site index increase $H50_{1990}$-$H50_{1950}$							
Pine	2.80	2.88	2.82	3.15	3.80	3.26	**2.88**
Spruce	2.39	2.98	2.61	2.65	3.45	2.89	**2.63**
Birch	3.17	3.69	3.19	2.93	4.15	2.94	**3.12**
Other	2.75	1.87	2.73	2.20		2.20	**2.66**
Total	**2.80**	**2.92**	**2.84**	**3.02**	**3.68**	**3.10**	**2.88**

1990s were used as classification variables and stand age in the 1990s and logarithmic transformation of thickness of organic layer of soil ln(OHOR+1) as continuous variables. A summary of GLM output is presented in Table 4.

Figures 2 and 3 present the average site indices H50 by dominant species and by age classes in the 1950s and in the 1990s respectively. Opposite slopes of site index trends can be seen in the 1950s (Figure 2) and in the 1990s (Figure 3).

Table 4 presents the results of general linear model of site index increase depending on all available factors. The model is significant; however, according to the coefficient of determination R-Square = 0.14, it describes only 14% of the variation in site index increase. According to the column of F-values, all factors are significant (at the level of $\alpha = 0.01$) in the general linear model. Stand age (in the 1990s) and generation (the same or different) have the greatest effect on the increase of site index.

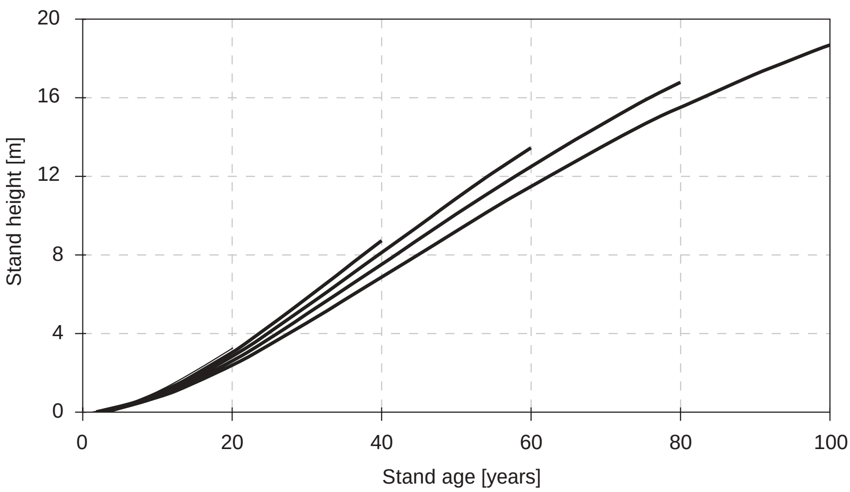

Figure 2. Average site index by dominant species and by age classes in the 1950s.

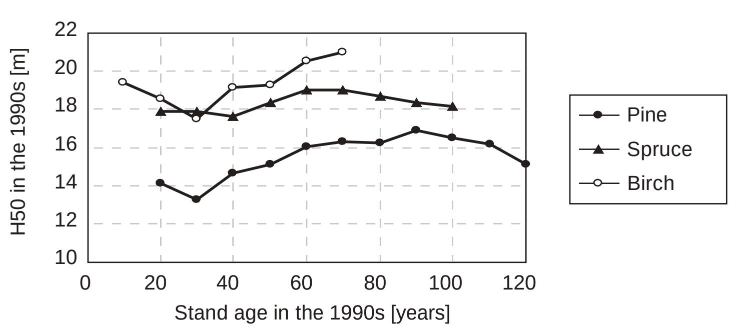

Figure 3. Average site index by dominant species and by age classes in the 1990s.

Effects of main classification variables as least-squared means according to the model are presented in Table 4. According to the model, if other variables are balanced, pine stands have the greatest increase of site index. The effect of ditching is about 0.5 meters both in the 1950s and in the 1990s. Stand generation has the greatest effect on the increase of site index. In the case of the same generation the increase in site index is remarkably higher than in the case of different generations.

4. DISCUSSION

4.1. Initial data

There is no doubt that statistically correctly sampled permanent plot data over a long period would provide the best information for estimation of forest growth change. Unfortunately, too few permanent plot data are available in Estonia by now. Much growth information can be obtained from stem analysis. However, the available stem analysis data have been collected subjectively for several purposes using different methods, and very often stem analysis data recording has been poor. Forest inventory data recorded for all forest stands after 10-year intervals are the most reliable data about Estonian forest history which can be used to detect changes in forest growth.

The chosen period of four decades was long enough to detect changes in forest growth. From all 50,757 plots, 23% had grown a new generation, which makes the comparison of the data more complicated. The forest inventory of the 1950s was the first after World War II, and its technology was quite similar to that used in Estonia nowadays. Earlier forest inventories between the two wars were considerably more different from the present-day forest inventories in ocular estimation of stands, mapping and data recording.

4.2. Correspondence between the stand data of the 1950s and the 1990s

Four decades is a rather long period for a forest. In addition to the natural development of the stand, several kinds of human activities like cutting, thinning, reconstruction etc. can take place. Unfortunately, human activities were not recorded during the period and even if they were, the difference model could not take them into account in site index calculation. Therefore, more than half of the data was excluded from analysis in this study. Evidently, different statistical estimates had to be calculated on the basis of different criteria. Several trials were carried out using different criteria: all possible data in analysis, data with full correspondence in analysis, etc. As a result, no great changes in the average increase of site index were observed.

4.3. Site index model and factors of site index increase

In this study, a site index model (Kiviste 1997) worked out on the basis of the set of single records of forest inventory data in 1984-1993 was used. According to that model,

Table 4. Summary of general linear model (GLM) procedure output. Number of observations: 21409. Dependent variable: Site index increase ($H50_{1990}$-$H50_{1950}$).

Source	DF	SS	MS	F	Pr > F
Model	33	24763	750.4	105	0.000
Error	21375	153064	7.16		
Total	21408	177827			
R-Square	RMSE	Mean			
0.14	2.68	2.11			

Source	DF	Type III SS	MS	F	Pr > F
Main species	3	1090	363	51	0.0001
Generation	1	1061	1061	148	0.0001
Forest district	22	15121	687	96	0.0000
Ditching 1950	1	478	478	67	0.0001
Ditching 1990	1	576	576	80	0.0001
Origin 1950	1	256	256	36	0.0001
Origin 1990	1	114	114	16	0.0001
Age 1990	1	779	779	109	0.0001
LN(OHOR)	1	644	644	90	0.0001
LSMEAN (Effects of classification factors)					
Main species	Pine	Spruce	Birch	Other	
	2.12	1.46	1.80	1.60	
Ditching	1950		1990		
	No	Yes	No	Yes	
	1.49	2.00	1.43	2.06	
Origin	Natural	Planted	Natural	Planted	
	1.94	1.55	1.86	1.63	
Generation	Same	Different			
	2.65	0.84			

an average increase in site index of more than 2 meters over the 40 years period was detected. The site index increase depends on many factors (Table 4), some of which are not easy to interpret. The drainage (ditching) factor is expected in the GLM model, however, its effect should be much more than 0.5 meters (in Table 4). Different results in site index increase for different dominant species could be expected, but it is surprising that the site index increase in spruce stands is much lower than in pine and birch stands. In Estonia spruce stands are growing mostly on mineral soils which are unditched while a big portion of pine and birch stands are growing on drained peatlands. Because of some inconsistency in recording of drainage in forest inventory data, it is possible that the higher site index increase in pine and spruce stands is actually the effect of drainage which has not been correctly recorded.

According to SAS GLM results (Table 4), site index increase is dependent on the forest district. This is evidently caused by systematic errors in ocular estimates of different measurers. As a rule, for each forest district a fixed person was appointed to carry out the forest inventory. That is why the systematic errors of a measurer can be a source of variation in GLM model as a factor of a forest district.

The most important factors that reduce the variation of site index increase are stand age in the 1990s and the generation indicator (the same or different generations). Generally, if a trend of improvement exists in site conditions, it should be more noticeable in the case of new generations than in the case of the same generations because young stands should use improved site conditions more effectively than old stands. According to our results (Table 4), on the contrary, the least-squared mean of site index increase is much higher in the case of the same generations (2.65 m) than in the case of different generations (0.84 m).

Although, at first sight this seems to be a contradiction, it can be explained by the improvement of site conditions. To illustrate that, a simple modelling example was computed using Richards' growth function (Richards 1959):

$$H = H_{\infty} \cdot (1 - \exp(-0.02 \cdot A))^2$$

where
H – stand height at desired age A,
H_{∞} – the height asymptote, a parameter of site productivity.

The height increment H' by Richards'growth function can be calculated as follows

$$H' = 0.04 \cdot H_{\infty} \cdot (1 - \exp(-0.02 \cdot A)) \cdot \exp(-0.02 \cdot A). \qquad (1)$$

Let us assume that 100 years ago the site productivity parameter H_{∞} was 20 m, and every year it increased by 0.10 m (site productivity increase 0.10 m for H_{∞} corresponds to 0.04 m for H50). According to that assumption, the site productivity parameter H_{∞} should have reached 30 m by now.

Using the height increment model (1) with the changing site productivity parameter H_{∞}, different height growth curves were calculated for stands of different ages. Figure 4 presents retrospective growth curves for stands of different ages (20, 40, 60, 80 and 100 years) by thin lines. Figure 5 reveals the poor growth of old stands because of poor site productivity during most of their life. It also shows the relatively better growth of young stands as they have grown all their life in better site conditions. Similar growth patterns have been observed, e.g., by Wenk and Vogel (1996) and Montero et al. (1996).

The site index model used in this study (Kiviste 1997) has been composed using a method that joins the height/age data of stands of different ages. In Figure 4 the resulting site index curve is presented by the thick enveloping line that joins 5 height/age points of the selected stands. Approximating these points with Richards' function, we get the following site index model

$$H = 1.92 \cdot H50 \cdot (1-\exp(-0.0273 \cdot A))^{2.21} \qquad (2)$$

Figure 4 shows clearly that in the case of accelerating growth the standard method of site index modelling gives a wrong growth curve with a deformed shape.

Let us observe a 100-year-old stand with the height of 18.69 m (Figure 5). According to site index model (2), the site index H50 in the 1990s can be calculated as follows

$$H50_{1990} = 18.69/(1.92\cdot(1-\exp(-0.0273\cdot100))^{2.21}) = 11.3 \text{ m.}$$

The height of the same stand 40 years earlier (at stand age 60 years) equals 11.23 m. According to the site index model (2), the site index H50 in the 1950s can be calculated as follows

$$H50_{1950} = 11.23/(1.92\cdot(1-\exp(-0.0273\cdot60))^{2.21}) = 9.4 \text{ m.}$$

That means that in the case of the same forest generations the site index H50 has increased by 1.9 m.

Lets us suppose that 40 years ago (at stand age 60 years and height 11.23 m) the stand was clear-cut, and now we have a new 40-year-old stand with the height of 7.58 m (Figure 5). Then, according to the site index model (2), the site index H50 in the 1990s can be calculated as follows

$$H50_{1990} = 7.58/(1.92\cdot(1-\exp(-0.0273\cdot40))^{2.21}) = 9.7 \text{ m.}$$

Consequently, in case of different generations the site index has increased only by 0.3 m. Thus, this simple example demonstrates how different generations produce a different change in the site index.

The effect of different site index increase by generations that became evident in this study appears when site curves underestimate stand height at higher ages. This bias is

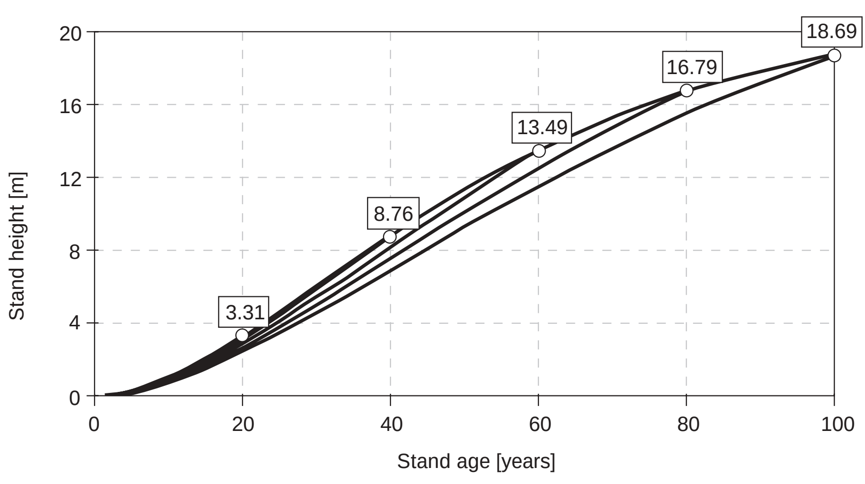

Figure 4. Results of a modelling example to show retrospective growth curves of stands of different ages (thin lines) and the site index curve (thick line) by our method in the case of improving site productivity.

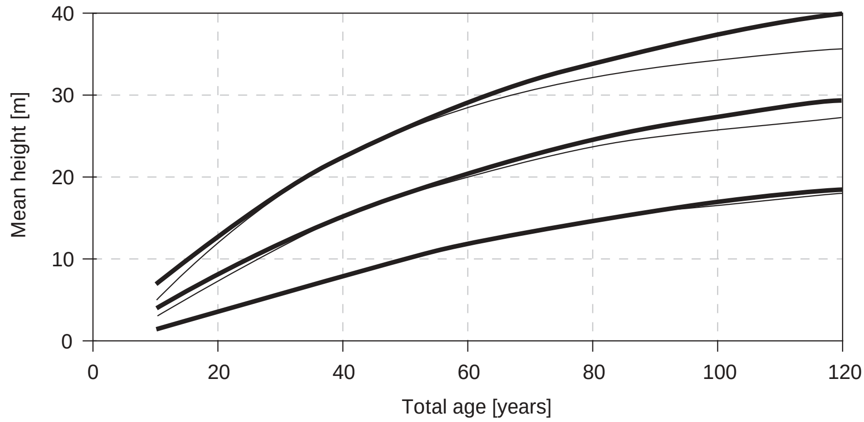

Figure 5. Site index curves by Orlov (thick lines) and by the difference model (thin lines) for pine stands in *Myrtillus* site type.

characteristic of all site index models based on age-class data due to “the selection effect“: full-grown stands are cut, and in higher age classes only slow-growing stands are left. However, while composing the site index model (Kiviste 1997) used in this study, height/age data of thicket-age and over-matured stands were exluded and by doing so “the selection effect“ was minimized. Also, in Figures 2 and 3, only birch data of the 1990s indicate the relatively higher site index in older stands. In the other cases the site index in older stands was not higher than in stands of other ages.

To be sure that site increase is not an artefact of modelling, we calculated inrease of site index using the Orlov’s site index tables model as well. Orlov’s site index tables were used for site productivity classifications all over the former Soviet Union, and they are still rooted in Estonian forest management practice. Orlov’s tables date from the 1920s, and they have often been criticised for being too primitive to describe the real stand height development and to be used in computer programs.

Table 5. Average of Orlov’s site index increase ($H50_{1990} - H50_{1950}$) by dominant species, drainage and generations

	Unditched forests			Ditched forests			
Dominant species	Same generations	Different generations	Total	Same generations	Different generations	Total	Total
Pine	1.70	1.31	1.64	2.53	2.71	2.56	**1.72**
Spruce	1.37	0.92	1.21	0.91	1.43	1.15	**1.21**
Birch	3.66	0.40	2.95	3.17	1.49	2.62	**2.85**
Other	4.03	1.88	3.58	3.72	1.54	3.01	**3.50**
Total	**1.97**	**1.05**	**1.78**	**2.68**	**1.85**	**2.45**	**1.86**

In this study, two models of Orlov's site index tables (Kiviste 1987), one for coniferous and hardwood species and another for deciduous species were used. Orlov's site index model for coniferous and hardwood species has higher height at higher ages as compared to the difference model for pine and for spruce used in this study (Figure 5). The difference in heights at higher ages was not so big when we compared Orlov's model for deciduous species with the difference model for birch stands, but at young ages a small difference like in Figure 5 was observed.

Using Orlov's site index models, the average increase in site index from the 1950s to the 1990s was calculated by dominant species, drainage and generations as presented in Table 5.

If we compare the average site index increase calculated by two different site index models (Table 3 and Table 5), remarkable changes can be noticed. This could be expected as the difference model depends on site type while Orlov's model does not. However, both models revealed an average increase in site index by about 2 meters.

5. CONCLUSIONS

According to this study, the site index of Estonian forests has increased during the last forty years. The average increase of site index H50 during that period has been about 2 m, depending on what site index model to use. However, a remarkably high standard deviation of site index increase (2.9 m) was found. Ditching of forest lands has been one of the most important factors in forest site improvement. The effects of several other factors like dominant species, stand origin, thickness of organic layer, etc. are also significant but hard to interpret.

In this study, the site index increase in the 1950s-1990s was used as a dependent variable in the analysis of Estonian forest growth change. However, the results are very much dependent on the site index model. Furthermore, in the case of changing forest site conditions, the methods of site index modelling in Estonia should be revised.

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CHANGES IN THE GROWTH, CONTENTS OF CARBOHYDRATES AND NUTRIENTS OF CONIFERS UNDER LONG-TERM INFLUENCE OF ALKALINE DUST

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ABSTRACT

Two-year-old seedlings of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), black spruce (*P. mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) were planted in a) sample plots influenced by high concentrations of cement dust and b) an unpolluted area. After four years of exposure, the six-year-old trees were dug up in the pre-bud-break period for morphological assessment. The high level of alkaline dust emitted from the cement plant and the concomitant alkalisation of the growth substrate retarded the height growth of trees and caused a decrease in total plant biomass. Contents of carbohydrates, especially soluble sugars tended to decrease. A misbalance in mineral nutrients' composition was found as well as severe manganese deficiency in all species. The partitioning of carbohydrates and mineral nutrients between plant organs had changed significantly.

Keywords: conifers, dust pollution, carbohydrates, nutrients, biomass

INTRODUCTION

In order to forecast and estimate the development of forest ecosystems, it is necessary to understand the response reactions of trees to pollutants, which are emitted by different industrial enterprises. In addition to the atmospheric pollutants O_3, SO_2, NO_x and acidic rains, which have been widely studied, industrial regions are often confronted with the problems of alkalisation due to the high content of various industrial alkaline dusts and ash.

Research efforts into the effects of anthropogenic dust and ash on plants have been relatively modest, though dust pollution formed about 10% of the total pollution in the world before 1990 (Eensaar 1988) and may be increasing due to extension of quarrying, opencast mining and road traffic (Farmer 1993). Dust effects on forest trees may

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manifest directly by covering the surface of aboveground organs and indirectly through changes in soil and precipitation.

Depending on the dust load, the duration of the effect, the chemical composition of dusts and the tolerance of the plant, dust pollution may cause negative or positive responses in plant growth and biomass formation. Braniewski and Chrzanovska (1988) consider the effect of cement kiln dust to be neutral or even stimulating as it does not cause visible necrotic or chlorotic lesions on assimilative organs of plants. However, several studies describe negative changes in physiology and biochemistry of plants under high levels of alkaline cement dust (Brandt and Rhoades 1973; Sporek 1983; Shukla et al. 1990; Farmer 1993; Mandre et al. 1994; Mandre and Klõšeiko 1997).

Alkaline dust pollution is known to affect several physiological processes linked to photosynthesis (Lal and Ambasht 1982), carbohydrate metabolism (Steinhübel 1962; Iliescu 1981; Mandre 1995b; Mandre and Klõšeiko 1997), pigment composition (Manning 1971; Borka 1980; Mandre and Tuulmets 1997) and mineral nutrition (Singh and Rao 1968; Lal and Ambasht 1982; Mandre 1995a).

The main objective of the current study was to describe the responses of different coniferous species to alkaline dust emitted from a cement plant by the use of morphological and biochemical parameters. Our results should contribute to a better understanding of the physiological background of growth inhibition of conifers in industrial areas and of anthropotolerance of coniferous trees to alkaline air pollution. In addition, the results will help to estimate the suitability of using coniferous species in creating green areas in industrial regions.

MATERIALS AND METHODS

Morphological and biochemical differences of five species of conifers (*Pinus sylvestris*, *Picea abies*, *P. mariana*, *P. glauca*, *Pseudotsuga menziesii*) grown in an area of heavy dust pollution were studied and compared with trees grown in an unpolluted control area with similar climatic conditions. The complex profile on which the investigation plots are located lies in the east-west direction at the southern edge of the North-Estonian coastal plain. The relief of sample plots is flat and the territories lie 15-30 m above sea level (Annuka 1994).

Climatically the areas investigated belong to the mixed-forest subregion of the Atlantic-continental region, where the influence of the Baltic Sea is strongly felt (mean annual t° is 4.9 °C, annual amount of precipitation 550-575 mm and dominating winds blow from the south-west at a mean velocity of 5.2 m sec^{-1} (Annuka 1994; Raukas 1993). The soils in the areas investigated are Gleyic Podzols, which show essential chemical changes in the vicinity of the cement plant.

Characteristics of sample plots

The experimental plot was located in the vicinity of the cement plant of Kunda (longitude 26°30’ E, latitude 59°20’ N). Apparently, the main damaging factor for trees in this sample plot was technological dust, which constitutes 87-91% of the total emission; SO_2, NO_x, CO and other gaseous pollutants make up the remaining 9-13% (Raukas 1993; Estonian Environment 1993, 1994; Estonian Environment 1994, 1995). The dust from electric filters contains many components, among which the following are predominant: 40-50% CaO; 12-17% SiO_2; 6-9% K_2O; 4-8% SO_3; 3-5% Al_2O_3; 2-4% MgO; but also Fe, Mn, Zn, Cu, B, etc. occur (Raukas, 1993). The dust load on the experimental plot was approximately 600-2400 g m^{-2} $year^{-1}$ depending on the velocity and direction of winds. High concentrations of anthropogenic dust (pH 12.3-12.6) in the air due to emissions from the cement plant have brought about significant alkalisation of the soil (pH of humus horizon is 7.8-8.1), precipitation (rain pH 5.9-7.1, snow melt pH 9.1-10.9), subsoil water (pH 7.1-7.9) and have changed their chemical composition in forest ecosystem (Mandre et al. 1994) (Figure1).

Control sample plot was situated on the relatively unpolluted territory of Lahemaa National Park about 34 km west from the cement plant, opposite to prevailing winds (longitude 26°00’ E, latitude 59°31’ N). The pH of rainwater measured during the investigation period was 6.1-6.6 and that of snow melt 6.7-7.0. The humic horizon of soil had pH 3.6-4.2. The character of growth conditions of trees on the control sample plot is given in Figure 1.

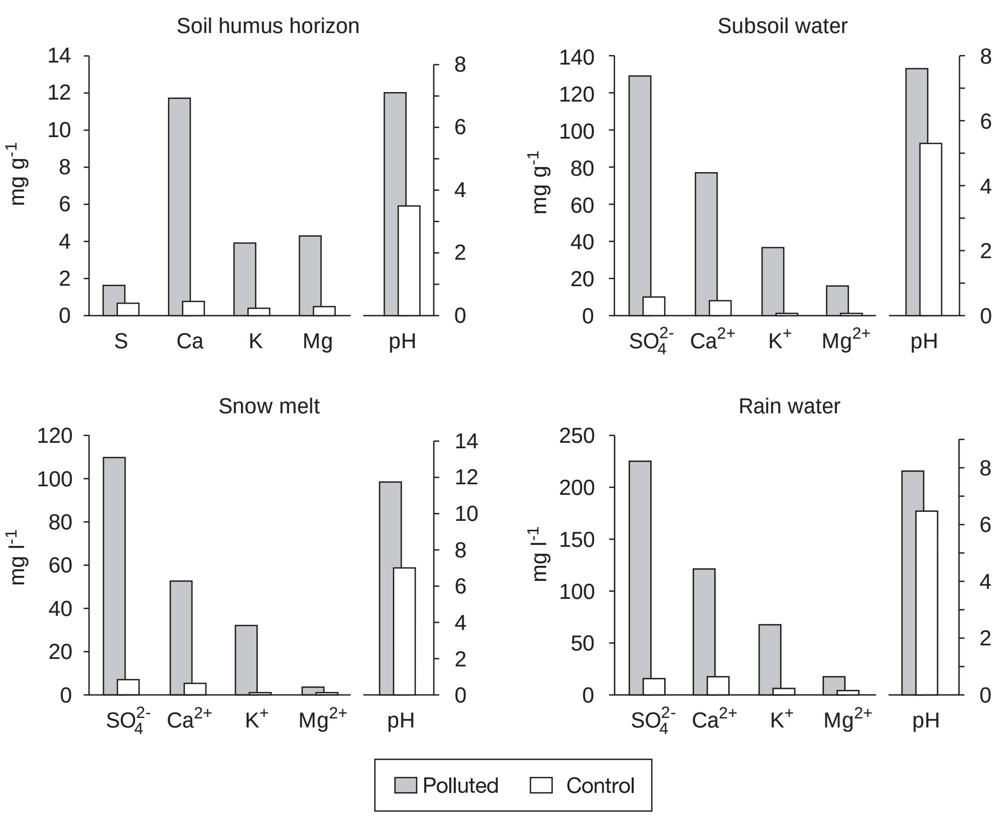

Figure 1. Growth conditions of trees on sample plots.

Morphological measurements

Two-year-old seedlings were planted in 1991. The seedlings were obtained from the tree nursery of Estonian Forest Institute and originated from the single mother trees. In late April - early May 1994 before bud break, 6-10 six-year-old trees of each species were dug up and the roots, stems (trunks of juvenile trees), shoots (two last age classes), needles of shoots and stems and buds were separated for the assessment of their fresh and dry mass (g), dry matter content (%), length (cm) and for the analysis of macro- and micronutrient contents in different organs. The height of the trees was measured every autumn beginning with the autumn after planting.

Chemical analysis

All the organs separated were carefully cleaned, cut into small pieces and oven-dried at 70ºC to stop metabolic activity (Wilde et al. 1979; Landis 1985). Only one-year-old needles and shoots were used for chemical analyses, because they are the most important source of photosynthate and mineral nutrients retranslocation for the new needles and shoots during the pre-bud-break period and during their first week of needle development (Ziemer 1971; Ericsson 1978; Marschner 1986). After grinding the dried plant material of different organs was subjected to chemical analyses. Concentrations of metals (Ca, K, Mg, Fe, Mn) were determined by atom adsorption spectroscopy (AAA-1N, Karl Zeiss, Jena), nitrogen was measured by the method of Kjeldahl and phosphorus by the ammonium molybdate-vanadate method using a spectrophotometer SPEKOL 11 (Carl Zeiss, Jena) at 460 nm in the Estonian Control Centre of Plant Production, which has an accreditation of the Estonian Standard Board.

In our study the standard methods for measuring chlorophylls (Chl) and carotenoids (Car), (Vernon 1960; Gowin and Goral 1977; Reich et al. 1986) were used. Needle samples of 0.2 g were fixed in liquid nitrogen and homogenised in 80% ice-cold acetone-water for 3-5 min in dim light and under low temperature conditions. The extract was filtered through a fritted-glass filter and the filter cake residue was washed with 80% acetone. The pigment content was measured with a SF-46 spectrophotometer (LOMO, St. Petersburg) by reading absorption of the chlorophyll extract at wavelengths 649 and 665 nm and the chlorophyll content was calculated according to the formulas by Vernon (1960). The carotenoid content was also determined spectrophotometrically at 470 nm in acetone solution using the method recommended by Lichtenthaler and Wellburn (1983).

Total soluble sugar and starch concentrations were estimated using the methods recommended by Arasimovich and Ermakov (1972), Ferenbaugh (1976) and Marshall (1984). The separated parts of 6–10 trees were immediately fixed in boiling 96% ethanol for 3 min and dried in the air. 1–5 g of dried and homogenised plant material was used for repeated extraction of soluble sugars with 80% ethanol, centrifuged and the soluble supernatant was collected. All the residue that remained after the removal of soluble sugars was dried, followed by gelatinisation in distilled water and digestion with 35% perchloric acid for complete extraction of all starch (Ferenbaugh 1976; Marshall

1984). The extraction of hemicelluloses was carried out with acid hydrolysis (2% H_2SO_4) as recommended by Arasimovich and Ermakov (1972) and Sofronova and Chinenova (1987). The extracts of soluble sugar, starch and hemicelluloses obtained were individually reacted with anthrone reagent (0.1% anthrone in 72% sulphuric acid) to produce a blue-green colour and their absorbancies were measured at 620 nm with a spectrophotometer (model SF-46, LOMO, St. Petersburg).

Statistical analyses

To find out differences between the data, correlation analysis and analysis of variance (ANOVA) were used with the help of packages Statgraphics 5.0 and MS Excel 5.0. Type I model was chosen for calculating sums of squares in ANOVA. Only the significant results obtained with the ANOVA were tested, using the multiple comparison test according to Duncan.

RESULTS AND DISCUSSION

Biochemical analyses

Cement dust, covering the plant organs above ground, acts as a light-selecting filter reducing penetration of photosynthetically active parts of the spectrum (Borka 1980), rising the temperature of plant tissues (Flückiger et al. 1978) and transpiration intensity (Singh and Rao 1981). Some earlier experimental work on the pigment composition indicated reduced photosynthesis and bleaching of leaves under dust pollution (Manning 1971; Borka 1980). Alkaline cement dust causes a decrease in chlorophyll *a* and other photosynthetic pigments in one-year-old needles of 60-80 years old Norway spruce and Scots pine (Ricks and Williams 1974, 1975; Mandre and Tuulmets 1995). Also in this study a serious decline in pigment contents of young *Picea abies* and *P. mariana* was found and also a decrease of chlorophylls was identified in both species (Figure 2). All these processes are closely related to carbohydrate metabolism and cause changes in carbohydrate content and partitioning.

Our data indicate that cement dust decreases the content of carbohydrates in conifers while the intensity of changes varies in different species (Figure 3). The partitioning of carbohydrates, especially of soluble sugars in young conifers changes significantly in an alkaline environment. The greatest changes were recorded in the contents of soluble sugars with average value being particularly low in *Picea mariana*. Soluble sugars seem to decrease relatively little in needles, but more in roots and stems, to some degree also in shoots. The content of starch and hemicellulose decreased as well, but less in comparison with changes in soluble sugars (Figure 3). Even elevated starch and hemicellulose contents due to cement dust exposure were recorded in roots and stems of white spruce and Scots pine. The ratio of soluble sugars to starch is below the control level in the trees grown under dust pollution and in an alkalised environment, except for Norway spruce.

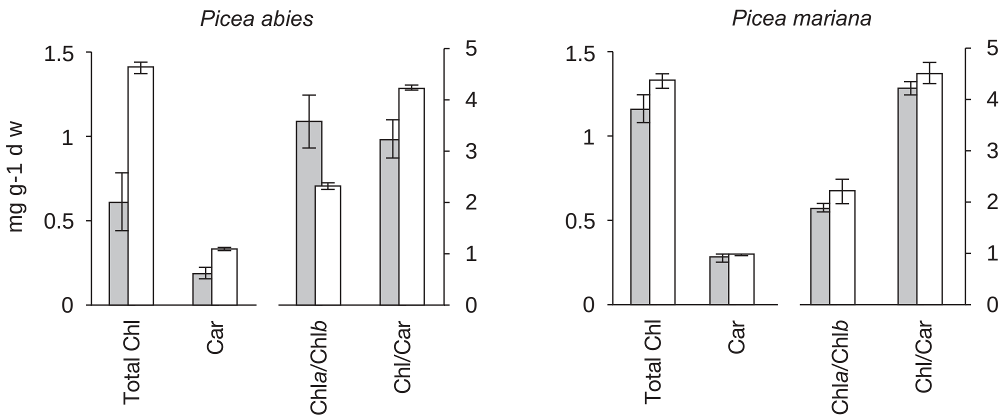

Figure 2. Deviations from the control in the pigment system and ratio in coniferous trees grown in the area affected by the cement plant (±SD, n=6).

Alkalisation of the growth substrate due to cement dust inhibits the uptake of several nutrients. Earlier investigations with 60–80-year old Norway spruce and Scots pine showed that cement dust exposure raises the Ca, K and S content in needles, but decreases that of Mn, N and P (Mandre 1995a). Similar results were obtained for foliar nutrient composition by Lal and Ambasht (1982). However, the present data show that changes in the needles do not reflect the whole organism, since exposure to cement dust changed nutrient partitioning (Figure 4).

As a consequence of cement dust exposure the contents of several elements (P, Mg, Fe, K) were higher than in the control trees in the above-ground organs, while in the roots they were close to (K, Mg) or significantly lower than in control trees (Fe, P), except in *Picea mariana* (Figure 4). The lower mineral elements contents and the reduced concentration of N, P, Fe and Mn in the roots points to difficulties with uptake of nutrients from the alkalised growth substrate or to an intensive translocation from the roots to the above-ground organs. The increased content of nutrients in the above-ground organs suggests the accumulation of nutrients from the dust layer on trees. In practice the above-ground nutrient uptake is known where treatment of above-ground organs with a nutrients solution increases the content of elements in tissues (Finck 1982; Miidla 1984; Kärblane, 1996).

N and Mn concentrations in conifers in the polluted environment were lower than the control and a general shortage of N and Mn occurred in the organism. Mn deficiency was shown earlier in plants growing in high pH soils by Farley and Drycott (1973), and Ca and Mn interdependence in plants was noted also by Foy et al. (1981) and Horst and Marschner (1978). As Mn activates a number of enzymes, particularly decarboxylases and dehydrogenases of the tricarboxylic acid cycle and phosphotranspherases involved in phosphorylation, both phosphorylation and respiration processes may become disturbed in plants in an alkalised environment. Mn deficiency may have the most severe effect on the level of carbohydrates. Vielermeyer et al. (1969) demonstrated a drastic drop of soluble carbohydrates and proteins, and Ness and Woolhouse (1980) showed reduced RNA synthesis in chloroplast under Mn deficiency.

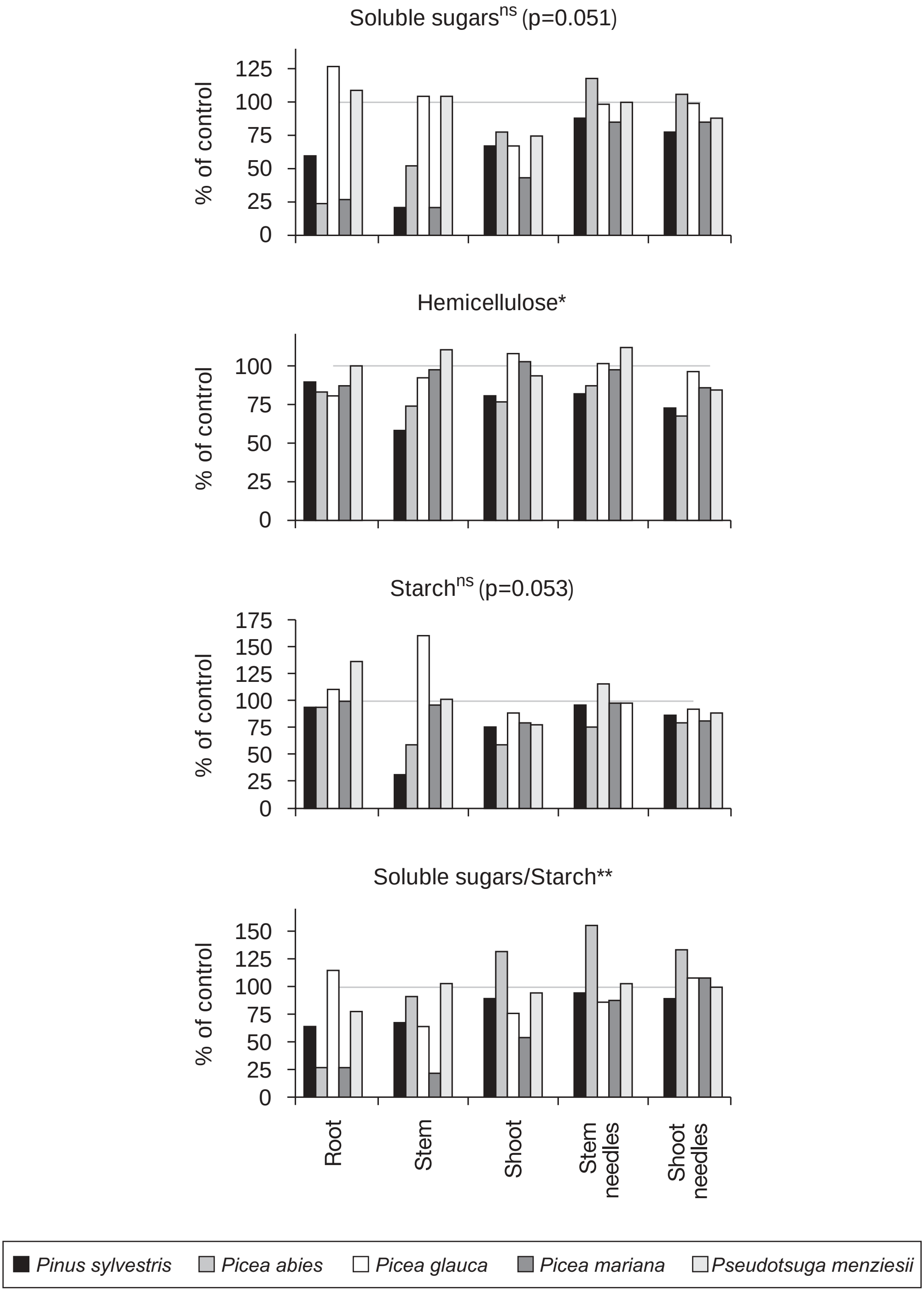

Figure 3. Deviations from the control in the soluble sugars, starch and hemicellulose in coniferous trees grown in the area affected by the cement plant. Significance of differences (ANOVA): **, p<0.01; *, p<0.05; ns, p>0.05.

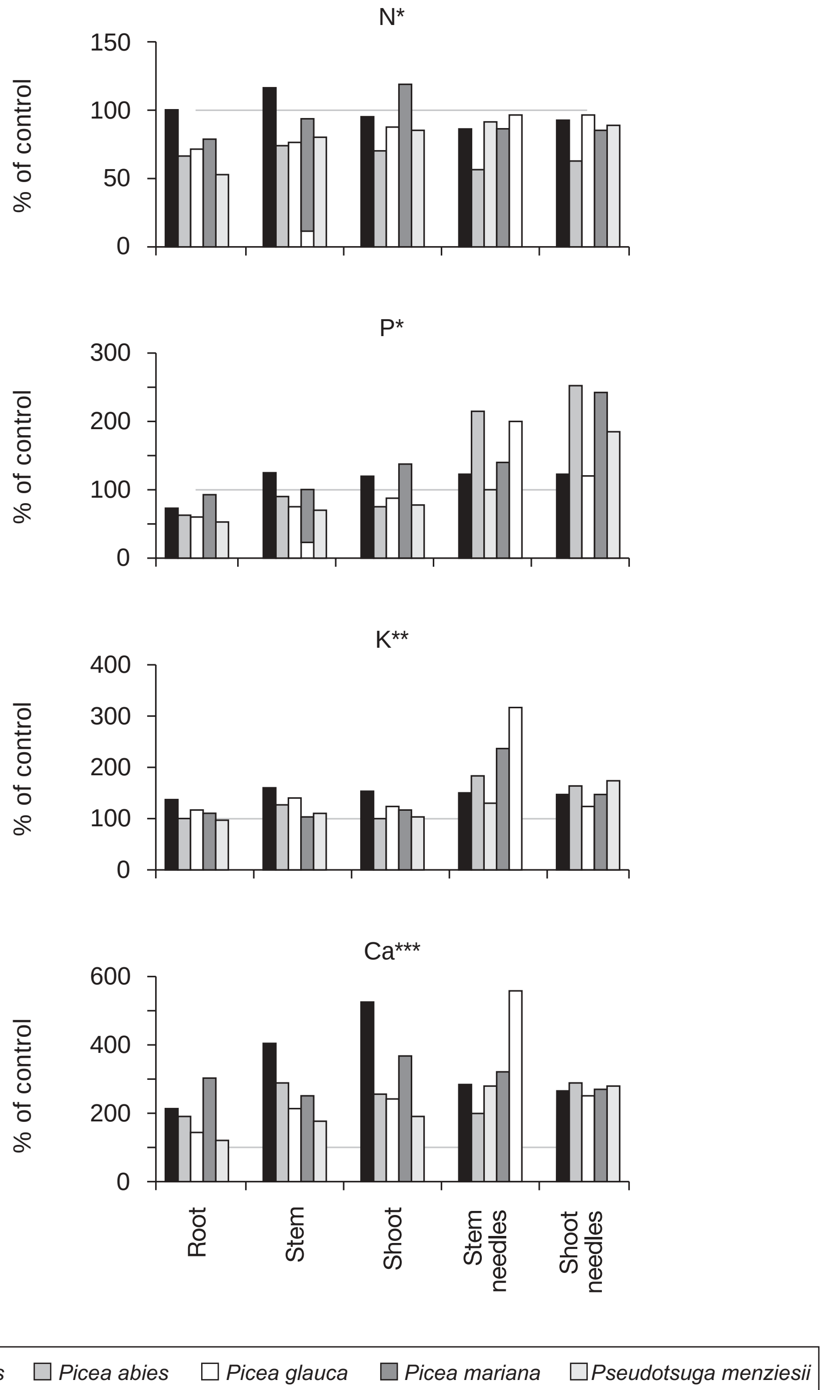

Figure 4. Influence of the dust pollution on the content of mineral elements in coniferous trees. Significance of differences (ANOVA): ***, $p<0.001$; **, $p<0.01$; *, $p<0.05$.

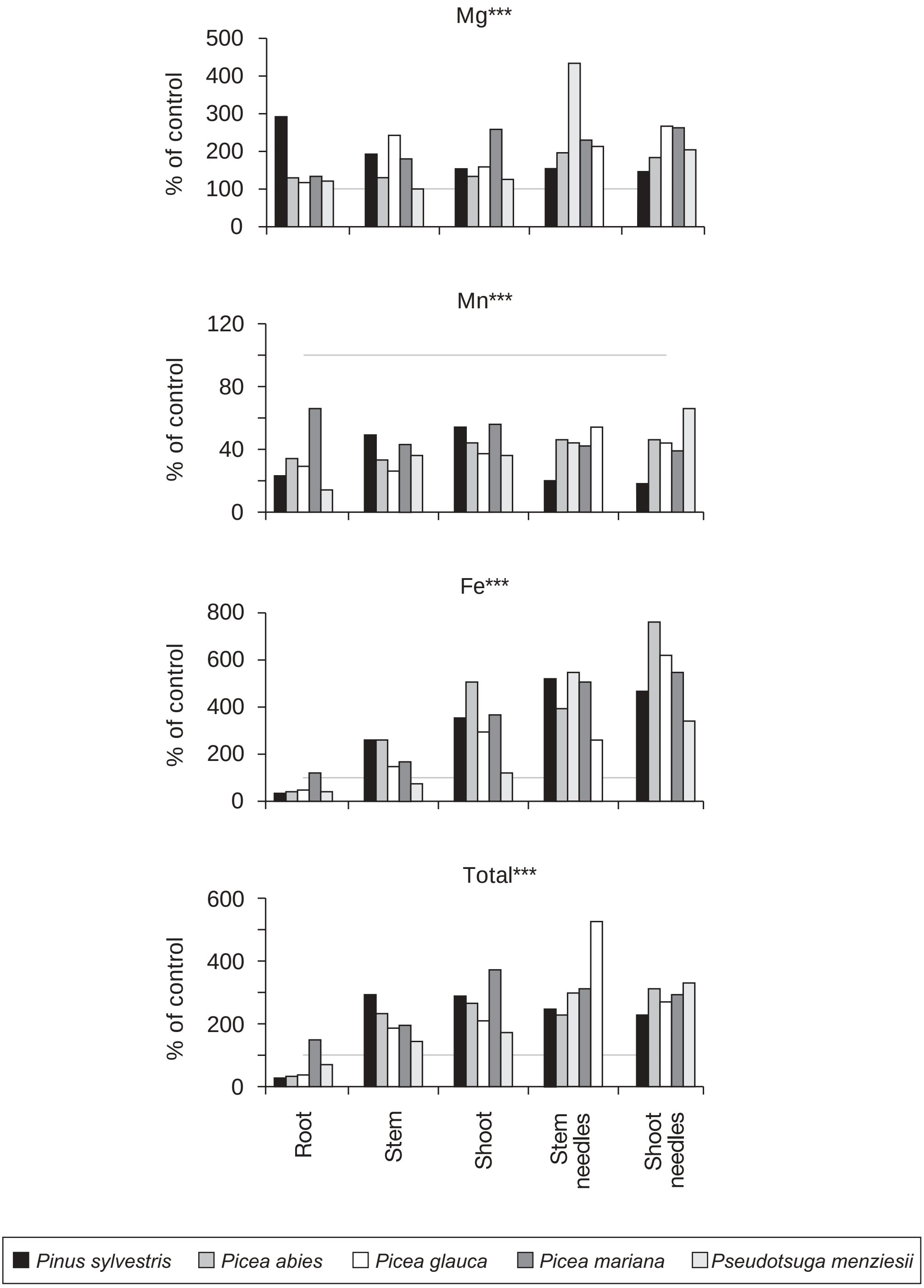

Figure 4 (continued). Influence of the dust pollution on the content of mineral elements in coniferous trees. Significance of differences (ANOVA): ***, p<0.001; **, p<0.01; *, p<0.05.

Several authors stress balance of nutrients as an important factor in the survival and development of plants (Marschner 1986; Kärblane 1996). It was ascertained that the ratios N/P, N/S and N/Mg in the needles of conifers are relatively stable all year round in optimum growth conditions (Mandre and Tuulmets 1993; 1995). Deviation of the ratios N/P and N/S from the optimum may cause drastic changes in plant metabolism (Odelin 1963; Pulmery and Moore 1965; Marschner 1986). Our findings indicate that in the organs of conifers growing in an alkalised environment and under dust pollution the ratios of the contents of most of the nutrients analysed had changed significantly (Figure 5).

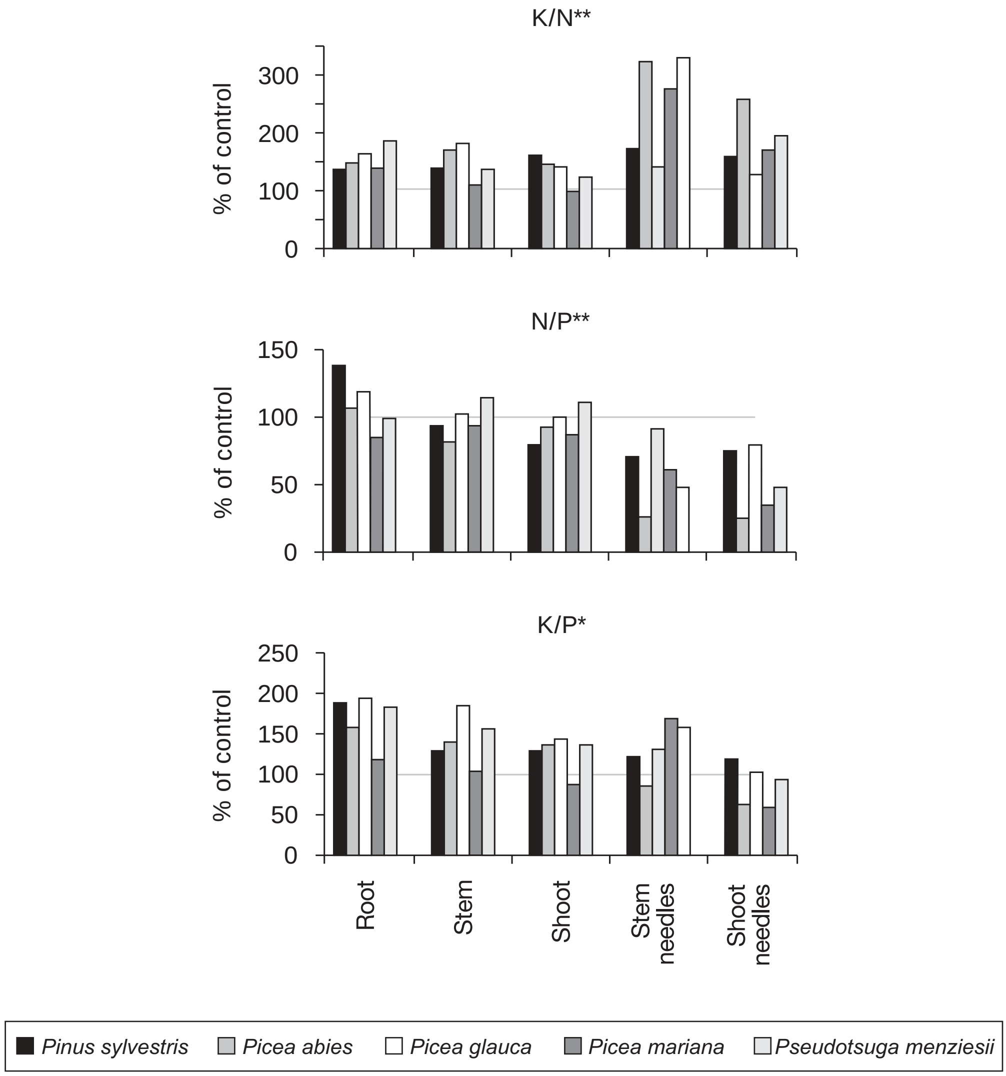

Figure 5. Influence of the dust pollution on the ratios of mineral elements in coniferous trees. Significance of ANOVA: **, $p<0.01$; *, $p<0.05$.

Morphological analyses

The alkaline dust emitted from the cement plant and the concomitant alkalisation of the growth substrate retard the height growth of trees and decrease total plant biomass. As compared with the control, the height growth of black spruce was most strongly inhibited of the five species studied. The inhibition was especially severe in 1992 and 1993 when the height was 31% and 25% of the control respectively (Figure 6).

In June 1991, the amount of precipitation was 2.3 times greater than the long-term normal but in the two following years it was only 1/3 to 1/8 of the long-term normal. It is reasonable to assume that abundant rainfall reduces significantly the negative impact of cement dust on the height increment of trees. Our data, based on height growth, indicate the tolerance of Douglas fir and the sensitivity of black and white spruces to alkaline dust.

The large amounts of cement dust had a strong negative effect on the formation of the biomass of the conifers. This was especially evident in case of the fresh and dry weight of roots, stems and shoots, less in case of needles (Table 1, Figure 7). The biomass of various organs of black spruce in particular was notably diminished by large amounts of dust.

Strong alkalization of the upper soil horizons (Annuka 1994) and imbalanced contents of nutrients in the soil and tissues of trees (Mandre 1995a) cause important changes in the root system of young trees. The fresh weight of the roots of trees growing in the polluted area was 3-50% and the dry weight 3-58% of these of the control trees. The dry weight of shoots was significantly smaller in the polluted areas, making up only 20% of the control as an average for the five species of conifers (Figure 7). The weight of shoots was especially small in case of black spruce. The fresh and dry weight of the needles of different conifers growing in a cement dust polluted environment was also smaller than the control. The content of dry matter had fallen in needles, but in the stems and shoots it was higher than in the control trees (Figure 7).

Statistical analyses

Dispersion analysis showed significant differences from the control of the biochemical and morphological characteristics of trees growing in polluted areas, but also differences between species and various organs (Tables 2 and 3).

Important causes of the reduction of growth and biomass are disbalanced composition of nutrients and decreased content of carbohydrates. Regression analysis revealed a dependence of the biomass of these organs on the N content for all conifers studied. Elevated contents of K and Ca in the organism and in the environment in the vicinity of the cement plant hinder the assimilation of N and its allocation within the organism (correlation coefficients $r_{N/Ca} = -0.727$, $p < 0.001$; $r_{N/K} = -0.782$, $p < 0.001$). Encrustation of assimilating organs with dust and decreased content of N and P in the tissues are important factors resulting in reduced contents of soluble sugars (SS), but also starch and hemicellulose and hindering their allocation in the organism in trees

Table 1. Average biomass (±SD) of different fractions of six-year-old coniferous trees.

Species	Organ	Fresh weight, g		Dry weight, g		Dry matter, %	
		Polluted	Unpolluted	Polluted	Unpolluted	Polluted	Unpolluted
Pinus sylvestris	Roots	6.4±2.96	127.7±8.70	3.1±1.23	55.5±5.81	49.5±3.47	43.4±2.35
	Stems	13.0±3.28	192.4±23.3	6.2±1.40	72.8±7.94	56.6±19.3	37.9±1.01
	2-yr shoots	0.4±0.25	4.3±0.84	0.2±0.12	1.9±0.52	55.2±6.43	46.7±1.40
	1-yr shoots	0.4±0.15	8.9±2.36	0.2±0.06	3.4±0.86	49.5±8.52	38.7±1.13
	2-yr needles	1.7±0.32	4.1±1.09	0.8±0.14	2.1±0.54	47.6±1.58	50.0±0.56
	1-yr needles	1.7±0.51	6.8±1.86	0.8±0.23	3.3±0.95	46.4±3.04	48.6±0.91
Picea abies	Roots	8.2±3.06	35.5±6.86	4.3±1.25	22.5±1.27	53.9±7.05	63.6±5.57
	Stems	8.1±3.10	45.7±13.42	4.4±1.54	22.5±9.60	54.8±2.50	51.4±6.90
	2-yr shoots	0.13±0.05	0.49±0.21	0.10±0.05	0.30±0.13	65.7±3.10	59.9±0.26
	1-yr shoots	0.09±0.03	0.77±0.37	0.06±0.02	0.43±0.20	62.1±3.85	56.0±1.85
	2-yr needles	0.28±0.06	0.29±0.06	0.15±0.04	0.22±0.09	54.3±9.68	63.0±1.47
	1-yr needles	0.36±0.05	0.73±0.11	0.19±0.03	0.43±0.06	54.4±3.26	58.2±1.48
P. mariana	Roots	1.8±1.04	56.3±9.06	1.0±0.52	35.7±6.76	53.2±1.53	61.7±8.66
	Stems	1.7±0.49	58.8±9.16	0.9±0.27	29.4±5.29	55.0±2.32	49.9±2.66
	2-yr shoots	0.01±0.001	0.69±0.28	0.01±0.001	0.45±0.20	85.4±10.24	64.7±3.15
	1-yr shoots	0.021±0.007	0.93±0.27	0.014±0.005	0.56±0.19	71.9±11.39	59.42±4.94
	2-yr needles	0.10±0.02	0.25±0.10	0.07±0.01	0.17±0.07	63.7±4.07	69.7±3.59
	1-yr needles	0.12±0.03	0.44±0.16	0.07±0.02	0.30±0.09	56.1±5.31	67.8±4.74

Table 1 (continued). Average biomass (±SD) of different fractions of six-year-old coniferous trees.

Species	Organ	Fresh weight, g		Dry weight, g		Dry matter, %	
		Polluted	Unpolluted	Polluted	Unpolluted	Polluted	Unpolluted
P. glauca	Roots	4.7±1.09	39.3±3.92	2.6±0.53	22.0±1.05	54.9±1.85	56.6±5.30
	Stems	4.5±0.40	87.7±13.21	2.3±0.17	40.3±9.93	51.4±1.33	46.2±0.91
	2-yr shoots	0.06±0.02	0.77±0.44	0.04±0.01	0.45±0.25	60.4±2.32	59.4±3.85
	1-yr shoots	0.08±0.04	0.85±0.14	0.04±0.02	0.46±0.09	55.0±4.49	54.89±3.20
	2-yr needles	0.18±0.04	0.31±0.09	0.10±0.03	0.18±0.05	55.4±2.49	59.6±4.44
	1-yr needles	0.24±0.04	0.53±0.21	0.13±0.03	0.30±0.12	52.5±1.99	55.8±1.54
Pseudotsuga menziesii	Roots	6.97±1.93	13.9±2.62	4.22±1.11	7.34±1.38	60.8±2.42	52.8±1.58
	Stems	7.98±1.93	18.17±3.91	3.98±0.77	8.55±1.69	50.4±3.24	47.1±1.07
	2-yr shoots	0.12±0.07	0.32±0.14	0.06±0.02	0.17±0.07	62.3±7.42	55.0±3.28
	1-yr shoots	0.07±0.03	0.31±0.21	0.05±0.02	0.17±0.11	65.3±7.64	55.4±3.80
	2-yr needles	0.68±0.24	0.69±0.26	0.39±0.15	0.40±0.15	57.7±4.82	58.2±6.41
	1-yr needles	0.52±0.06	1.08±0.89	0.27±0.03	0.47±0.13	51.9±3.35	52.4±14.54

1-yr – one-year-old shoots and needles formed in 1993; 2-yr – two-year-old shoots and needles formed in 1992.

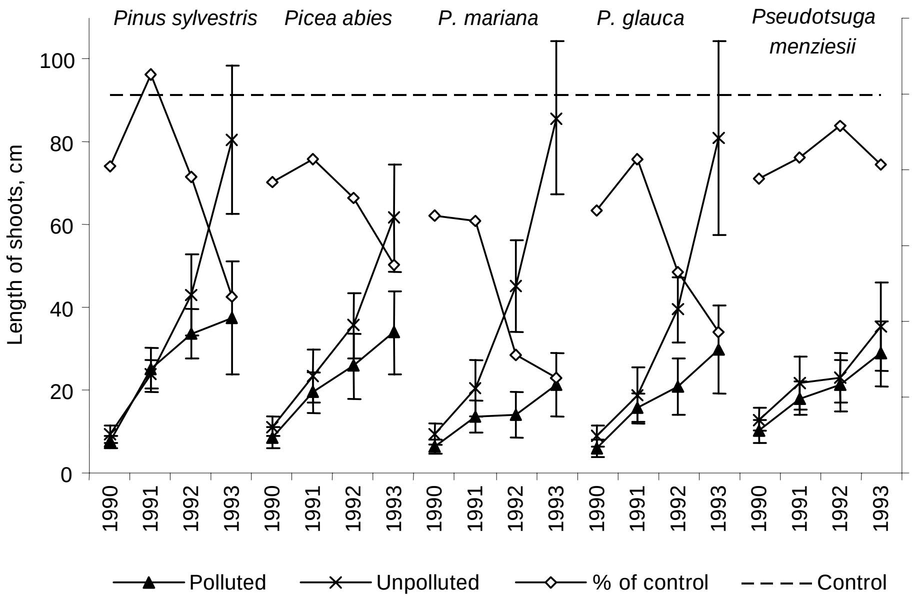

Figure 6. Comparison of the growth of conifers in the unpolluted area (control) and under the influence of cement dust (at a distance of 0.5 km from the cement plant) (±SD).

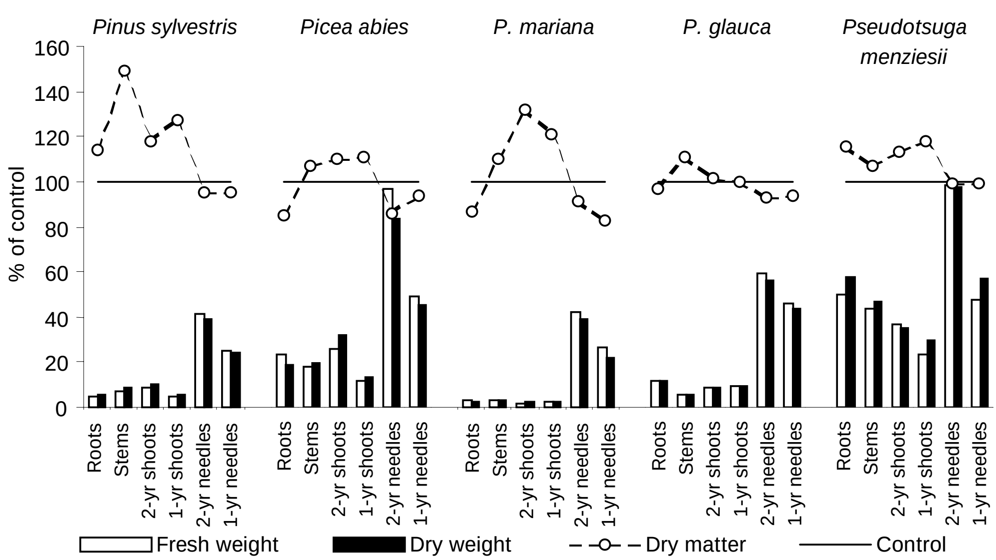

Figure 7. Comparison of the biomass and dry matter level of different organs of spruces in the polluted and unpolluted sites (% of control). 1-yr – one-year-old needles and shoots formed in 1993; 2-yr – two-year-old needles and shoots formed in 1992

growing in areas affected by alkalisation and dust pollution (correlation coefficients $r_{SS/N} = 0.68$, $p < 0.001$; $r_{SS/P} = 0.72$, $p < 0.001$; $r_{SS/Mn} = 0.61$, $p < 0.05$). In the trees damaged by dust pollution the content of carbohydrates and their allocation in the organism depend notably on the accumulation of the predominating elements of dust Ca, K and Mg into tissues.

Acknowledgements

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Table 2. Changes (% of control) in the means of measured parameters in different organs of species influenced by cement dust. Means in a column followed by the same letter(s) are not significantly different (p<0.05) according to Duncan's multiple range test. DW – dry weight, HT – hemicellulose

Species	DW	HT	N	Fe	K/P	N/P
Pinus sylvestris	14.8 b	94.6 b	97.6 c	236.5 b	135.5 b	88.4 b
Picea abies	38.1 c	76.5 a	65.5 a	277.2 b	109.9 ab	55.4 a
Picea glauca	17.7 b	98.7 b	84.1 bc	234.1 b	146.7 b	97.7 b
Picea mariana	7.4 a	93.2 b	91.6 bc	289.3 b	101.3 a	68.3 ab
Pseudotsuga menziesii	69.1 c	75.3 a	78.7 ab	124.3 a	142.0 b	78.0 ab

Table 3. Changes (% of control) in the means of measured parameters of organs in different species influenced by cement dust. Means in a row followed by same letter(s) are not significantly different (p<0.05) according to Duncan's multiple range test. DW – dry weight, DR – dry matter

Parameter	Root	Stem	Shoot	Stem needles	Shoot needles
DW	11.4 a	10.7 a	11.8 a	57.7 b	62.4 b
DR	98.6 a	115.8 b	114.5 b	91.3 a	93.4 a
SS/ST	52.7 a	61.2 ab	85.3 ab	102.3 b	106.5 b
P	66.9 a	90.0 a	96.1 a	149.4 b	175.8 b
K	110.7 a	125.9 a	118.8 a	192.6 b	149.6 a
Fe	49.9 a	164.6 b	296.2 c	429.8 c	527.5 d
Total	51.9 a	203.6 b	253.7 b	307.4 b	283.6 b
Ca/P	276.2 b	284.1 b	307.5 b	206.9 a	153.7 a
K/N	153.3 a	145.1 a	132.3 a	235.3 b	177.6 a
K/P	165.5 c	139.9 b	123.5 b	129.0 b	85.1 a
N/P	108.0 b	96.4 b	93.4 b	54.8 a	47.9 a

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THE RECOGNITION PROJECT

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ABSTRACT

Background, objectives, approaches, and organisation structure of the research project RECOGNITION are presented. In the project, the causes and consequences of the increased growth of forests in many European regions during the recent decades will be investigated. Concerning potential causes, primary focus is set on the relative importance of nutrients (particularly N and CO_2), climate, and land-use changes. Two research approaches are combined in the project: (i) A correlative approach, based on multivariate analysis of existing, available data describing growth, nutritional status, and other environment variables (e.g. climate variables) of various European forest stands, and (ii) a modelling approach, where models on different scales of forest ecosystems (physiological models, population models, ecosystem/tissue models) will be applied to conduct scenario analyses. Among probable consequences, site-specific risks for forest sustainability will be analysed and adequate future management strategies will be developed. RECOGNITION shall be carried out over three years, starting in April 1999, involving 5 project partners and 17 associated partners. In total, researchers from 12 European countries will co-operate. The project co-ordinator is the European Forest Institute. The project was proposed to the European Union (FAIR programme) for funding.

Keywords: cause analysis, consequences, growth change, European forests, research project

1. BACKGROUND

In many European regions, forest growth has increased considerably during recent decades (Spiecker et al. 1996). Also, various factors which influence growth and vitality of forests as climate (Schönwiese and Rapp 1997, Menzel 1997), atmospheric CO_2

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concentration (Fricke and Wallasch, 1994) atmospheric N and S deposition, soil chemistry (pH, base cation supply, C/N ratio; von Zezschwitz 1985, Hallbäcken and Tamm 1986, Hildebrand 1994, Prietzel et al. 1997) and forest nutrition (cf. Prietzel et al. 1997) have changed significantly during the past decades and are probably still changing at present. In densely-populated areas of Europe, forests often have been utilised or exploited for centuries for various purposes (e.g. forest pastory, resin production, litter raking; cf. Glatzel 1999). This resulted in nutrient depletion and/or a reduced vitality of the respected ecosystems. After devastative forest utilisation had been stopped, the ecosystems have recovered. Besides atmospheric deposition, this recovery at many sites contributes to the observed recent changes in soil chemistry, stand nutrition and forest growth.

The general growth increase of European forests as well as the observed levels and trends of important climate and deposition variables show a considerable regional variation (cf. Barrett and Berge 1996, Schönwiese and Rapp 1997). Concerning the spatial pattern of recent changes in soil chemistry and forest nutrition, at present only limited information is available. This is due to the fact that most of the currently-existing plots (e.g. those of the level II network) to identify and quantify these changes have been set up not earlier than 5 to 10 years ago.

Thus, the discussion of interrelationships between recent changes of forest growth, forest nutrition, and climate is currently based on insufficient information. There is an urgent need for further research concerning this issue. The complex nature of the problem requires a close co-operation of forest yield scientists, forest soil and nutrition scientists, and forest ecophysiologists.

2. OBJECTIVES AND WORKING HYPOTHESES

The research project RECOGNITION project investigates the relationships between recent changes of growth and nutrition of Norway spruce, Scots pine and European beech forests in Europe. Its *major aims* are to:

- identify the potential causes for recent growth trends in Europe and to investigate their interactions with focus on the relative importance of nutrition, climate, and land-use changes,
- focus on growth analyses on selected sites where conditions and availability of historical data allow testing of specific hypotheses and models about changes in site productivity,
- analyse the long-term consequences and risks of observed changes for sustainability and to assess the implications of future management strategies.

The basic *working hypotheses* are (concerning the causes for recent growth changes of European forests):

- Changes in site productivity can be accounted for by trends and spatial patterns of anthropogenic N, S, and H^+ deposition interacting with different site

conditions as e.g. inherent soil N availability, availability of other nutrients or water, and the nutritional status of the stand.
- Changes in the availability of N, P, and base cations are not sufficient to explain changes in site productivity. CO_2 concentration is also important. Furthermore, silvicultural management and land use history (e.g. nutrient depletion by litter-raking and forest pastory) may also be of relevance at some sites.

Concerning the consequences for recent growth changes of European forests, the basic working hypotheses are:

- Increase in growth will continue to 2100 as CO_2 concentrations and temperature increase.
- Precipitation changes in the future will significantly modify growth trends.
- Some sites in Europe may be able to maintain increased tree growth with no adverse effects but on others tree growth may encounter severe site limitations.

3. RESEARCH APPROACHES

The work content of the RECOGNITION project comprises the combination of two different research strategies. One strategy (*Correlative Approach*) is based on multivariate correlation analysis (e.g. multiple regression with measured parameters or synthetic factors/principal components as input variables) of existing, available data describing growth, nutritional status, and other environmental variables (e.g. climate, deposition) of various European forest stands. Stands consisting of the main tree species Norway spruce (*Picea abies*), Scots pine *(Pinus sylvestris)*, and European beech *(Fagus sylvatica*) will be studied.

In the *Historic Development Investigation (HDI)*, data from long-term (>20 yr.) time-series describing growth and nutrition of European forest stands (e.g. control plots from ca. 50 forest fertilisation experiments) are used to identify recent **temporal** patterns of changes. In addition to existing growth or yield data, the growth of the respected stands will be assessed retrospectively, using dendroecological methods. In the *Present State Analysis (PSA)*, **regional** patterns of forest growth trends are also assessed retrospectively by Prof. Spiecker, who is one of the RECOGNITION partners and related to regional patterns of present stand nutrition, soil chemistry, important climate variables, deposition, and other important site variables. Besides data from various European forest element cycling studies (e.g. Farabol, Höglwald, Solling, Tönnersjöheden), the level II network of the UN/ECE (cf. De Vries et al. 1997) would constitute a particularly promising basis for PSA, since it comprises more than 600 plots all over Europe, and since at all plots all variables are measured using standardised methods. The data set will be analysed after adequate stratification and / or according to gradients of probably important growth-determining variables (e.g. N deposition, foliar N levels). Combination of HDI and PSA is a powerful tool to assess past and recent interrelationships between forest growth, forest nutrition, site fertility and climate in European forests.

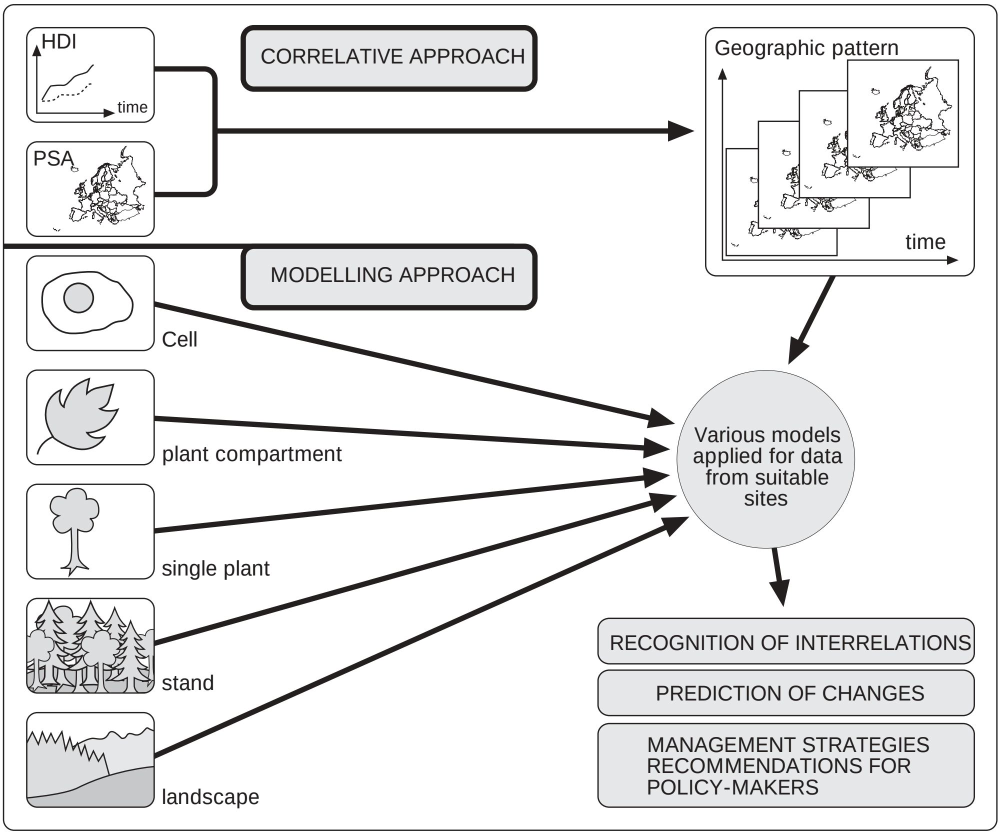

Figure 1. Schematic view of the research concept of the RECOGNITION project.

In the *Modelling Approach*, models on different scales of forest ecosystems (physiological models, population models, ecosystem/tissue models) will be applied to data from suitable studies of the Correlative Approach to conduct scenario analyses. Furthermore, the Correlative Approach and the Modelling Approach will be combined to compare the results of the scenario analyses with recent trends measured in European forest stands. Finally, sustainability prognoses as well as management recommendations will be derived (Figure 1).

4. ORGANISATION STRUCTURE

The RECOGNITION project is carried out over three years (from April 1999 to March 2002) by 5 Project Partners from Finland, Germany, Sweden, and the UK, who are

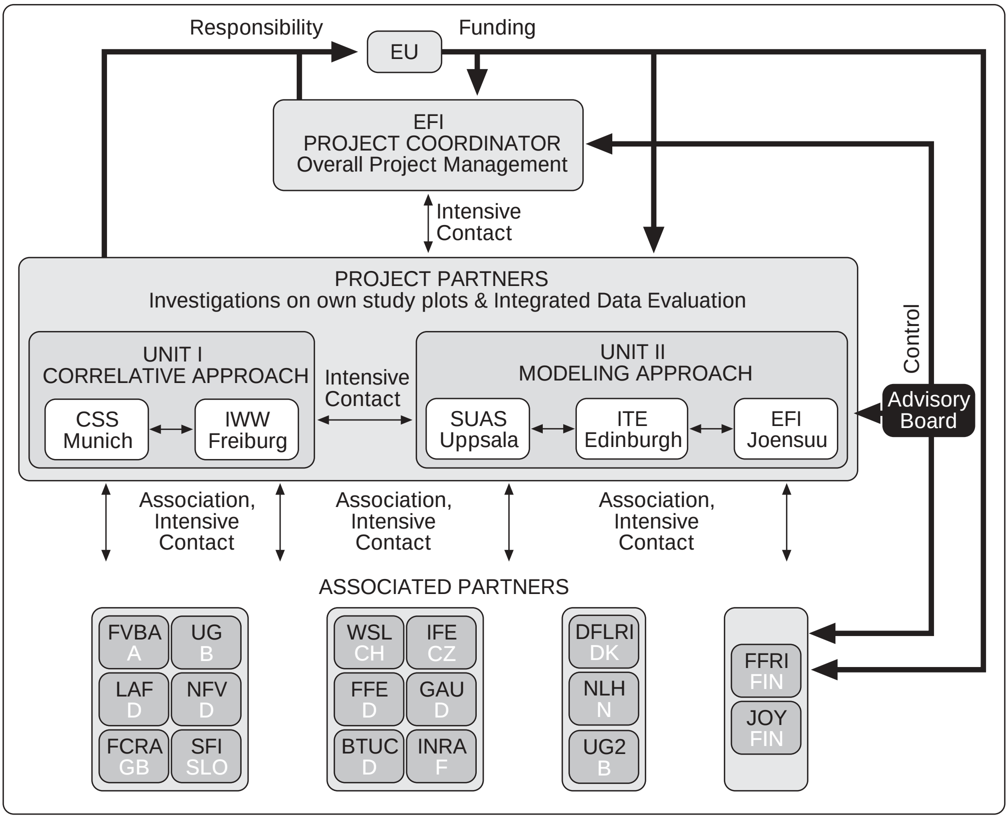

Figure 2. Organisation structure of the RECOGNITION project.

responsible for major project tasks. 17 research groups contributing results from regional studies will be Associated Partners (Figure 2). In total, 12 European countries will participate at the RECOGNITION project. The Project Partners investigate their own study plots and are in addition in charge of the integrated data evaluation. Unit 1, consisting of the Institute for Forest Growth, University of Freiburg/Germany [IWW] and the Chair of Soil and Site Science, University of Munich/Germany [CSSS] is responsible for the conduction of the Correlative Approach. Unit 2, consisting of the Institute of Terrestrial Ecology at Edinburgh /UK [ITE], the Swedish University of Agricultural Sciences at Uppsala/Sweden [SUAS], and the European Forest Institute at Joensuu/Finland [EFI], is responsible for the conduction of the Modelling Approach. Project Co-ordinator is the European Forest Institute. The research activities of all Project Partners and the Associated Partners as well as the general progress of the project will be supervised by an Advisory Board elected by all project participants.

Acknowledgements

The major part of Chapter 2 (the formulation of the project objectives and the working hypotheses) were taken from the RECOGNITION project proposal to the European Union written by Dr. T. Karjalainen (EFI).

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GROWTH TRENDS OF EUROPEAN FORESTS – WHAT CAN BE FOUND IN INTERNATIONAL FORESTRY STATISTICS?

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ABSTRACT

Information on forest increment in international forestry statistics collected by FAO and UN-ECE/FAO is based on estimates provided by the countries. The terms and definitions related to the statistics may or may not be consistent in different countries and they may have changed over the years. This paper illustrates the estimated forest increment in Europe and compares the available definitions in order to describe the growth trends of the forests in Europe.

Keywords: international statistics, growth trends, increment, definitions, defoliation

1. INTRODUCTION

In a study by Spiecker et al. (1996), it was shown that in many areas in Europe the increment of trees has been higher in recent years than in the past. This study utilised data from permanent sample plot experiments, data from inventories and sample tree data.

The aim of this paper is to investigate how visible such growth trends are in European forests by studying internationally collected forestry statistics. By 'international' forestry statistics we mean the reported forest resources information collected by UN-ECE/FAO, which has been compiled using national forest statistics and inventories as the basic source.

Such forestry statistics are primary sources of information not only to forest research but also to other forest related research disciplines. It is not the intention of this paper to analyse in detail the causes for changes in the growth trends of European forests but to investigate the possibilities and limitations of international statistics to serve as data sources for research questions such as the development of increment in Europe.

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The FAO forest resources information was first collected in 1947/48, since then at 5 year intervals (1955, 1958, 1963, 1970) and since 1970 it has been collected every ten years. The next upcoming Forest Resources Assessment will be available in the year 2000. The figures in this paper are based on these data (UN 1955; UN 1963; UN 1976; UN 1985; UN 1992), which have also been published by Kuusela (1994). Other 'international' statistics in Europe are collected by EUROSTAT (EUROSTAT 1995, 1998).

What can be seen from these statistics is that the total forest area in European countries (excluding the former USSR) has increased from 135.6 million hectares in 1950 to 149.3 million hectares in 1990, but the area of 'exploitable' forest, which does not include conservation forests, has been rather stable during the past 40 years. In that time period the growing stock of exploitable forest, however, has increased by 43% and the net annual increment by 55%. The recorded fellings have always been below the net increment. In 1950, the recorded fellings represented 96.4% of the net increment, in 1990 this figure was 70%. The natural losses information which has been firstly reported for the 1980 Forest Resources Assessment (UN 1985) have only increased slightly between the 1980 and 1990 assessment. Therefore, the forest balance has, according to the statistics, been positive during that period in Europe. This paper will discuss the possible reasons for today's high level of increment in international statistics.

1.1 Basic concepts

Firstly, it is important to clarify the basic concepts regarding increment statistics. *Gross increment* is the total increase of the *growing stock* during a given time period, consisting of the increment of those trees which were part of the growing stock in the beginning of the period, and trees exceeding the measurement threshold during the time period. The threshold level varies in different European countries, for instance, in Finland it is the diameter at 1.3 meters breast height, in Russia there is a minimum of 8 cm diameter at breast height, and in Switzerland this minimum is 12 cm.

The *net increment* is the part of *gross increment* excluding the trees which have died for natural causes during a given time period (*natural losses*).

Natural losses and *fellings* together constitute the *drain*. The difference between the gross increment and the drain is called *forest balance*. The forest balance shows the total change of the growing stock between two time periods, and it can be used to check the consistency of estimates of two successive forest inventories. The fellings are further divided into *removals* and *logging residues* (the part of felled stemwood which is left in the forest). The removals are transported out of the forest and have been recorded either as *over- or underbark* volume.

1.2 Reasons for changes

The possible reasons for changes in the net increment in the statistics over the years can be divided into three main groups. They can also be consulted to explain the differences in increment estimates between countries having similar growing sites and climate.

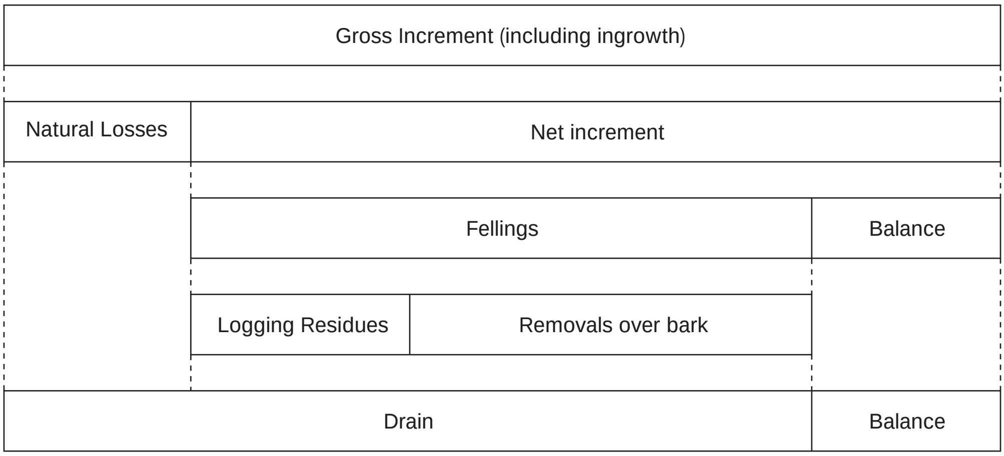

Figure 1. Components of balance (net change) of growing stock volume.

- Changes in *forest structure* will automatically cause changes in increment. The characteristics of the forest structure include the mean volume of growing stock, age class structure and tree species distribution. Traditionally, forest management aims at high wood production at a sustainable level by modifying the density of the stands, the distribution of age classes and the tree species composition. Silvicultural measures speed up the regeneration of forest stands and shorten the rotation periods. Thinnings of young and middle-aged stands decrease the amount of natural losses and minimise the differences between gross and net increments.
- The *definitions* of increment – or forest area or growing stock – may change. More accurate *measurement methods* can also alter the increment figures. One of the main reasons for the underestimation of the net annual increment has been the omission of the increment of those trees which were felled or had died during the period. For instance, in Finland and Sweden that component of increment was not taken into account in the national statistics before the 1960s. If the increment has been assessed using yield tables, the assessment method and the definition of growing stock volume and that of forest area, in particular, have an impact on the increment estimate.
- The third category are *environmental changes* affecting the increment. These can be considered ‘real’ changes and not consequences of alteration of the forest structure, the development of modified assessment methods or changes in the definitions. Changes in the environment are partly due to intensive forest management – like drainage of peatlands or fertilisation – but those of interest today are those in which human impact is indirect or not fully understood (Spiecker et al. 1996). The impacts of climate change and the deposition of different chemicals belong to this category. The impact of environmental factors can be identified only in cases where the impact of forest structure and definitions can be excluded.

2. CHANGES IN FOREST STRUCTURE IN EUROPE ACCORDING TO UN-ECE/FAO STATISTICS

2.1 Area, growing stock and net annual increment

The area of exploitable forest in Europe has not changed considerably since the first Forest Resources Assessment in 1950. It has increased by approximately 0.6 % in 40 years given the results of the latest assessment implemented in 1990 (Table 1).

The same accounts for the distribution of the coniferous and deciduous forest area. Conifers cover about 64% of the total forest area in Europe throughout all UN-ECE/ FAO Forest Resources Assessments.

In the same time period the growing stock, however, has increased from 13 billion m^3 in 1950 to 18.5 billion m^3 in 1990. This is a gain of volume in European forests of nearly 43%. A high increase volume occurred, for example, in Austria, France, FRG, Italy, Poland and Sweden. Only few countries show negative development between 1980 and 1990 (Albania, Greece, Portugal, Romania).

The net increment has increased even more rapidly than the growing stock. The gain of the net annual increment amounts to 55% in the 40-year period of the European countries reporting to UN-ECE/FAO. A large increase in the net increment can be found in Austria, Finland, France, FRG, Poland, Spain and Sweden. Only two countries have had a decreasing trend between 1980 and 1990 (Albania, Greece).

2.2 Age distribution

The age class distribution has been reported in the Resources Assessments of 1980 and 1990 (UN 1985; UN 1992). In general, a trend towards an increase in area in older age classes can be suspected from the country data. This trend, however, does not apply to all individual countries (Figures 2 a/b). A more detailed investigation of the data in selected countries shows that the change cannot only be detected in the applied forest management but also in the change of definition or inventory methodology. For example in Austria there is an increase towards older age classes. This is due to the fact that former classified protection forests are nowadays considered exploitable forest (Schwarzbauer 1994). These mostly old forests are the reason for the increase in forest

Table 1. Forest Statistics of European countries. (UN 1955, UN 1992; Kuusela 1994).

Europe*	Unit	1950	1990	change %
Total forest area**	mill. ha	135.6	149.3	+7.1
Exploitable forest area	mill. ha	132	133	+0.6
Growing stock	bill. m^3	13	18.5	+43
Net annual increment	mill. m^3	377	584	+55
% of conifers of growing stock	%	64	64	0

* Countries subject to this paper: Albania, Austria, Belgium, Bulgaria, Cyprus, Czechoslovakia, Denmark, Finland, France, FRG, GDR, Greece, Hungary, Ireland, Israel, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, Turkey, United Kingdom, Yugoslavia.

** Exploitable and unexploitable forest.

area > 120 years (Class 8). Figure 2a shows that Finnish forests are shifting towards younger age classes, 1-4 being <10-60 years (Metsätilastotiedote 354 1996).

A time span of 10 years for monitoring the age class structure in European countries through the official UN-ECE/FAO statistics is rather short. More data is needed to identify a trend in the development of the age structure throughout Europe. The forthcoming Forest Resources Assessment 2000, compiled by UN-ECE/FAO, which include age classes, will allow to draw a better picture of the age class development.

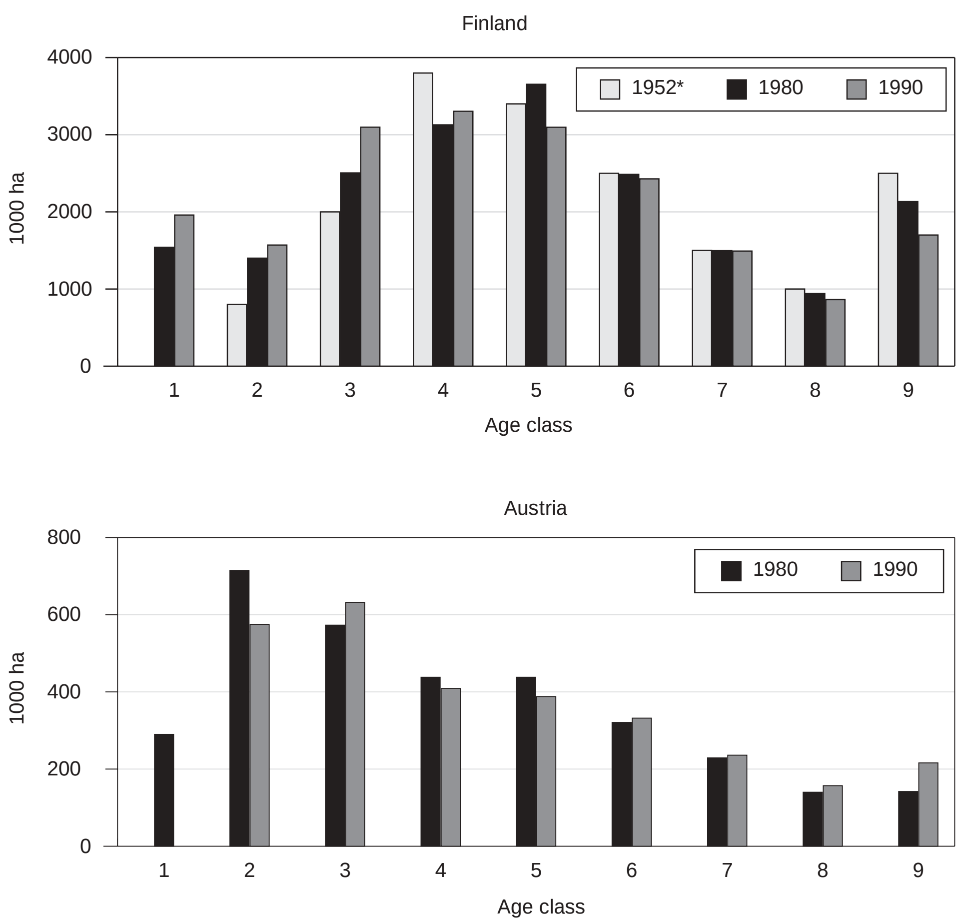

Figure 2a and b. Age structure development in Finland and Austria. (UN 1985; UN 1992; Metsätilastotiedote 354 1996).

(Age classes): (1) < 10 years; (2) 11-20; (3) 21-40; (4) 41-60; (5) 61-80; (6) 81-100; (7) 101-120; (8) 121-140; (9) >141.
Austria: 1980 class 1 data not available
Finland: 1952* Age classes 1 and 2 are not separated (aggregated in age class 2)

2.3 Net annual increment as a percentage of the growing stock

The increment percentage should in principal decrease when the mean age or mean volume are increasing. A calculation of the net annual increment as a percentage of the growing stock in exploitable forest of Europe showed only minor changes in the period of 1950-1990, despite the high increase in the net annual increment (Figure 3 a/b). At the individual country levels different trends can be observed. In general, the percentage is increasing slightly in the Nordic countries.

In Central Europe, especially in Germany (FRG, GDR), France and Italy, in particular, the percentage of the net annual increment of the growing stock has decreased. In the western Mediterranean region, particularly Spain, there has been an increase from 3.5% to 6.1%.

The question that arises is whether the increase in the increment and growing stock and a possible shift of age structure towards older age classes are reflected in the increment percentage. The rather parallel upward trend in both the net annual increment and the growing stock in Europe account for a stable increment percentage (Figure 3b). A likely change towards less middle-aged fast growing age classes would contradict this development and suggest a decrease in the increment percentage.

2.4 Development of net annual increment and natural losses in European forests

The net annual increment equals to the gross annual increment excluding nature losses (Figure 1). Natural losses estimates have changed very much according to a number of European countries between the 1980 and 1990 assessment (Figure 4).

In particular, Sweden had a 2.7 million m^3 decrease in natural losses corresponding to an increase of 25 million m^3 in its net annual increment. In Poland, the net annual increment increased about 2 million m^3 while the natural losses increased about 4.7 million m^3. A similar or an even more dramatic change in natural losses occurred in former Czechoslovakia. Natural losses increased from 0.2 mill. m^3 to 5.2 million m^3. The net annual increment remained consistent at approximately 17 million m^3.

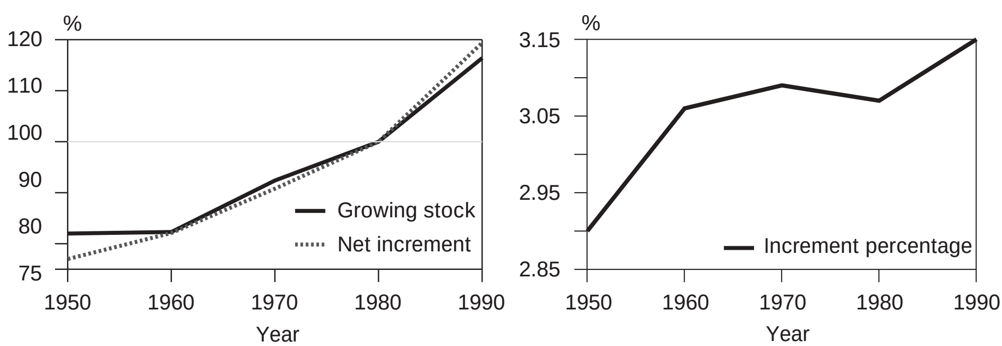

Figure 3a and b. Development of the growing stock, increment and increment percentage (1980 = 100%) between 1950 and 1990 in Europe. (UN 1955, UN 1963; UN 1976; UN 1985; UN 1992; Kuusela 1994).

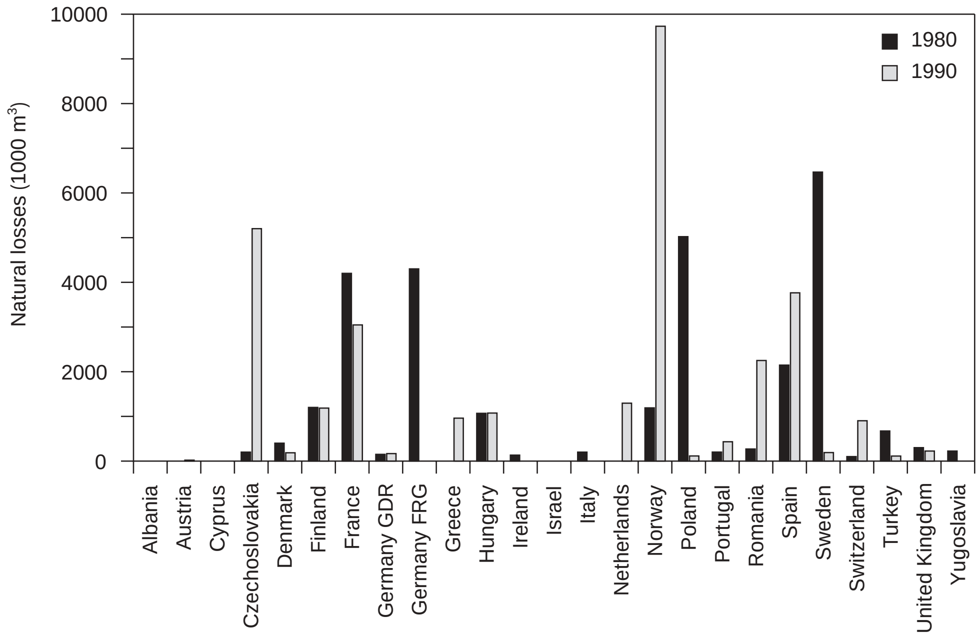

Figure 4. Natural losses statistics of exploitable forest in European countries in 1980 and 1990 (UN 1985; UN 1992) for a ten year period.

Trees which have died for natural causes have sometimes been collected from the forest afterwards. This may cause problems in reporting these as natural losses or/and fellings.

3. INTERNATIONAL AND NATIONAL DEFINITIONS OF EXPLOITABLE FOREST AREA, GROWING STOCK, ANNUAL NET INCREMENT

There are two levels of definitions for exploitable forest (forest in use), growing stock and the annual increment, that is, the international and national levels.

At the *international level*, FAO and UN-ECE/FAO definitions for growing stock and the net annual increment have not changed since the 1950s. The only addition to the net annual increment definition was a *'stated minimum diameter'* (UN 1992). The definition of exploitable forest, which defines the area for calculating the growing stock and the annual increment figures, has become less strict in 1990 compared with earlier assessments.

In 1990, *forest* was defined as: *'Land with tree crown cover (stand density) of more than about 20% of the area; continuous forest with trees usually growing to more than about 7 m in height and able to produce wood'* (UN 1992).
and *exploitable forest* as: *'Forest without legal, economic or technical restrictions on wood production'*

In 1960 the definition of exploitable forest was more concrete: *'All forest from which industrial wood, fuel wood, and/or other products are extracted and forest which are now being used intermittently'* (UN 1965).

The definition of exploitable forest has changed, but its area has only slightly increased during the period between 1960-1990 (Table 1). However, there have been some changes within the exploitable forest class; some exploitable forests have been converted to unexploitable, and some wooded lands or agricultural area to exploitable forests, respectively.

At the *national level,* forest area definitions and measuring methods vary widely in different European countries (Table 2).

The UN-ECE/FAO has implemented its assessments of forest resources in Europe based on its definition of *'forest'*. A question which could be asked is, whether the reported forest area statistics from the individual countries were adjusted to match the ECE/FAO definitions for each of the forest resources assessments. For instance Finland included "Forest land" and "Scrub land" in the figures for the UN-ECE/FAO statistics, the minimum potential production being $0.1 m^3/ha/a$.

The variables used to estimate the increment vary for single tree volume measurements (Table 2). Thus, the increment estimates can be expected to increase if, e.g. the starting point of the volume measurement methods change from stump to ground.

Measurement methods in the national forest inventories may also change over time. Improved national forest inventory systems provide better estimates but also make the time-series statistics inconsistent. For example, in Western Germany, ECE/FAO statistics showed a significant increase of the net annual increment from 34.0 million m^3 in 1980 to 50.9 million m^3 in 1990. The growing stock respectively doubled from 1100 million m^3 in 1980 to 2198 million m^3 in 1990. The 1990 estimates delivered to UN-ECE/FAO from West Germany were based on a new sampling system.

Another example of definition change and its effect on the increment statistics is that of the Finnish National Forest Inventory. The measurement of the dbh threshold had been altered from 2.5 cm to 0 cm in the 1970s. This resulted in a 0.7% increase in growing stock and a 2.1% increase of the gross increment (Kuusela and Salminen 1991)

4. ENVIRONMENTAL CHANGES

The impact of other factors than those mentioned above can be detected only if these are excluded. Another possibility is to assess indicators which may correlate with the attribute in question. For example, the Forest Health Monitoring Programme of the European Union (ICP-Forests) has successfully managed to set up a harmonised measurement programme covering 35 countries in Europe. Among the attributes measured, the defoliation of trees has been the best known.

The question arises if the assessment of defoliation can be utilised in estimating the growth development of trees in the different European countries. According to ICP Forests assessment, the development of defoliation in Austria, Finland, France and

Table 2. National forest area definitions and tree volume measurements (European Commission 1997).

Country	Forest area definition			Single tree volume		
	Minimum width (m)	Minimum crown cover	Minimum area (ha)	Minimum d.b.h., cm	Minimum top stem diameter, cm	Starting point of volume
FRA 1990*	-	20%		-As stated by the countries.		
Austria	10	30%	0.05	5	0	Ground
Belgium	9 m/ 25	-/20%	0.1/0.5	7	7	Stump
Denmark	20	-	0.5	-	-	Stump
Finland**	-	-	0.5	0	0	Stump
France	15	10% or 500 stems/ha with c.b.h. <24.5 cm	0.05	24.5 cm (c.b.h.)	7	Ground
Germany	10	-	0.1	7	7	Ground
Greece	30	10%	0.5	10	0	Stump
Ireland	10	20%	0.5	7	7	Ground
Italy	20	20%	0.2	3	0/3	Stump
Netherlands	30	20%	0.2	5	0	Ground
Norway**	-	-	0.1	12	0	Stump
Portugal	15	10%	0.2	5	0	Ground
Spain	20	5	0.25	7.5	7.5	Stump
Sweden**	-	-	0.25	0	0	Stump
Switzerland	25-50	100% to 20%		12	7	Ground
UK	50	20%	2	0	0	Ground

\- not applied
* UN-ECE/FAO Forest resources assessment 1990
** Minimum potential production 1 m^3/ha/a

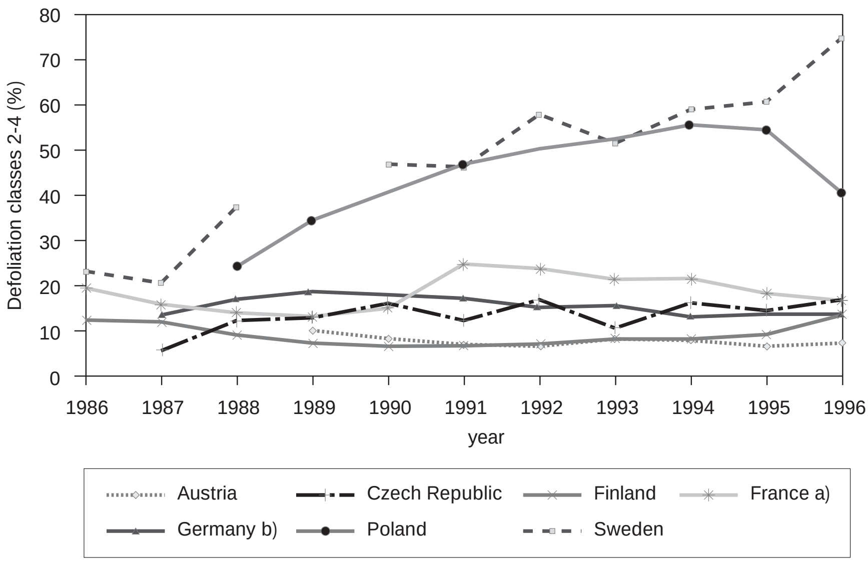

Figure 5. The share of defoliated conifers 1986-1996 in selected European countries in classes 2-4* (ICP Forests 1996; ICP Forests 1997).
* Damage class 2 (moderate defoliation); Damage classes 3 and 4 (severe and dead). a) 16x16 km network after 1988; b) For 1986-1990 only data for former Federal Republic of Germany.

Germany are showing rather stable percentages (ICP Forests 1996; ICP Forests 1997). In 1996 Austria had the lowest percentage of trees in the damage classes 2-4 (7.3%) meaning moderate, severely damage and dead. In Germany and Sweden this percentage is nearly 17%. In Czech Republic and Poland the defoliation of conifers had been constantly increasing since 1987, Czech Republic reaching the highest percentage in 1996 (74.9%). Poland had its peak in 1994 (55.6%) and since that year has been declining to 40.5%.

A closer look at the increment development of Poland and Czech Republic (Figure 6) shows a slow but steady increase of the net annual increment in Czech Republic. The Polish increment decreased between 1970 and 1980 but increased steadily until 1995 reaching 34.2 million m^3 (LAS 1997). The area of exploitable forest has only expanded very slightly in the two countries.

However, both Poland and Czechoslovakia show high annual natural losses according to the UN-ECE/FAO figures from 1980 and 1990 presented in Figure 4 but at the same time as seen in Figure 6 a slight increase in net annual increment in those countries. A similar trend in an increase of natural losses, but at a much lower magnitude, could be observed for Norway, Spain, Switzerland and Turkey. In the available national statistics of Czech Republic, damaging agents such as abiotic agents and insects infestations are responsible for the main amount of the annual salvage fellings (Figure 7).

Natural losses and salvage fellings have most likely occurred in old forests, indicating that young, fast growing forests should be compensating the loss in net annual increment. The official UN-ECE/FAO statistics on age class distribution show only rather minor changes between 1980 and 1990 (UN 1985; UN 1992).

In summary, Figure 5, which had been derived from IPC Forests data, showed an apparent increase in defoliation of conifers in both Czech Republic and Poland. A similar trend could be observed for broadleaved species but at a lower rate since first

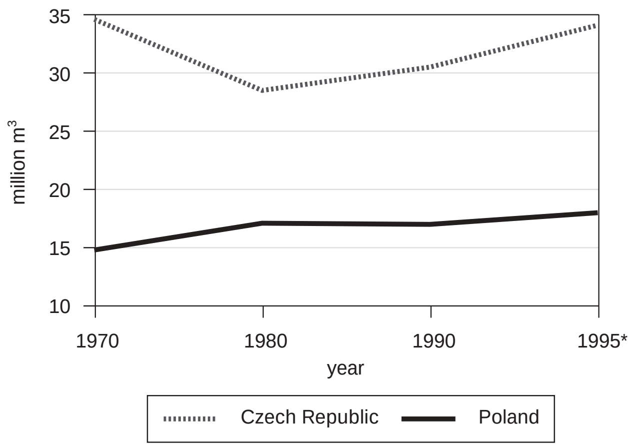

Figure 6. Net annual increment development in Czech Republic and Poland in million m^3 (Report on Forestry…1996; UN 1976; UN 1985; UN 1992; LAS 1997).
*The net annual increment for Poland in 1995 has been calculated as an average of the increment figures from 1990 to 1995 utilising national statistics (LAS 1997).

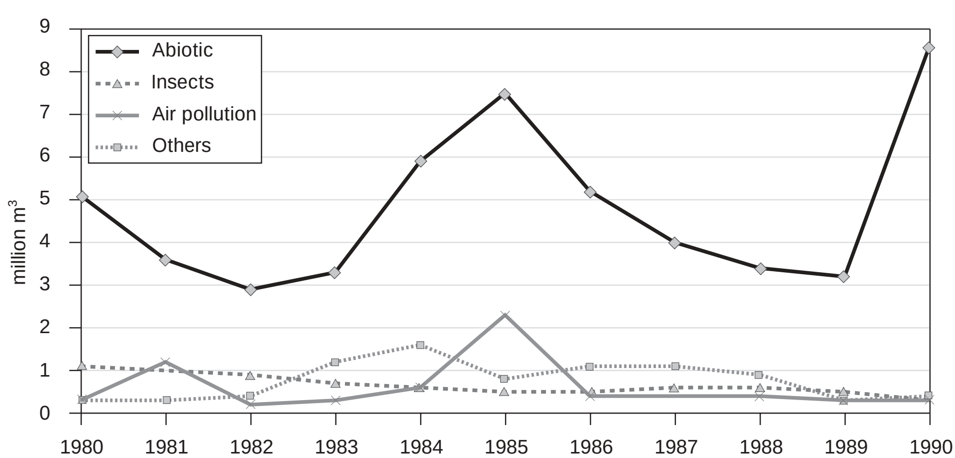

Figure 7. Salvage fellings by damaging agent in the Czech Republic 1980-1990 (Report on Forestry…1996).

monitoring the defoliation rate. Official international statistics show an increase in the total net annual increment, thus meaning that defoliation and total net increment in the countries can not be directly linked. For a thorough investigation of the causes sources other than the international statistics have to be taken into consideration.

5. CONCLUSIONS

According to the available statistics, it is evident that the net and gross increment of European forests has been increasing during the period from 1950 to 1990. Changes in the definitions and measurement methods used in the countries most likely supplement to exaggerating the increase of the increment found from the international statistics. A substantial part of the increase is due to intensive forest management, aiming at higher wood production. Up to a certain biological maximum, a higher growing stock contributes to higher increment figures.

As this paper focuses mainly on the available international forestry statistics, the possible influence of other factors contributing to an increasing increment cannot be excluded, as can, for instance, the influence of environmental changes. Thus it can be concluded that a thorough analysis of causes of increasing increment is not possible using available international statistics.

In order to analyse the growth trends using the statistical data in the future, the following recommendations can be made for further developing the international statistics:

- The development of the forest structure (especially those attributes related to increment) should be collected with sufficient accuracy and details.
- The methods of data collection/reporting should be made comparable between the countries and consistent over longer time periods. If the original estimates are not consistent, they should be converted into a comparable format for the international statistics.
- Effective indicators should be searched to estimate the status of the forests and their future development.

The development of the growing stock and the increment in European forests according to international statistics will be an interesting topic to follow up after the release of the Forest Resources Assessment 2000 data. This will allow to continue the analysis of the increment development as carried out in this paper.

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ESTIMATION OF NITROGEN DEPOSITION ON 27 RENECOFOR PLOTS (FRANCE) FROM 1993 TO 1996

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ABSTRACT

Nitrogen bulk and throughfall deposition was measured from 1993 to 1996 on 27 sites, well distributed over France. Mean weighted maximum concentrations for $N\text{-}NH_4$ were 1.1 ppm in bulk (b) and 2.5 ppm in throughfall (t) and for $N\text{-}NO_3$ 0.59 and 1.82 ppm. Maximum deposition for $N\text{-}NH_4$ was 14.1 (b) and 13.7 kg ha^{-1} yr^{-1} (t) and for $N\text{-}NO_3$ 10.7 and 15.7 kg ha^{-1} yr^{-1} respectively. The lowest estimated critical loads for total mineral nitrogen, 0.2 keq ha^{-1} yr^{-1}, were exceeded 100% during the 4 years, both in bulk and throughfall. The highest critical loads, 1 keq ha^{-1} yr^{-1} were exceeded only in 10% (b) and 18% (t) of the cases (n=102, 27 stations x 4 years).

Keywords: atmospheric deposition, throughfall, nitrogen, nitrate, ammonium

1. INTRODUCTION

Nitrogen is one of the major nutrients found in soils (Bonneau 1995) and humus where it is almost entirely present in various organic forms, which are the only forms that allow the storage of nitrogen over the long term (Ulrich and Bredemeie 1993; Mackenzie et al. 1993). The nitrogen pool in the forest soils was created by accumulation and fixation from the atmosphere over several hundreds or thousands of years. However, nitrogen cannot be absorbed in its organic forms by the roots of most of the important temperate tree species (Plassard et al. 1997). Before it can be absorbed, nitrogen must be mineralised either by means of enzymes directly emitted by the tree roots (low percentage of total mineralisation) or by means of saprophyte myceliums or ectomycorhizas (most of the total mineralisation) (Plassard et al. 1997).

The two main mineral forms which can most easily be absorbed by the roots are ammonium (NH_4^+) and nitrate (NO_3^-). In the nutrient cycle of a forest ecosystem with no

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human impact, most of the needed nitrogen is provided by the mineralisation process. Natural background atmospheric input is estimated to be only 0.1 to 0.2 kmol ha^{-1} yr^{-1} (Ulrich and Bredemeier 1993). In the last few decades, however, increasing amounts of atmospheric mineral nitrogen have been observed:

(i) the main source of nitrate concentrations in rainwater is the emission of nitrogen monoxide (NO) from vehicles powered by internal combustion engines. The NO_2 formed after the first oxidation by ozone or other oxidants in the air can then be incorporated in water vapour, because it is soluble. There it is oxidised a second time, mostly by H_2O_2. NO_2 can also be oxidised by ozone in the air (Toupance 1987). The density of vehicle traffic has been steadily increasing since the last century.

(ii) ammonium is mostly formed from ammonia given off by animal excrements from increasingly intensive pig, cattle and chicken breeding stations and from mineral nitrogen fertilisers (NH_4NO_3, etc.) (Draaijers et al. 1989).

These external inputs of nitrogen in mineral forms unbalance the nitrogen pools in forest ecosystems and may cause nitrogen saturation (Moldan et al. 1995), increase acidification and lead to related symptoms of dysfunctioning, partly due to accelerated growth which, in turn, can cause nutrient imbalances in trees in stands with poor mineral pools (Harrison et al. 1995). The objective of this paper is to:

- compare the major regional emission patterns for nitrate and ammonium with atmospheric mineral nitrogen inputs throughout France, measured on 27 of the 102 permanent plots (bulk and throughfall) of the French RENECOFOR-network (Ulrich 1995, 1997) and on 5 other plots (bulk only),
- compare the observed deposition levels with critical levels defined for Europe, thus allowing, in regions where levels are exceeded, to assume problems related to accelerated tree growth.

2. MATERIAL AND METHODS

2.1. Sampling sites

The sampling sites are all situated in large forested areas at distances of at least 4 km and up to 44 km from any one emission source, whether it be a cities or an industrial complexe. Diffuse agricultural sources are not analysed in detail because they are too numerous and too heterogeneous, even though their contribution to concentrations is quite important in several regions, as will be shown below. The locations of the 27 forest sites and of 5 other sites with open field measurements can be found in Figure 1 and a more precise description is given in Table 1.

For this paper, we preferred the use of bulk data instead of wet-only data for open field deposition, because bulk data are more meaningful for the study of nutrient cycles in forest ecosystems than the wet-only deposition. On an annual basis, wet-only deposition is known to be 20 to 30% lower than bulk deposition (Ulrich and Williot 1993). The differences are mostly due to local or regional influences, but the latter are exactly what we were searching for. Forest ecosystems accumulate the total load, not just the wet-only load.

The annual precipitation at the sites is representative of the range in France, varying from 681 mm in the Paris basin to over 3161 mm in the southern Cévennes at Mont Aigoual (site HET 30 on Figure 1), where annual precipitation can range from 2500 to 4600 mm from one year to the next.

2.2. Sampling

The data analysed were collected during 4 years, from December 30th, 1992 to January 1st, 1997. Weekly sampling was carried out every Wednesday by local foresters, who were given special yearly training. Weekly sampling is the highest frequency adopted in almost all forest ecosystem monitoring networks all over the world. In networks with a high number of sites it is a compromise between the loss by evaporation of a small percentage of the ions NH_4, NO_3 and SO_4, and the high cost of very frequent sampling (for example on an event basis).

Samples in open fields were collected using bulk samplers installed at a height of 1 m. The samplers consist of polyethylene funnels 20 cm in diameter. The funnel channels the precipitation directly into the sampling bottle, which is then sent to the laboratory. Inside the funnel, a small flexible polyethylene grid prevents insects from entering the bottle. At each site, two bulk samplers are installed making it possible to choose between two independent samples in case of contamination by bird droppings. No preservatives were used. Snow was sampled for analysis in special buckets, in which polyethylene bags were placed. The snow was melted at 6°C maximum in a clean room before taking a sample. After each sampling, the equipment was carefully rinsed with deionized water and dried. The vegetation at the sampling site was kept down in order to avoid contamination by high grass, etc. In all stations the distance from the samplers to the nearest obstacle was at least twice its maximum height (OMM 1990).

Throughfall samples were taken by means of 3 gutters (each 2.17 m long and 13 cm wide), with a total collecting area of ca. 0.85 m². The water coming from all the gutters was collected in up to three polyethylene barrels of 55 litres each. The same rinsing procedure was applied as for open field equipment. Snow was sampled with the same buckets as in the open field (n=4). After sampling, the bottles were stored locally in a special refrigerator at 4°C. Once every 4 weeks the samples were sent to the central analysis laboratory in Evry (Paris region).

Weekly precipitation was measured during the snow-free season by means of a standard precipitation gauge, developed by METEO-FRANCE (Cahier des Spécifications Techniques 1980), at a height of 1 m. In regions with snowfall in winter, precipitation was measured by means of totalisers (open field n=2 ; under forest cover n=6) at a height of 1.2 m. In these totalisers, an anti-freeze agent melted the depositing snow and allowed direct measurement of precipitation in mm.

Table 1. List and location of the plots where bulk and throughfall deposition was monitored.

Station[1]	Latitude	Longitude	Altitude (m)	4-yr mean open field precipitation (mm)	Nearest emission sources (km, direction from the station)
CHP 40	43°44’19’’ N	0°50’32’’ W	20	1121	Dax (17, W), Mont-de-Marsan (32, NE)
CHP 59	50°10’16’’ N	3°45’16’’ E	149	886	Cambrai (40, W), Valenciennes (24, NW)
CHS 35	48°10’41’’ N	1°32’01’’ W	80	841	Rennes (10, SW)
CHS 41	47°34’09’’ N	1°15’36’’ E	127	733	Blois (4, NE), Orléans (60, NE)
CPS 77	48°27’14’’ N	2°43’02’’ E	80	681	Fontainebleau (6, S), Melun (10, NW), Paris (48, NW)
DOU 71	47°05’35’’ N	4°05’10’’ E	650	1493	Autun (20, SE)
EPC 08	49°56’51’’ N	4°48’35’’ E	480	1368	Dinant (32, NNE), Charleville (18, S)
EPC 63	45°45’20’’ N	2°57’58’’ E	950	1186	Clermont-Ferrand (8, E)
EPC 74	46°13’42’’ N	6°20’58’’ E	1200	1408	Geneva (10, W), Thonon-les-Bains (20, NE)
EPC 87	45°48’00’’ N	1°48’55’’ E	650	1596	Limoges (44, E)
HA 057[2,3]	47°51’40" N	7°29’20’’ E	218		Mulhouse (16, SW) Bâle (32, SSE)
HA 305[2,3]	47°47’30" N	7°25’15’’ E	230		Mulhouse (6, SW) Bâle (30, SSE)
HA 380[2,3]	47°47’00" N	7°27’00’’ E	231		Mulhouse (8, W) Bâle (28, SSE)
HA 318[2,3]	47°39’30" N	7°29’00’’ E	255		Mulhouse (17, NW) Bâle (14, SSE)
HET 30	44°06’55’’ N	3°32’36’’ E	1400	3161	Montpellier (58, SE), Ales (42, E)
HET 54	48°30’35’’ N	6°42’23’’ E	325	920	Epinal (40, SW), Lunéville (18, NW), Nancy (38, NW)
HET 64	43°09’01’’ N	0°39’29’’ W	400	1402	Pau (28, NE)
PL 20	42°15’56’’ N	8°50’49’’ E	1100	1612	Calvi (34, NW), Porto (12, W)
PM 17	45°58’59’’ N	1°16’25’’ W	15	836	La Rochelle (20, N), Rochefort (28, E)
PM 40	44°02’46’’ N	0°00’02’’ W	150	959	Agen (52, NE), Mont-de-Marsan (44, SW)
PM 72	47°44’53’’ N	0°20’04’’ E	153	831	Le Mans (26, NW), Tours (46, SE)
PM 85	46°52’37’’ N	2°08’18’’ W	5	806	Nantes (56, NE), St. Nazaire (40, N)
PNP 65[2,4]					Lourdes (26, N), Tarbes (41, NNE)

[1] CHP = *Quercus robur* / CHS = *Quercus petraea* / CPS = mixture of CHP and CHS / DOU = *Pseudotsuga menziesii* / EPC = *Picea abies* / HET = *Fagus sylvatica* / PL = *Pinus nigra laricio corsicana* / PM = *Pinus pinaster* / PS = *Pinus sylvestris* / SP = *Abies alba*
[2] Measurements in open field only
[3] Measurements in 1996 only
[4] Measurements in 1994 and 1995 only

Table 1 (continued). List and location of the plots where bulk and throughfall deposition was monitored.

Station[1]	Latitude	Longitude	Altitude (m)	4-yr mean open field precipitation (mm)	Nearest emission sources (km, direction from the station)
PS 44	47°32’24’’ N	1°48’05’’ W	38	935	Nantes (34, SE), St. Nazaire (38, SW)
PS 67	48°51’01’’ N	7°42’39’’ E	175	823	Strasbourg (24, S), Haguenau (7, SE)
PS 76	49°27’14’’ N	0°44’53’’ E	70	925	Le Havre (40, W), Rouen (20, E)
SP 05	44°29’25’’ N	6°27’33’’ E	1360	1063	Gap (28, W)
SP 11	42°52’02’’ N	2°06’04’’ E	950	1210	Foix (40, W), Carcassonne (40, NE)
SP 25	46°58’34’’ N	6°27’42’’ E	1000	1644	Pontarlier (10, SE), Besançon (40, NW)
SP 38	45°25’17’’ N	6°07’53’’ E	1100	1527	Chambéry (24, NW), Annecy (54, N), Grenoble (34, SW)
SP 57	48°36’36’’ N	7°08’02’’ E	400	1327	Strasbourg (48, E), Nancy (68, W)
SP 68	47°56’01’’ N	7°07’31’’ E	680	1350	Colmar (12, NNE), Mulhouse (28, SE)

[1] CHP = *Quercus robur* / CHS = *Quercus petraea* / CPS = mixture of CHP and CHS / DOU = *Pseudotsuga menziesii* / EPC = *Picea abies* / HET = *Fagus sylvatica* / PL = *Pinus nigra laricio corsicana* / PM = *Pinus pinaster* / PS = *Pinus sylvestris* / SP = *Abies alba*
[2] Measurements in open field only
[3] Measurements in 1996 only
[4] Measurements in 1994 and 1995 only

2.3. Analysis

The "Laboratoires WOLFF" was selected to analyse the rain water because of their high quality standards of analysis. This laboratory is a private company which also analyses the French EMEP (European Monitoring and Evaluation Programme) and BAPMoN (Background Air Pollution Monitoring, world-wide) precipitation samples. It therefore participates in regular European and world-wide ring-tests. It also participated in the Italian ring-test, organised by the Istituto Italiano di Idrobiologia, Italy (Mosello et al. 1994).

The weekly samples were mixed at the laboratory with proportions calculated for each weekly sample, to give one representative weighted sample, the weekly precipitation quantity being in relative proportion to the 4-weekly quantity. Only one of the two samples collected each week was used to mix the 4-weekly mean sample, unless the quantity of one sample was too small to analyse all the parameters.

$N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ were analysed by ion chromatography according to the French norm, AFNOR T90-042 (1988), and to the international norm, ISO\CD 10304-5 (1995). The detection limit for the two ions are respectively 0.03 and 0.02 ppm with a reproducibility of 3-4% for concentrations ranging from 0.2 to 2.3 ppm.

3. RESULTS

3.1. Ammonium concentrations

Mean annual precipitation weighted concentrations are presented in Table 2. We can distinguish the regions with intensive agriculture from those with extensive agriculture by the different levels of ammonium concentrations. This is possible because ammonium is known to be a rapidly depositing ion, after its emission at ground level, because its dry deposition rate is high (Erisman and Bleeker 1997). Three greater regions can be distinguished (compare with locations of the sites in Figure 1):

(i) high concentrations in throughfall (mostly above 0.9 ppm) in the North-West (North of the line starting at PM 85, passing by CPS 77 and ending at EPC 08);
(ii) like (i) but in Alsace, in the North-East;
(iii) low concentrations South of the line in (i). This distribution was expected, even though concentrations near the Brittany region are much lower than expected. This might be due to the relatively long distances of our measuring sites (50-150 km) from the very strong emission sources of the numerous pigsties in the region.

Maximum monthly ammonium concentrations in the open field were measured near Le Mans (PM 72) with 22.7 mg/l $N\text{-}NH_4^-$ and in throughfall at Notre-Dame-de-Mont (PM 85), with 24.4 mg/l. The maximum mean precipitation weighted annual concentrations where found to be respectively 1.1 mg/l (EPC 63, in the Puy-de-Dôme department) and 2.53 mg/l (PS 76, near Rouen and Le Havre).

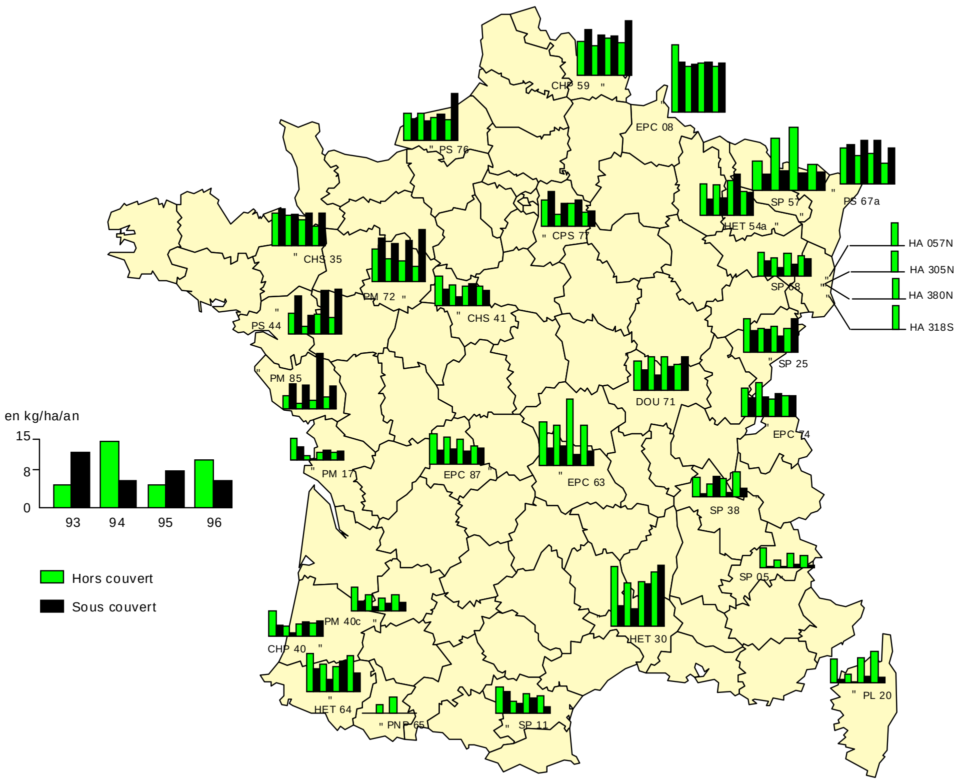

Figure 1. Annual ammonium (N-NH_4) deposition of bulk (grey) and throughfall (black) precipitation from 1993 to 1996 in the sub-network CATAENAT; values are in kg/ha/yr.

In the Meurthe-et-Moselle department, near Baccarat (HET 54a) and in Alsace, near Haguenau (PS 67a), a slight decrease in mean annual concentrations can be observed during the 4 years. No increase is observed at any of the stations.

3.2. Nitrate concentrations

It is more difficult to see spatial differences in the concentrations for nitrate, because the emission sources are more diffuse and the precursors as well as nitrate itself can be transported over longer distances. Therefore, only the sites which are most distant from large agglomerations show low concentrations in both bulk and throughfall. This is the case in Southern France, in the Landes (CHP 40 and PM 40c), at Mount Aigoual (HET 30), in the silver fir stands in the Isère department (SP 38), in the Hautes-Alpes department (SP 05) and in the pine stands in Corsica (PL 20). In all other stands mean annual precipitation weighted concentrations varied considerably during the 4 years.

Three cases where throughfall is significantly higher than bulk were observed, probably due to high dry deposition on the foliage: (i) in the Ardennes region (EPC 08), most likely

Table 2. Nitrate and ammonium mean precipitation weighted annual concentrations in bulk and throughfall precipitation from 1993 to 1996 (values are in mg/l).

Station	Bulk precipitation								Throughfall precipitation							
	N-NO_3				N-NH_4				N-NO_3				N-NH_4			
Station	1993	1994	1995	1996	1993	1994	1995	1996	1993	1994	1995	1996	1993	1994	1995	1996
CHP 40	0.29	0.22	0.23	0.26	0.50	0.18	0.25	0.24	0.42	0.33	0.44	0.21	0.31	0.08	0.40	0.39
CHP 59	0.50	0.37	0.52	0.52	0.79	0.71	0.79	0.84	0.42	0.30	0.47	0.35	1.28	1.11	1.02	1.74
CHS 35	0.31	0.26	0.31	0.29	0.83	0.62	0.64	0.60	0.56	0.47	0.33	0.47	1.32	0.93	1.13	1.48
CHS 41	0.50	0.24	0.35	0.36	0.93	0.53	0.47	0.68	0.64	0.50	0.41	0.56	0.73	0.29	0.75	0.74
CPS 77	0.35	0.29	0.46	0.46	0.79	0.34	0.62	0.51	0.44	0.74	0.75	0.67	1.34	0.90	1.01	0.90
DOU 71	0.24	0.22	0.24	0.29	0.45	0.41	0.44	0.45	0.72	0.53	0.74	1.19	0.37	0.23	0.41	0.74
EPC 08	0.46	0.40	0.41	0.56	0.97	0.70	0.66	0.91	1.28	1.36	1.02	1.55	1.03	1.02	0.98	1.43
EPC 63	0.25	0.24	0.26	0.31	0.86	0.62	1.12	0.78	0.84	0.65	0.85	1.32	0.69	0.49	0.37	0.60
EPC 74	0.25	0.50	0.24	0.29	0.40	0.54	0.24	0.32	0.62	0.76	0.47	0.81	0.42	0.54	0.44	0.48
EPC 87	0.39	0.22	0.22	0.25	0.43	0.30	0.31	0.30	0.62	0.39	0.48	0.82	0.35	0.30	0.34	0.51
HA 057	—	—	—	0.55	—	—	—	0.79	—	—	—	—	—	—	—	—
HA 305	—	—	—	0.54	—	—	—	0.72	—	—	—	—	—	—	—	—
HA 380	—	—	—	0.52	—	—	—	0.63	—	—	—	—	—	—	—	—
HA 318	—	—	—	0.56	—	—	—	0.75	—	—	—	—	—	—	—	—
HET 30	0.32	0.23	0.28	0.23	0.52	0.31	0.34	0.25	0.43	0.32	0.35	0.37	0.26	0.19	0.43	0.32
HET 54	0.41	0.41	0.43	0.50	0.80	0.69	0.65	0.65	0.90	0.66	0.88	1.11	0.65	0.58	1.10	0.97
HET 64	0.35	0.28	0.30	0.28	0.62	0.37	0.40	0.49	0.70	0.46	0.75	0.50	0.63	0.30	0.78	0.43
PL 20	0.26	0.22	0.26	0.24	0.33	0.12	0.32	0.33	0.46	0.34	0.38	0.28	0.05	0.01	0.12	0.08
PM 17	0.28	0.21	0.28	0.31	0.61	0.08	0.17	0.25	0.73	0.23	0.77	0.86	0.51	0.02	0.36	0.41
PM 40	0.30	0.25	0.28	0.29	0.50	0.34	0.31	0.35	0.28	0.18	0.40	0.35	0.27	0.11	0.25	0.24
PM 72	0.40	0.26	0.33	0.31	0.87	0.44	0.49	0.55	1.06	0.70	0.58	1.14	1.51	1.00	1.27	2.19
PM 85	0.28	0.18	0.25	0.25	0.38	0.11	0.22	0.33	1.51	1.10	1.57	0.80	1.10	0.82	2.22	0.89
PNP 65	—	0.17	0.18	—	—	0.15	0.23	—	—	—	—	—	—	—	—	—

Table 2 (continued). Nitrate and ammonium mean precipitation weighted annual concentrations in bulk and throughfall precipitation from 1993 to 1996 (values are in mg/l).

Station	Bulk precipitation								Throughfall precipitation							
	$N\text{-}NO_3$				$N\text{-}NH_4$				$N\text{-}NO_3$				$N\text{-}NH_4$			
Station	1993	1994	1995	1996	1993	1994	1995	1996	1993	1994	1995	1996	1993	1994	1995	1996
PS 44	0.21	0.18	0.24	0.30	0.54	0.15	0.37	0.46	0.69	0.41	0.46	1.06	1.57	0.60	1.20	1.95
PS 67	0.59	0.49	0.47	0.53	0.99	0.68	0.67	0.61	1.76	1.50	1.00	1.82	1.71	1.63	1.46	1.64
PS 76	0.39	0.33	0.47	0.45	0.59	0.50	0.54	0.60	0.56	0.72	0.75	2.32	0.66	0.56	0.98	2.53
SP 05	0.20	0.18	0.24	0.19	0.48	0.14	0.26	0.22	0.05	0.02	0.07	0.06	0.05	0.03	0.08	0.06
SP 11	0.31	0.22	0.25	0.22	0.55	0.22	0.32	0.24	0.92	0.35	0.58	0.37	0.61	0.26	0.37	0.11
SP 25	0.26	0.24	0.25	0.30	0.45	0.30	0.29	0.33	0.63	0.50	0.31	0.67	0.37	0.36	0.22	0.60
SP 38	0.28	0.23	0.25	0.35	0.30	0.18	0.22	0.35	0.11	0.11	0.14	0.29	0.10	0.38	0.07	0.16
SP 57	0.37	0.44	0.44	0.46	0.48	0.77	0.78	0.52	0.67	0.75	0.58	1.19	0.51	0.52	0.40	0.68
SP 68	0.31	0.25	0.24	0.34	0.43	0.28	0.28	0.40	1.08	0.48	0.46	1.15	0.60	0.28	0.30	0.67

Table 3. Observation in excess of permitted limits for drinking water for nitrate and ammonium concentrations in wet-only, bulk and throughfall precipitation.

Type of solution	Number of analytical results (1993-1996)	Number in excess of the limits for nitrate (maxi. in mg/l $N\text{-}NO_3$)	Number in excess of the limits for ammonium (maxi. in mg/l $N\text{-}NH_4$)	% of excess for ammonium compared to the total number of analytical results
Wet-only	350	0 (maxi. : 1,83)	193 (maxi. : 3,33)	55,1 %
Bulk	1485	0 (maxi. : 9,20)	853 (maxi. : 22,68)	57,4 %
Throughfall	1400	2 (maxi. : 13,85)	818 (maxi. : 24,38)	58,4 %
Stemflow	192	1 (maxi. : 15,05)	80 (maxi. : 17,48)	41,7 %
Total	3427	3	1944	56,7 %

because of the industrial environment and the high population density on the Belgian side of the border, (ii) in Alsace (PS 67a), because of high traffic density and intensive corn agriculture in the plain situated between Karlsruhe and Mulhouse and (iii) in the Vendée department (PM 85), where winds coming from the West, but turning to the East after having passed several major cities probably contribute to the higher levels (Zéphoris, M., 1996, Météo-France, personal communication). In all 3 cases, the nitrate peaks are associated with ammonium and sulphate peaks and sometimes with higher concentrations of all other cations, which indicates an enrichment by multiple sources.

A steady, but slow increase in annual nitrate concentrations was observed during the 4 years in the open field near Baccarat (HET 54a) and in the West of the Vosges mountains at Abreschviller (SP 57), and in throughfall at Brotonne (PS 76) and in the silver fir stand in the Isère department (SP 38).

3.3. Comparaison of ammonium and nitrate concentrations with the standards for drinking water

The French statutory order n°89-3 of January 3rd 1989 concerning drinking water defines acceptable limits for nitrate and ammonium. For nitrate the limit is 50 mg/l as NO_3 (which means 11.29 mg/l as N-NO_3) and for ammonium 0.5 mg/l as NH_4 (which means 0.388 mg/l as N-NH_4). Table 3 presents the number and percentages of observations in excess of these limits for the 4 weekly samples, analysed between 1993 and 1996.

Nitrate concentrations only rarely exceed the limits, whereas ammonium concentrations do so in more than 50% of the cases. This result indicates that rain water in France contains high concentrations of ammonium, largely originating from agriculture.

3.4. Ammonium deposition

The impression given by the mean weighted concentrations is slightly changed by annual deposition values. In some areas with low concentrations but high to very high annual precipitation the total load is high, with up to 14.1 kg ha^{-1} yr^{-1} on EPC 08 in bulk and 13.7 kg ha^{-1} yr^{-1} on HET 30 in throughfall (Figure 1). There is a spatial gradient between the Northern part of France with higher deposition, and the South. Exceptions must be made for the Mont Aigoual station (HET 30), the sites SP 25 and EPC 74 in the Alps and DOU 71 and EPC 63 in the Massif Central, due to their high to very high precipitation, although concentrations are low.

On 19 of the 27 sites, ammonium deposition is reduced in throughfall compared to bulk deposition. In the other 8 sites, ammonium dry deposition seems to be so important that the direct absorption in the canopy (up to several kg ha^{-1} yr^{-1}) is not sufficient to reduce the load in throughfall. Six of the 8 forests where this is the case are near or down-wind from regions with high animal production pointing to intensive animal farming the likely source of ammonia emission (Brun et al. 1989):

- Mormal forest (CHP 59), in the North
- Rennes forest (CHS 35), in Eastern Brittany

- in the Ardennes (EPC 08), in the North near the Belgian border
- Bercé forest (PM 72)
- Gavre forest (PS 44)
- Notre-Dame-de-Monts forest (PM 85), near the Atlantic ocean.

The site in the forest of Haguenau (PS 67a) is located in the Alsace plain, which is characterised by intensive agriculture. In the Fontainebleau forest (CPS 77), there are several possible explanations:

- an influence by emissions/erosion from the agricultural fields surrounding the forest,
- medium range transport from a large agricultural area called “Beauce“, situated to the West of the forest (in the prevailing wind direction),
- an influence by tourism (several million visitors per year in a forest of 17 000 ha)
- an influence by intensive horse riding activities in this forest (4 horse centres with ca. 200 horses in the area surrounding the permanent plot.

3.5. Nitrate deposition

The spatial distribution of nitrate deposition (Figure 2) is quite different from that of ammonium. The highest loads are observed on sites in the plume of major urban areas:

- the Ardennes (EPC 08), in the plume of Belgian agglomerations
- the North-Eastern quarter of France: PS 67a in the Alsace plain, HET 54a and SP 57 in the plume of the Paris basin and Nancy, EPC 74 in the plume of Geneva
- the Mont-Aigoual (HET 30), which receives ca. 60% of its precipitation from the Mediterranean region (Bézier-Montpellier-Nimes).

In general, annual deposition reaches no more than 4 kg ha^{-1} yr^{-1}, with maximum values of 10.7 (open field) and 15.7 kg ha^{-1} yr^{-1} (throughfall), observed at Mont Aigoual in 1996 due to an exceptionally heavy annual precipitation. The region “Provence-Alpes-Côte d’Azur“ was classified by the “Institut Français de l’Environnement“ as the second highest nitrogen oxide emitting region in France, after the Paris basin (Ifen 1995). We can therefore suppose that the concentrations at Mont Aigoual, while low, originate mainly from this region, as is the case for sulphate (important petrochemical industry around Marseille).

The only steady increase in nitrate deposition during the 4 years was observed in the Isère department in throughfall (SP 38).

3.6. Total nitrogen bulk deposition

Total nitrogen deposition best indicates those regions which are subject to high inputs and where forest growth might be influenced. The four-year averages for bulk deposition are shown in Figure 3. High inputs are mainly recorded in the North, the East

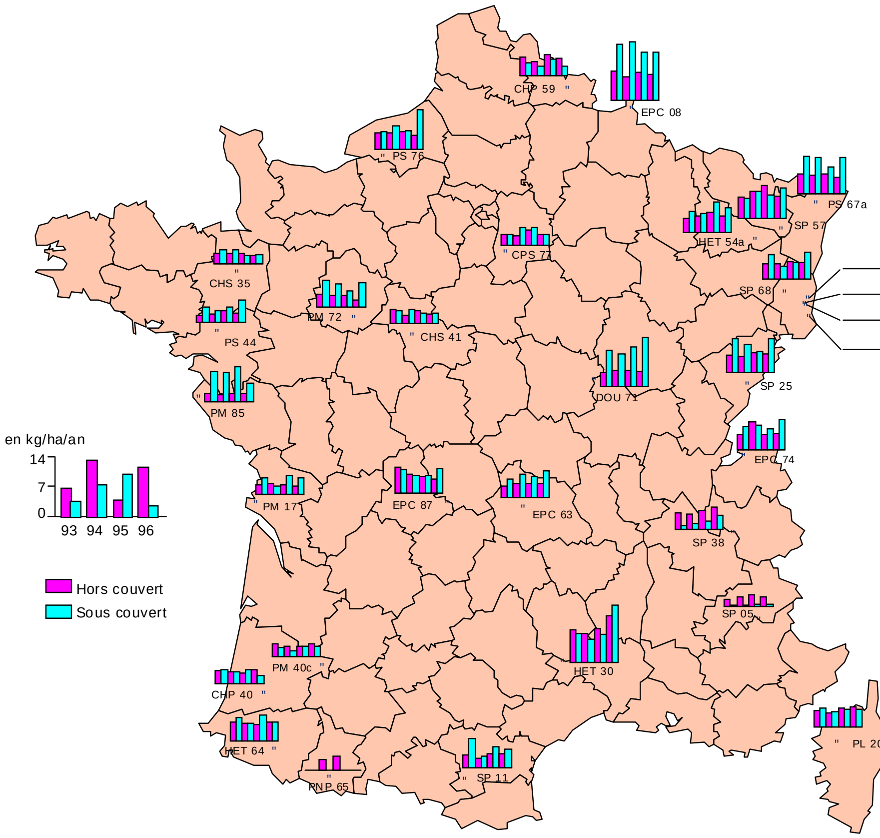

Figure 2. Annual nitrate (N-NO_3) deposition of bulk (dark grey) and throughfall (light grey) precipitation from 1993 to 1996 in the sub-network CATAENAT; values are in kg/ha/yr.

and in parts of the Massif Central. In fact, it would be more interesting to show total nitrogen deposition under the forest cover, but our calculations made using the model from Ulrich (1983) concerning canopy exchange processes, have not yet given results which enable us to estimate nitrogen dry deposition and absorption. Further calculations including other models will be made in the future.

3.7. Enrichment factors

In the case of nitrogen, enrichment factors (annual throughfall/bulk deposition) only have an indicative value, because nitrogen is strongly absorbed by the foliage. The range (minimum and maximum factors) are as follows: for NH_4 0.05 to 6.76 and for NO_3 0.08-4.19. This range shows strong absorption processes and at the same time, despite absorption, strong enrichment of throughfall deposition, as stated above.

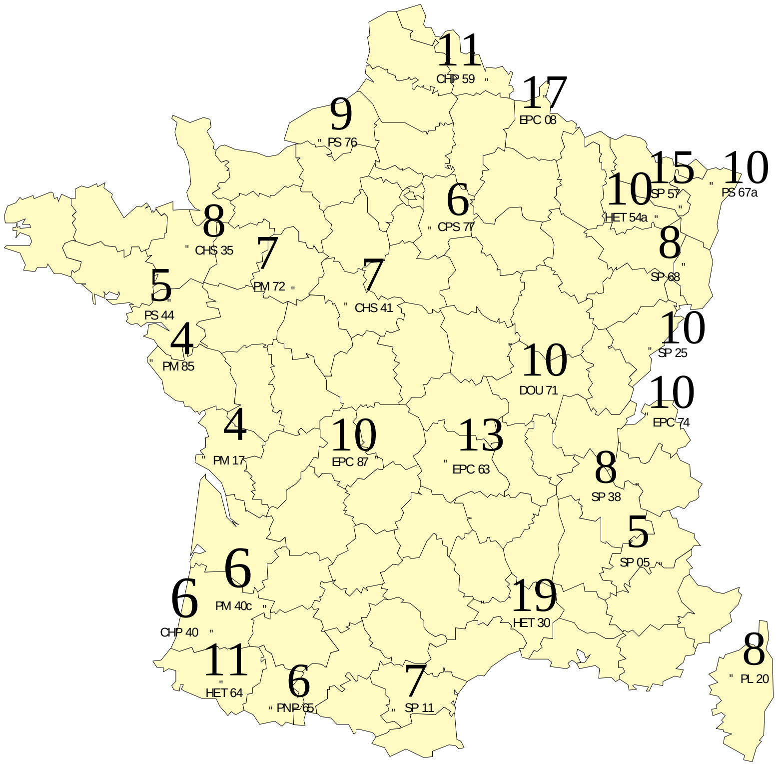

Figure 3. Mean total nitrogen deposition in bulk precipitation ($N\text{-}NH_4$+$N\text{-}NO_3$) during the period 1993 to 1996 in the sub-network CATAENAT; values are in kg/ha/yr.

3.8. Critical loads

Critical loads for nitrogen are defined as the maximum nitrogen deposition which does not cause eutrophisation or nutritional imbalance in any compartment of the ecosystem. A very general estimation of critical loads for total nitrogen ($N\text{-}NO_3$+$N\text{-}NH_4$) is give by Hettenlingh et al. (1991) for France: (i) 2.8 kg ha^{-1} yr^{-1} (0.2 keq ha^{-1} yr^{-1}) for nitrogen-rich ecosystems; (ii) 14 kg ha^{-1} yr^{-1} (1 keq ha^{-1} yr^{-1}) for nitrogen-poor ecosystems. Compared to the annual nitrogen deposition in the open field on the RENECOFOR plots, the lower limit is exceeded in 100% of the plots and the upper limit in 10%. Under forest cover, also 100% of the lower and 18% of the upper limit are exceeded.

In fact, this comparison is only indicative, because the calculations made by Hettenlingh et al. (1991) are based on very general spatial data in France. A more precise approach to the critical loads is presently under way by Party et al. (1997), who are using much more precise information on geology, geochemistry, vegetation cover and meteorology. When their work is finished, probably in 1999, a more realistic comparison with actual deposition will be possible.

Table 4. Throughfall deposition measured on 27 RENECOFOR plots, compared to other recent or older French deposition data and recent data from other European countries (non-exhaustive) ; values are in kg ha^{-1} yr^{-1}.

Reference	$N\text{-}NO_3$	$N\text{-}NH_4$	Throughfall precipitation (mm)
Vosges, spruce and silver fir period: 3/1989-3/1991 (Dambrine and Nourrisson, 1991)	2-13	2-11	583-1514
Vosges – Aubure, young and old spruce, period: 10/1988-9/1995 (Dambrine and Pollier, 1998)	6,2-12,4	2,9-6,2	920-964
Vosges, silver fir, period: 1993-1996, SP 57 et SP 68	3,1-6,8	1,8-4,2	540-919
Ardennes, spruce, period: 10/1985-9/1988 (Nys, 1991)	16-23	15-20	971-1169
Ardennes, spruce, period: 1993-1996, EPC 08	11,1-13,7	10,2-10,7	717-1026
Mont Lozère, beech and spruce, 1983-94 (Didon-Lescot, 1996)	3,6-19,5	2,9-12,5	958-2136
Mont Aigoual, beech, 1993-1996, HET 30	8,3-15,8	4,9-13,7	2010-4277
27 RENECOFOR stations, 1993-1996	0,2-15,8	0,1-13,7	532-2618
France in general, 1966-1990 (Ulrich and Williot, 1993)	1-33	0,8-33	—
Ireland, 4 spruce stands, period: 1991 à 1996 (Boyle et al., 1997)	0,9-9,4	1,4-9,4	846-1121
The Netherlands, Douglas fir, period: 1987-1993 (Erisman, 1997)	10,1-11,5	35,8-40,2	459-622
Bavaria in 1996, 16 stations, conifers and broadleaves (Preuhsler and Kennel, 1997)	3,7-13,5	3,7-14,2	414-1412
Austria, two oak coppice with standards stands, (Berger and Glatzel, 1994)	5,5-6,3	3,4-6,1	355-413

3.9. Comparison with other French and European data

The French throughfall deposition data from the above presented plots are compared in Table 4 to historical French data (Ulrich and Williot 1993) and to other stations near the permanent plots followed by scientists working on input-output budgets as well as to recent deposition data from some other European countries (non exhaustive).

In the Vosges mountains, the global range of nitrate and ammonium deposition measured on the RENECOFOR plots is lower than those measured between 1989 and 1991 in the regional network DEMENT (Dambrine and Nourrison 1990) on comparable silver fir and spruce stands, as well as in young and old spruce stands from the experimental watershed Aubure (Dambrine and Pollier 1998). The values within the DEMENT-network vary widely depending on the geographical location of the station. It is therefore possible that in different locations, deposition differs more or less strongly, partly due to major differences in annual precipitation depending on altitude (ranging from 700 to 2500 mm from the bottom to the top of Vosges mountains).

In the Ardennes region, near the Belgian border, the RENECOFOR plot is near a station which was followed for 3 years by Nys (1991). In our study, we measured a much lower range for both nitrogen compounds, up to 10 kg ha^{-1} yr^{-1} less for each.

In the Cévennes mountains we can compare the Northern part (experimental watershed of the Mont-Lozère, Didon-Lescot, 1996) to the Southern part (Mont Aigoual, HET 30), the two sites being 35 km in distance from each other. The Northern part receives only half as much annual precipitation as the Southern part, where there is a 4-yearly average of 3.161 mm. Despite this difference in rainfall, the Mont-Lozère has a proportionately higher nitrogen level than the Mont-Aigoual.

Compared to other European countries (Austria, Germany (Bavaria), Ireland, The Netherlands), the range of levels of RENECOFOR nitrate or ammonium deposition is quite comparable, except for the Netherlands. Ammonium deposition in the Netherlands can be considered to be the highest in Europe. The maximum French values reach only a third of their levels.

4. CONCLUSION

The objective of the RENECOFOR-network is to monitor possible long-term changes in forest ecosystems. The measurement of deposition leads to one of several ecosystem-related indicators. Atmospheric deposition is, with elementary N_2 fixation from the atmosphere by specialised plants or microbes, the only external source of nitrogen. In nitrogen-poor ecosystems, high external inputs of nitrogen are rather positive for their trophic level, but only if the rest of the mineral pools are sufficient to bear the rise in this level. The above results show that some of our poorest ecosystems might already be suffering from problems related to amounts of nitrogen in excess critical loads even though this does not seem to be the case for most of our monitored forests. Problems may also appear in the near future. Whether this is really the case will be studied more closely in the next few years by cross-relating analyse concerning different nitrogen-related indicators also monitored in the network (for example: inventory of flora, foliar nitrogen levels, soil nitrogen pools, different factors of nitrogen with other elements). Nevertheless it seems that nitrogen deposition is sufficient to stimulate growth in many French forest ecosystems, whatever the side-effects might be.

Acknowledgements

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GROWTH TRENDS IN EUROPEAN FORESTS – DO WE HAVE SUFFICIENT KNOWLEDGE?

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ABSTRACT

In addition to the so-called natural changes, environmental changes and human activities have altered forest growth for centuries. Many recent case studies indicate an increasing growth trend in European forests. The investigations are based on forest inventories, permanent plot and tree analysis data. The observed trends are species specific, which vary locally and are modified by remarkably wide periodic growth variations. On the European scale, species and site specific quantitative information about the extent and spacial as well as temporal variation of growth acceleration is lacking. Future growth may differ from past observations. A better understanding of the changes in site conditions, their causes and consequences is needed to guide sustainable management of European forests.

Keywords: growth trends, site productivity, European forests

1. FOREST GROWTH – AN INDICATOR OF ENVIRONMENTAL CHANGES

Forests are and have always been exposed to environmental changes. These changes are *natural* environmental changes as, for example, climatic variations or extreme climatic events followed by disturbances such as pests, diseases, fire, storm or snow. Environmental changes are caused by *human* actions as well as, for example, forest degradation due to pasturing and litter racking, and historical management practices such as choice of tree species and provenances, site preparation, weed control, regeneration methods, tending, thinning, liming, fertilization, amelioration, drainage and wildlife management. These influences may change forest ecosystems considerably. Today we have to acknowledge that human activities change the environment locally, regionally and globally. Land use history and forest management as well as climate

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changes, including changes in air temperature, elevated CO_2 and O_3 and also sulfur and nitrogen deposition are discussed as driving factors for growth changes. Site has to be considered as not being constant but changing with time.

Forest growth research is asked to give information not only on growth as a result of site and stand characteristics but also on the extent to which growth deviates from earlier observations. In the past it was often assumed that site specific growth patterns do not change significantly with time. Changing environmental conditions raises the question of whether site conditions, and as a consequence growth patterns have changed. The title of this seminar "Accelerating growth, causes and consequences" suggests accelerating tree growth is occuring in European forests. This paper describes aspects of recent research in forest growth and growth changes.

Growth responses of trees are indicators of environmental change in their spatial and temporal extent. They can provide information for large areas over long time periods. They are, however, by themselves not a sufficient tool for the diagnosis of specific causes. When we talk about forest growth we may think of total biomass production, tree growth including growth of roots, trunk, branches and leaves or wood volume growth per hectare. This paper will concentrate on wood volume growth calculated from tree diameter and height simply because these are the only data available over long time periods in many European countries. The following definitions are used:

- site: *totality of environmental conditions existing at a particular location;*
- site productivity: *wood production potential of a site for a particular species or forest type and*
- growth trends: *long-term site-induced deviations from former growth rates.*

This paper concentrates on site-induced deviations from expected growth. Other effects on forest growth data such as inconsistencies in inventory methods, changes in forest area over time, changes in species and age class distribution, and changes in silvicultural methods are taken into account.

2. EXISTING GROWTH DATA

2.1 Forest inventory data

The first national survey in Europe was carried out in Finland in the early 1920s. Today national forest surveys are conducted in most European countries. Many inventories are designed on a statistical basis (European Commission 1997). These inventories cover the forest conditions and the variability of forest stands and sites for the entire inventory area in a representative way. The sampling errors can be given for all estimated parameters when the same type of systematic sampling is used. As sample plots are typically laid out in a sample grid, forest inventory data can be regionalized, for example, with geostatistical methods. For further large-scale analysis of possible causes, data can be combined with other geo-referenced data such as climatic data, soil maps, or maps of atmospheric deposition (Spiecker et al. 1996).

Sample-based forest surveys are a rather recent concept for European forests. For most European national forest inventories only two or three survey cycles have been accomplished and long-term and medium-term growth data are not available. These national surveys have been designed independently and have different traditions and objectives. Besides the differences in the time period covered and the number of observations, major differences can be found in measurement rules for important attributes, such as forest area definition or volume estimation (Päivinen et al. 1999). The measurement methods might be modified with time, due to changed information needs and new experience. Changes through time might be partially related to the differences in definitions and may not totally reflect real changes. Inventory data are the most appropriate data to describe growth of large forests in a representative way.

2.2 Permanent research plot data

Many forest research organizations in Europe have established hundreds of long-term permanent plots. The earliest were established in the middle of the 19th century. The great advantage of long-term permanent plot data is the generally well-documented stand history. The trees within the plots have been numbered and the diameters of all trees as well as the heights of selected trees have been remeasured at certain intervals over a long time period. Also survivor growth, ingrowth, mortality and cut have been measured. The earliest permanent research plots generally were established to determine wood volume growth potential of a site for a particular species or forest type. Later, new research objectives were added: provenance trials, spacing and thinning trials, fertilizer trials etc. Disadvantages of long-term permanent plot data are the non-representativity due to insufficient replications, subjective implementation and low periodic time resolution.

Stand growth can be expressed as basal area, height or volume growth. Basal area growth is easy to measure, but is more influenced by silvicultural measures than height growth. Volume growth combines basal area and height growth, including stem form and its changes over time. A comparison of long-term volume growth is only valid if consistent methods for tree volume estimates are used.

If stand characteristics are estimated on the basis of models derived from periodical sample tree measurements, the number of sample trees must be adequate. The heights of stands are usually estimated from 20-40 sample trees. The previous selection of the sample trees has an influence on the results. Consistent methods have to be applied when changes in site productivity are investigated. Trees in different social classes may also show different growth trends. These trends, arising from natural stand dynamics, must not be misinterpreted.

Analyzing growth trends in mixed species stands is problematic due to differences in the growth rhythms of tree species and the continuously changing competition between them. Thus different species can show positive and negative growth trends in the same stand depending on tree age, species composition, type of mixture and site influences.

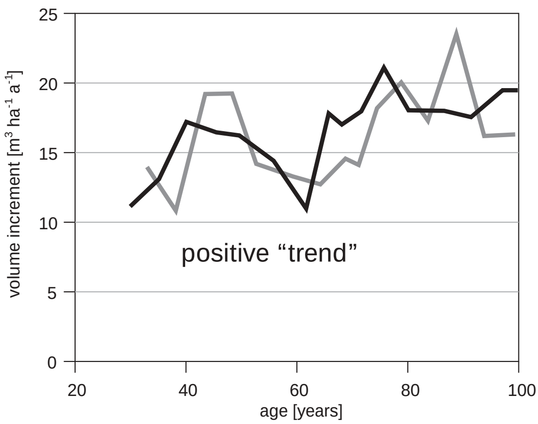

Figure 1. Positive trend of volume growth per hectare and year of a Norway spruce (*Picea abies* L. (Kast.)) stand on two adjacent long-term permanent plots (data source: Forest Research Station Baden-Württemberg, Germany).

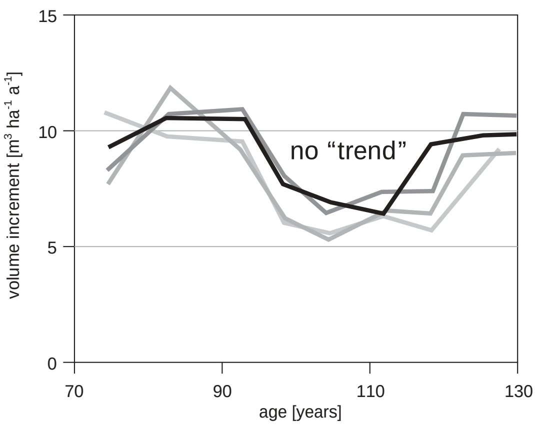

Figure 2. Periodic variation of volume growth of four differently thinned beech stands (*Fagus sylvatica* L.). The period of growth depression may last a decade and more (data source: Forest Research Station Baden-Württemberg, Germany).

2.3 Tree stem analysis data

The measurement of annual rings and shoots allows the reconstruction of tree growth over long observation periods with yearly time resolution on any site where forests are growing. As a result height growth, diameter growth, development in stem form and volume growth of individual trees can be described retrospectively. This source of data may be used when no long-term permanent plot data are available and/or a yearly time resolution of growth is required.

For the reconstruction of height growth, trees generally have to be cut. Annual shoot growth can be identified along the stem but it has to be checked by counting annual rings. When annual shoots are missing or more than one shoot per year has been identified the interval of ring checking along the stem has to be shortened. Some species do not develop annual shoots that can easily be detected. By cutting discs at short distances along the stem, height growth can be estimated by determining cambial age

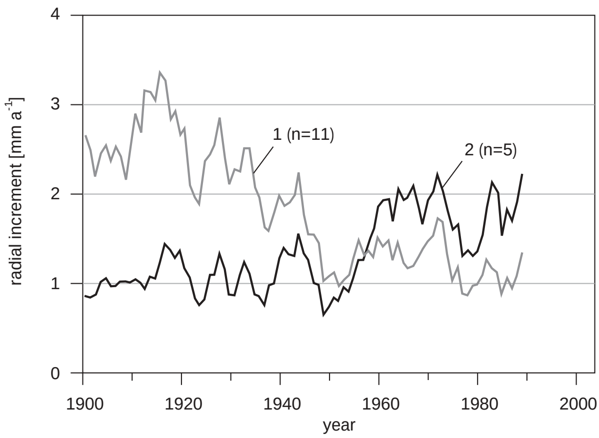

Figure 3. Differences in radial growth trends of Norway spruce caused by past competition: 1: wide initial spacing, little subsequent thinning (Kenk 1990) and 2: heavy release since 1930 (Spiecker 1992).

and height of the discs (Newberry 1991). Annual radial growth can be measured by cutting discs at predefined locations along the stem and by measuring annual growth along several radii in order to analyze irregular and eccentric radial growth. As an alternative increment cores can be used to measure annual ring width. Here the trees do not need to be cut but will be damaged and possibly infected by fungi.

A main problem with tree analysis data is that the stand history may not be known and that it is impossible to find individual trees which represent stand growth over a long-term period by their growth. Even all surviving trees in a stand may not represent past growth of the stand adequately (Spiecker 1992). Individual competition dynamics are influenced by the constellation of neighboring trees which may be modified by thinning operations, genetic and site induced differences in growth dynamics of neighboring trees, natural mortality or ingrowth. The population representing the stand is changing over time. Thus tree analysis does not generally allow a reliable reconstruction of the long-term basal area or volume growth of a stand. An example of management influences on radial growth is shown in Figure 3. This figure also shows the large year to year variability of radial increment (see also Becker et al. 1989, Spiecker 1986 and 1991).

Methods of detecting site-related growth trends from radial increment or ring width data of single trees has to include non-site factors, especially stand density and aging (e.g. Van Deusen 1987, Briffa 1992, LeBlanc 1993). To minimize competition effects, dominant trees should be selected. The growth reaction of dominant trees may however differ from the reaction of codominant and suppressed trees. The potential of tree-ring measurement lies in the precise reconstruction of the annual variability of increment. Events with strong effects on tree growth are rather easy to detect (Schweingruber et al. 1990). Tree-ring analysis has been successfully used especially in short and medium term dendro-ecological studies.

Data from height analysis may be used as indicators of site productivity. However, the reliability of this indicator has to be validated. The combination of tree analysis data with permanent research plot data provides an improved data base for detecting growth trends.

Combining single tree analysis data with periodically measured plot data helps to overcome some limitations of each of the two data sources. The combination may provide reliable area related annual growth values. In addition, systematic errors of periodic diameter measurements can be detected and eliminated (Spiecker 1991). The results of forest inventories in terms of species composition, or stand and site characteristics can be used as a basis for testing how representative observations on growth and yield plots are.

3. DETECTING CHANGES IN FOREST GROWTH

3.1 Detecting growth changes in forest growth by comparing the growth of trees and stands with different germination dates

Deviations of actual growth from expected growth indicates site productivity changes. As a reference of expected growth past growth of stands with similar characteristics on the same location or on sites with similar history and actual site characteristics may be used. Yield tables generally do not fulfill these requirements and therefore do not describe expected growth adequately. Growth trend estimation methods have been discussed by several authors (Zahner 1988, Cook et al. 1990, Van Deusen 1991, Dupouey et al. 1992, Spiecker et al. 1996). Further methodological information is given in many publications relating to growth effects caused by forest damage for example by McLaughlin and Bräker (1985), Lorenz (1987), and Deutscher Verband Forstlicher Forschungsanstalten, Sektion Ertragskunde (1988).

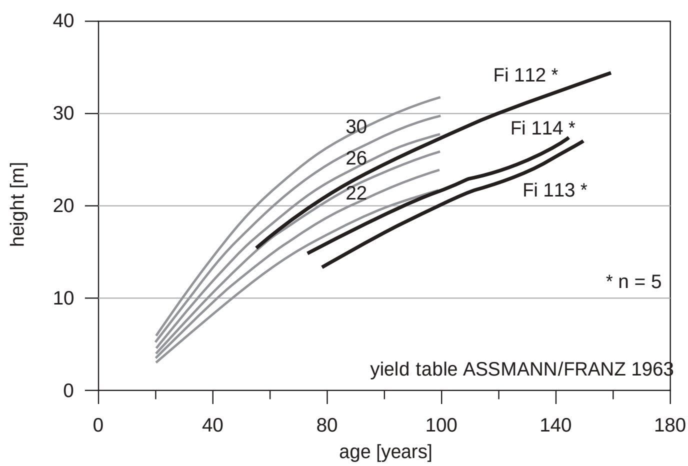

Figure 4. Height growth of dominant Norway spruce trees at three sites in the Black Forest. Height growth has increased in recent decades despite the old age of the trees (Kenk et al. 1991).

Changes in site productivity may be observed by analyzing height growth of old trees. Unexpected changes in growth rate may be caused by environmental changes or they may as well be the result of a site specific growth pattern. An example for changing growth patterns is presented in Figure 4.

Site induced growth trends are analyzed by comparing growth of stands with different germination dates. The following conditions must be fulfilled: site conditions at a given point in time must be the same; management practices must be constant over time, especially when diameter growth is used for comparison; genetics and stand structure of the compared stands should be similar and finally fluctuations in growth conditions such as unfavorable weather conditions have to be taken into account.

When individual tree data are compared, equal competitive regimes and site distributions in time must be represented by the data. Otherwise a possible trend cannot be found by the analysis. Examples for this method are described by Untheim (1996, Figure 5) using height growth data and by Abetz 1984, Becker 1989, Bert 1992, Schneider and Hartmann 1996 and Schadauer 1996 using tree ring data. Site classification at a single point in time is a problem in growth trend studies, because possible growth trends may be caused by site changes, such as soil succession and these changes are not characterized by this classification. The problem exists when site classification is based on height development as well as when plant communities in the stand are used as reference.

Comparisons between several site types may give a better insight into possible causes. For example, regional comparisons of site types with good and poor nutritional status could be helpful. Additional information could also be drawn from analyzing tree response to fertilization.

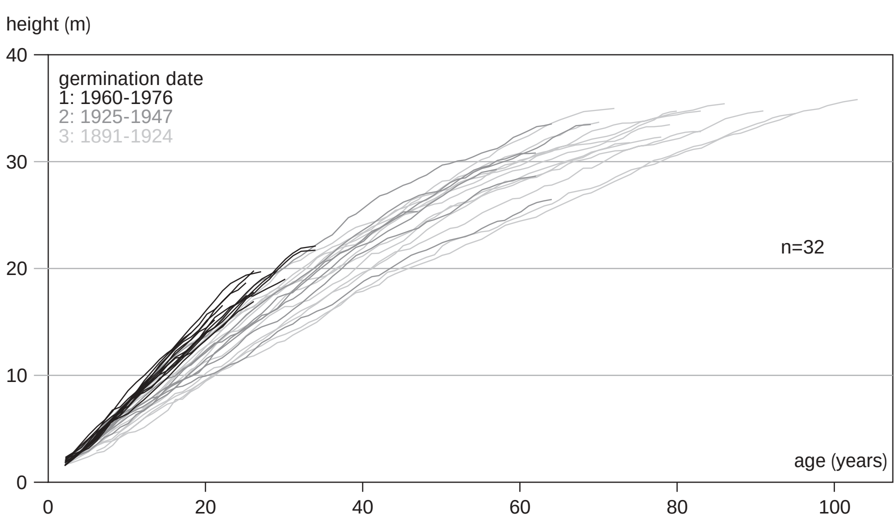

Figure 5. Height growth of Norway spruce with different germination dates at a Swabian Alb site. In earlier times trees were growing slower (Untheim 1996).

3.2 Detecting growth changes in forest growth by comparing the growth of successive generations

Growth patterns of successive generations on an identical geographical location have been compared by several authors (e.g. Kenk et al. 1991, Keller 1992, Eriksson and Johansson 1993). This is a straight forward approach for detecting site productivity changes. In cases where the second generation stand has not been measured, single tree height development data might be compared with research plot data of previous generations (Figure 6).

Interpretation has to consider aspects of management practices and genetic structure as mentioned in Section 3.1. In addition several consecutive generations of the same species might alter site productivity. If there are enough height data available from successive tree generations in a region, some kind of correction could be made by modelling the site index change as a function of time.

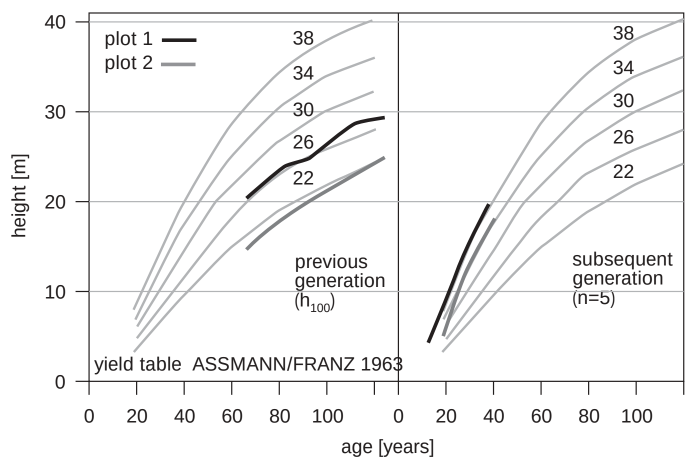

Figure 6. Dominant tree height growth of two successive Norway spruce generations on the same plot; h_{100}=mean height of the 100 thickest trees per hectare; in subsequent generation mean height of five dominant trees (source: Kenk et al. 1991).

3.3 Detecting changes in forest growth by comparing growth with yield tables or other growth models

Yield tables and other growth models are often used as growth references. For the interpretation of deviations from the reference the date base of these references must be known. The requirement listed in 3.1 have to be fulfilled when yield tables or other growth models are used for reference. Modeling single tree growth by using long-term constant factors such as topographic and edaphic characteristics and varying site factors such as weather conditions as predictor variables, enable comparisons to be made between past response and current response. Assuming that tree competition, genetic and aging influences are removed from the time-series, an altered response must be due to changing site factors. This method thereby allows a separation of expected reactions from unknown reactions.

The most difficult problem is related to detrending. There is no superior method of removing aging and competition trends. Analysis must be carried out carefully to avoid eliminating parts of the investigated long-term trend signal. No statistical theory explains how well the observed signal in tree rings estimates the expected signal. In most cases, we must rely on statistical measures of signal strength, frequency domain definitions of signal and noise, and knowledge about sites, stand histories, and tree biology (Cook and Briffa 1990).

Height growth, especially top height growth, is often used as an indicator of site productivity. For height growth data, the definition of stand height, the measurement method, and the method used for relating height to age has to be consistent. The calculation of volume growth on the basis of height and basal area growth must be done according to the same rules, as volume functions can be very sensitive to changes in the independent variables.

Studying the trend of dominant height development on the basis of site index curves is not possible, when site index curves are based on long-term observations within a time of change in growth conditions. A growth trend may then be included in the site index curves and possible changes within the time period to be analyzed will not be discovered.

4. RECENT CHANGES IN FOREST GROWTH

The main interest in growth changes at a European level refers to changes in site productivity such as changes in water and nutrient supply (EFI Research Report No. 5: Spiecker et al. 1996). It is difficult to separate these growth trends which reflect long-term changes in site productivity from episodic changes caused by extreme events such as frost, drought, snow and storm damage, fire, by insect attacks or fungal diseases or by a combination of several events which will be followed by a reverse change. Growth trends are defined as long-term deviation of actual growth from expected growth. The analyses are based on the above mentioned three data sources: inventory data, research plot data and tree analysis data. Since existing data had to be used, the quantity and quality of available data vary. In some countries no long-term growth data are available in an appropriate form. Some data reported in the EFI publication refer to case studies on rather small areas, others – as for example some inventory data – refer to larger regions or nations. The time span of available data varies from few decades to several centuries. Since the data analyzed were usually not collected for analysis of long-term growth trends, some variation in the applied standards is unavoidable.

Because of these shortcomings, the EFI Research Report does not present growth development of forests in Europe in a uniform and statistically representative way. However, the results may still allow some conclusions to be made at the European level. 22 papers written by 45 scientists from 12 countries are presented in this report. Most studies were conducted in Northern and Central Europe. Only two studies refer to

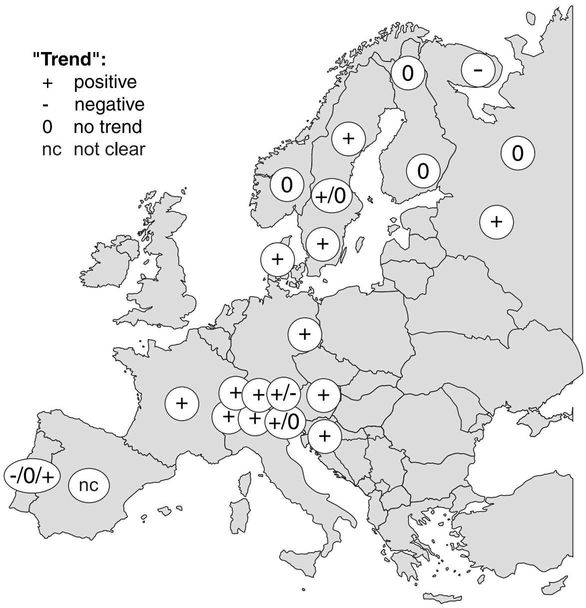

Figure 7. Growth trends in European Forests, 22 studies from 12 countries (Spiecker et al. 1996).

Southern Europe. In total 61 scientists independently reviewed the individual contributions and gave valuable comments.

The growth of European forests has changed considerably in recent decades. Although the methods applied varied according to the data available, most studies showed the same general trend: site productivity has increased on many sites. An increasing growth trend has been observed in the southern regions of Northern Europe, in most regions of Central Europe and in some parts of Southern Europe. The results derived from long-term observations on permanent plots and from tree analysis are supported by inventory results which are representative of large areas, but cover generally shorter observation periods. Site productivity, in terms of wood volume, increased on various sites in recent decades by up to 50%, in some cases even more. Annual tree height increment increased in the order of 2-5 cm, varying with species, site and age of the trees. No clear trend was found in the most northern part of Europe, in rare cases in Central Europe and in some observations in Southern Europe. A decreasing trend was found in exceptional cases where extreme growth conditions such as intense exposure to pollutants or exceptional climatic conditions occurred. Several other publications on changes in forest growth support the findings described (e.g. Schmidt 1969, Pretzsch 1985, Spiecker 1986, Gereke 1988, Kenk and Spiecker 1988, Becker 1989, Kenk et al.1991, Kauppi et al. 1992, Keller 1992, Becker et al. 1994, Kuusela 1994, Spelsberg 1994, Elfving and Tegnhammar 1996).

These findings indicate changes in environmental conditions have occured. The generally accelerating growth may have been caused by one factor, a factor combination or by regionally changing factors which finally had similar effects on growth. Forest growth therefore is by itself not a sufficient tool for the diagnosis of specific causes.

As potential causes land use history, forest management practices, natural disturbances, climate, including nitrogen deposition and elevated CO_2 content of the atmosphere, and other factors, including a combination of several factors are in discussion. The significance of each possible cause potentially varies in space and time. Growth responses to the influencing factors are modified by species, provenance, site and stand conditions. It is difficult to draw general conclusions regarding their effects on forest growth. It is possible that one factor or a factor combination or even various factor combinations at different locations influence growth. It is equally possible that several different factors influence forest growth simultaneously and that their total effects change individual effects.

5. CONCLUSIONS

Many different case studies clearly indicate that the productivity of many forest sites in Europe has changed. Site productivity has been increasing for several decades. Some studies showed no trend and in rare cases a decreasing trend was observed. The rate of growth acceleration varies with species and provenances, with site including micro-variation of site, age, management practices, extreme events, diseases, disturbances and other factors. No complete information exists on species, provenance and site specific growth changes on a European level.

The observed growth trends may involve additional risks; trees may be more susceptible to drought and frost as well as to diseases. The risk of windthrow may increase when trees get taller and when standing volume increases. To predict future forest development, as well as assessing risk, a better understanding of the causal relation between the changing environmental factors and the growth changes is needed. Information about causes and consequences of accelerated growth is still lacking.

The traditional aim of forest growth studies is to develop growth models of trees and stands on different sites under different treatments. Today, we have to consider that sites change on a larger scale. This leads to the conclusion that past growth observations may not reflect actual growth adequately and past experience cannot be used for predicting forest growth. New models for predicting growth based on current and future driving variables are required. Long-term empirical field data and results from laboratory experiments combined with modelling could be a way for interdisciplinary research to widen the knowledge about the causes for changes in the growth trend of the forests in Europe.

Also our aims to utilize the forests change over time. We need information about changes in site properties, about site adaptation of species, about effects of management practices on growth, about wood quality and other properties of trees as well as about changes in the goals of forest management. New adaptive planning tools have to be applied to scope the uncertainty and risk. The amount and complexity of the scientific problems evolving from the observed forest growth trends show that solutions can only be developed by an interdisciplinary cooperation of scientists at an international level. This cooperation will lead to a more comprehensive understanding and will provide a more realistic and reliable information basis for decision support in sustainable forest management.

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SPATIAL ANALYSIS OF RADIAL GROWTH OF NORWAY SPRUCE IN NORWAY

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ABSTRACT

Radial growth measured for Norway spruce (*Picea abies*) trees by the Norwegian Forest Inventory were divided into a western (coastal) and an eastern (continental) region and decomposed using a median polish algorithm. The growth was generally lower, and the variation higher, in the western than in the eastern region. A latitudinal trend was found in both regions, with high radial growth in the far south and gradually lower growth further north. The two trends had similar shape, but their overall levels were different. The shape was interpreted as a climatic north-south gradient, with high radial growth broadly corresponding to warmer climate and a longer growing season. The overall difference between the two regions is probably an effect of less favourable growing conditions in the coastal region. The study emphasises the complementary relationship between forest inventories and data obtained from experimental or monitoring plots. A forest inventory can not provide the rigorous experimental control needed to test a hypothesis, but it does offer a statistically representative environment for further examination of the predictive power of a hypothesis.

Keywords: forest growth, Norway spruce, forest inventory, median polish

1. INTRODUCTION

The reader may be puzzled to find a paper on the spatial analysis of tree growth in the proceedings of a seminar on causes and consequences of *accelerating* tree growth. The analysis of growth alone is not sufficient to address the question of whether the process is accelerating or not. Within the general scope of the seminar, the aim of this paper is fourfold. First, the paper examines the measurement and mapping of growth that is clearly a prerequisite for future studies of growth change. Second, the geographical

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approach used in this paper can help identify regions where the growth is exceptional and where further studies should be carried out. Third, the paper draws attention to the study of forest inventory data. Although the forest inventory does not provide the control and rigour of the well-designed scientific experiment, it is a representative arena where scientific results can be tried out and ideas for new experiments can be found. Last, the paper presents a simple, non-parametric method – median polish – that can be used to search for spatial patterns among the regular sample points often used in forest inventories and forest monitoring programmes.

2. MATERIAL

Candidate sample plots were located on a 3 × 3 km lattice throughout Norway. A systematic random sample was collected, consisting of 40% of the candidate plots that fell within a forest and was stocked with Norway spruce (*Picea abies*) (see Tomter (1997) for details and definitions). The result was 1492 sample plots with 11452 trees (Figure 1). Diameter at breast height was first measured during 1986-1993 and later remeasured in 1994 or 1995.

Change in diameter at breast height was used as a measurement of tree growth. The annual increment was transformed to percent of the diameter at the beginning of the period in order to get comparable figures. Let D_{t1} and D_{t2} be the diameter at time t_1 and t_2. Relative growth G was calculated as

$$G = \frac{(D_{t2} - D_{t1}) \times 100}{(t_2 - t_1) \times D_{t1}}$$

The median of G for the trees on each plot was used as a summary measurement of relative growth for the sample plots.

The climate in Norway is dominated by a north-south gradient due to the elongated position across the northern latitudes. Conditions along the coast are also different from those found in the inland. Much of the coast is outside the natural range for Norway spruce, but the species is spreading into these areas by natural expansion as well as through tree planting programs. The study consequently divided the data along county boundaries into a coastal and a continental climatic region (Figure 1).

3. METHODS

Median polish (Tukey 1977) was used to decompose the data and search for spatial trends. This method extracts an overall effect, a row effect and a column effect from a data matrix. Median polish is resistant against outliers and avoids many problems involved in the perhaps better known trend-surface methods (Chorley and Haggett 1965). Median polish is used by geostatisticians to remove trends from data as a preparation for kriging (Cressie and Read 1989, Cressie 1991) but can also be used for

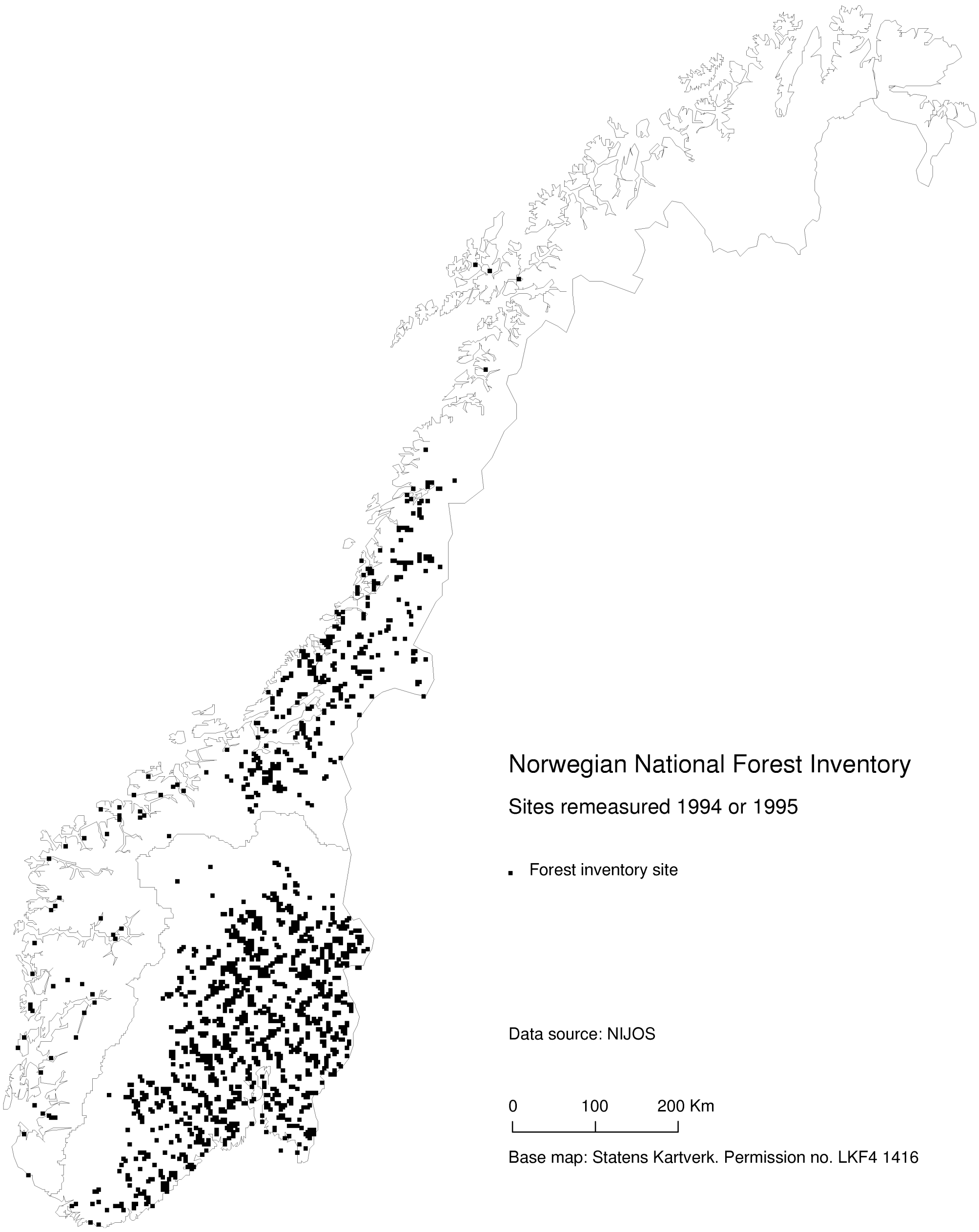

Figure 1. Diameter at breast height for Norway spruce (*Picea abies*) was measured on 1492 sample points, stratified into a coastal (north and west) and a continental (southeastern) region.

trend detection (Haining 1990, Strand 1995). If the observations z are located on an $m \times n$ lattice $[z_{ij}\ \{i=1..m, j=1..n\}]$, then

$$Z = a + c + r + \varepsilon$$

represents a decomposition of the $Z_{n\times m}$ matrix of observations into an overall effect a, a vector of column effects $c_{1\times m}$, a vector of row effects $r_{n\times 1}$, and a matrix of residuals $e_{n\times m}$. The two vectors c and r are non-parametric measurements of a horizontal and a vertical trend. c will represent a west-to-east trend and r a south-to-north trend. Any measurement of central tendency could be used to extract a, c and r, but the median has the advantage of being less sensitive to extreme values.

The median polish of an n×m matrix is a repetitive algorithm. The first step is to find the median of each row and store these in the vector of row medians -r. The row medians are then subtracted from the original values. Next, column medians are calculated for the residuals. The column medians are stored in the column vector c. The results are again subtracted from the matrix, leaving a new set of residuals. This time, the extraction is also carried out on the row vector. Its median is stored in a and subtracted from the elements of the row vector. The process is repeated, with c and r polished along with the matrix until the change obtained is below a certain threshold (0.01% was used). The algorithm was implemented using Delphi 2.0 in a Windows'95 environment and tested on data from Cressie (1991 p. 34).

c and r were plotted in scattergrams. East-west co-ordinates were measured from 15°E with a false easting of 500 km. The distance north was measured from equator. Summary points were obtained by dividing each vector into three portions (I, II and III), each containing approximately one third of the data. Within each portion, the distance and the growth values were treated as two independent variables and the median was calculated for both. The two medians define the summary point for the portion (Velleman and Hoaglin 1981). Each vector has three summary points. A scattergram was used to compare the six summary points obtained for the two r vectors.

4. RESULTS

Median annual radial growth was 1.57% in western and 1.83% in eastern Norway. The west-east trend in coastal Norway (Figure 2a) shows a positive deviation from the overall median but no trend. In western Norway (Figure 2b), high variation was found in the far south and the far north. There is a weak tendency towards increasing negative growth (relative to the regional median) northwards. The growth in eastern Norway was lower than average in the far west and in the far east (Figure 2c). There is a fairly consistent north-south trend in this region, with higher growth in the south and lower growth in the north (Figure 2d).

The six summary points are shown in Figure 3. The four summary points that describe the trend in the middle and northern portion of the two regions fall on a linear, slightly negative line. The shape of this line is

$$G = 4.298 - 0.6634\times D$$

(where G is growth in percent and D is distance north of equator in kilometres $\times 10^{-3}$). The trend is relative to the two regional medians that account for the difference between the coastal and the continental region. The two regions thus exhibit a common trend,

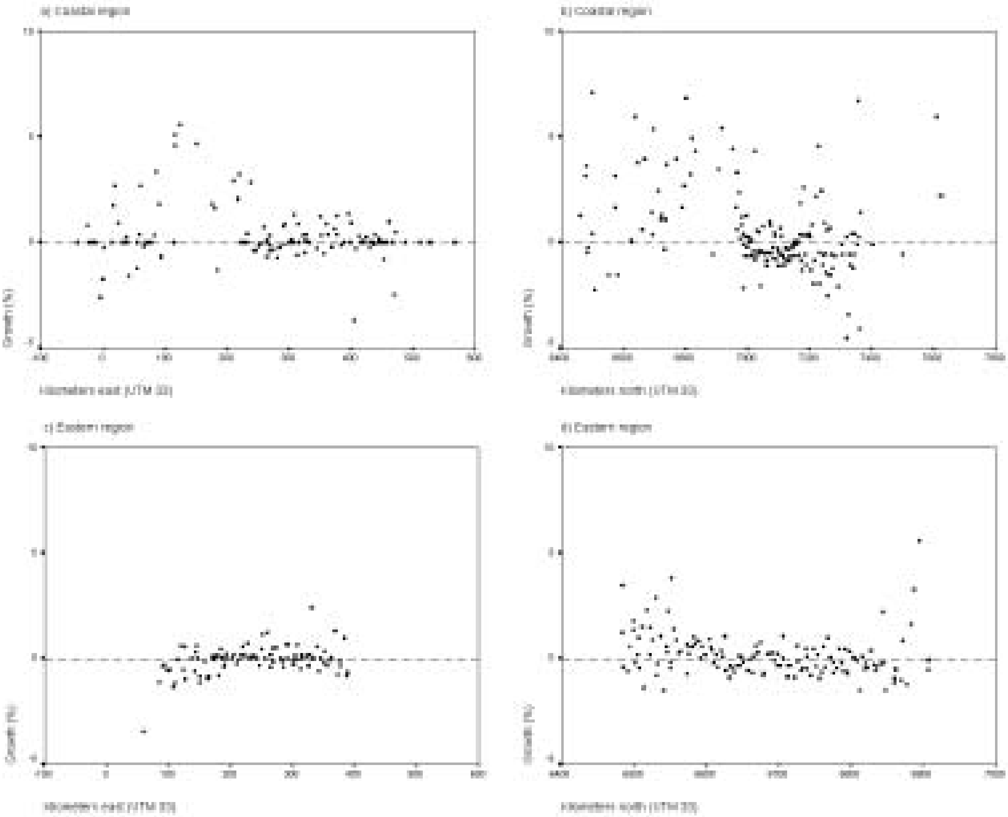

Figure 2. Trend diagrams of radial tree growth of Norway spruce (*Picea abies*) in Norway. Each point represents the median growth in % of all sample points located a certain distance east or north. Figures a) and b) show the coastal region, c) and d) show the eastern region.

offset to a slightly lower total in the western region. This trend may be interpreted as a climatic gradient related to the length of the growing season. The two summary points for the southernmost partition of each region are both positive outliers.

5. DISCUSSION

The results show a consistently higher increment in the continental, compared to the coastal region, together with a negative latitudinal gradient shared by the two regions. Some possible explanations are discussed below.

Measurement error: The first measurement where conducted during the years 1986 to 1993 while the second measurement was taken either in 1994 or 1995. The period between the two measurements may vary accordingly, from 1 year (1993-1994) up to 9 years (1986-1995). In the former case the growth indicates the effect of a single year,

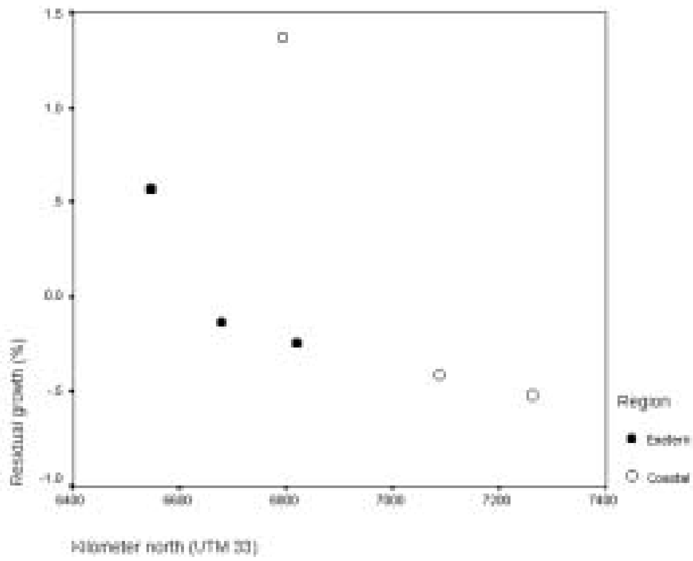

Figure 3. Summary points for latitudinal trends. Figures are relative to the regional medians (1.57% in the coastal and 1.83% in the eastern region).

while growth is averaged over 9 years in the latter case. The sampling method in the second campaign (1994 and 1995) was properly randomized, while the first campaign (1986 to 1993) was carried out county by county. The time interval (t_2 - t_1) is thus spatially autocorrelated and this may have produced a bias in the results.

Nitrogen fertilising: Nitrogen is a limiting factor for forest growth and increased Nitrogen input, e.g. from airborn depositions, may lead to increased growth (Nihlgård 1985). Nitrogen depositions in Norway are highest in the south and along the southernmost part of the westcoast. So far, no clear connection has been established between increased Nitrogen input and forest growth in Norway (Abrahamsen et al. 1994) but the spatial deposition patterns described by Tørseth and Semb (1995) does give some indication of a possible relationship. First, a large part of the forest in the eastern region is located in the south (Figure 1) where the deposition is higher. The forest in the coastal region is mainly located further north, where depositions are lower. Nitrogen depositions may thus have contributed to the generally higher growth rate in the eastern region. Depositions within each of the two regions are generally higher in the south than in the north, with a steep increase in depositions in the far south of each region. The most heavily affected area extends further north along the coast than in the interior, a fact that corresponds well with the patterns observed in Figure 3.

Statistical support: Figures 2b and 2d shows considerable variation among the row medians in the southernmost part of both regions. These areas have few sample plots and the high variation may be a result of weak statistical support. Median polish is a robust method in the sense that the influence of the occasional extreme is minimised, but high variation is a problem in areas with weak data support.

Site quality: The site quality is a summary of local climatic, topographic and pedologic factors that constitute the physical environment for forest production. In Norway, site quality is measured as the mean height of the trees 40 years after reaching breast height (The H_{40} system; Tveite 1977). Site quality can vary considerably in marginal areas. Coastal Norway is at the limit of, or even outside, the natural range for Norway spruce (Sykes et al. 1996). Much of the spruce forest in the southwest is thus planted, generally on land with highly favourable conditions. This may explain the overall positive residual here, 1.37% above the regional median (Rune Eriksen, NIJOS, pers. comm).

Climatic factors: The climatic factors that influence tree growth are rainfall, topography and the length of the growth period. The growth period is defined as the period that starts when the mean daily temperature rises above 6ºC in the spring and ends when the mean daily temperature falls below 6ºC in the autumn. The length of the growth period in Norway varies from 204 days at Lista in the far south to 126 days in Alta in the extreme north. Considerable variation is added by strong topographic effects: Slirå, located at 1300 meter asl has a growth period lasting only 61 days (Johannessen 1977). The linear trend in tree growth corresponds well with the gradual shortening of the growth period with increasing latitude.

6. CONCLUSION

The study included only two inventory periods and was thus limited to study growth and not *accelerated* growth. Still, the study shows that considerable variation can be hidden behind a national statistic and that this variation can exhibit systematic spatial patterns.

The variation in forest growth within Norway seems to correspond well with climatic factors: The growth rate is higher in the continental region – protected from the direct impact of North-Atlantic cyclones by a mountain range – than in the coastal region that is more exposed to the oceanic storms. The length of the growth period is reflected in a latitudinal growth gradient. The high radial growth in the southernmost part of both regions does seem to correspond with high deposition of Nitrogen (Tørseth and Semb 1995), but this is only an indication of a possible relationship that require further investigation.

The study does also shed light on the relationship between forest inventories and data obtained from experimental or monitoring plots. A forest inventory can not provide the rigorous experimental control needed to test a hypothesis. The experiment, on the other hand, is usually carried out on a location selected for its particular qualities. In a statistical sense, the experimental plot and the subjectively selected monitoring site are examples of purposive sampling – never really representative of anything but themselves. A hypothesis that has survived repeated testing in this controlled environment, still needs to have its predictive power tried outside the laboratory conditions. The forest inventory is an extensive and statistically representative model of the productive forest and thus an arena where the hypothesis can be set to work. This does not imply that the hypothesis is tested against the forest inventory – rejection is not justified because a hypothesis fails under conditions where experimental control is absent – but a demonstrated ability to make correct predictions in an inventory environment would certainly strengthen the confidence in the hypothesis.

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THEME II

POSSIBLE CONSEQUENCES OF THE INCREASED FOREST GROWTH

ASSESSMENT OF LONG-TERM CHANGES IN TIMBER QUALITY: COMBINING NATIONAL FOREST INVENTORY DATA AND GROWTH AND WOOD QUALITY MODELS

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ABSTRACT

In this paper, we propose to assess timber quality of a standing tree from usual forest inventory measurements such as tree age, height and diameter at breast height (dbh). Growth equations are used to reconstruct the past growth of a tree and to predict its current internal structure, namely ring distribution. These models are linked to allometric equations that estimate the characteristics of branches, to models that predict physical wood properties such as wood basic density from ring distribution and to a glass-log software that simulates the sawing and grading of any board located in a stem whose morphology is known in detail.

The French Forest Inventory data for Norway spruce are available at three dates, 1973, 1981 and 1992, respectively C1, C2 and C3. We have chosen one of the most important French districts for Norway spruce in France, the Vosges district, which is located in the North-eastern part of France (58 799 ha and 13 326 000 m^3 in 1995). The forest area of pure even aged represent almost half part of total Norway spruce area and volumes. Between the first and second forest inventory (C1 and C2), both forest area and total volumes have increased (respectively + 86% and + 84%). Between C2 and C3, the forest area remains the same but the standing volume has increased consequently (+42%) mainly because of the growth of relative young planted stands. At the three inventory dates, the standing volume was respectively 214, 205 and 302 m^3/ha for Norway spruce and 350, 324 and 297 m^3/ha for fir (*Abies alba*) which timber is used exactly in the same way than Norway spruce timber.

In the second part of this paper we will analyse for C1, C2 and C3, (i) the stands dominant heights for the same stand age classes, (ii) the stand ages for similar breast height diameter classes and (iii) the timber properties for similar breast height diameter classes (25 cm and 40 for example).

In the last part of this paper we will discuss the possibility of taking into account the increase of fertility into a stand growth and wood quality model modelling approach.

Keywords: wood quality, forest inventory, modelling

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INTRODUCTION

Recent research works carried out on the change of forest productivity in Europe indicate that forest growth has considerably changed over recent decades (Spiecker et al. 1996). The observed trends vary according to species and to geographical area, but most studies show that site productivity has increased in many central European and Nordic countries. One of the means used to detect and assess the magnitude of such changes consists in analysing the data gathered by successive national forest inventories (Houllier et al. 1995).

The purpose of this workshop is to present the current state of the art regarding both the causes and consequences of forest growth trends. Within this context, this paper aims at investigating one of these possible consequences, namely the change in timber quality of forest resources in a given geographical area. The basic idea is to combine National Forest Inventory data, obtained through successive surveys, and a set of growth and wood quality models (Houllier et al. 1995).

The method is applied to Norway spruce (*Picea abies*) in the 'Vosges' district, located in the north-eastern part of France. This district is the second one in France for Norway spruce in terms of both forest area and total standing volume. The growth and wood quality models involved in this paper have been built and validated in this very region.

Timber of fir (*Abies alba*) is always used in the sawmill without distinction from Norway spruce timber. The wood of both species is very similar from physical and anatomical point of view. Their timber is used for building wooden roof trusses or any other product in house construction such as glue laminated beams, pallets, etc. Therefore, we will also take the fir timber resource into account.

METHOD FOR ASSESSING TIMBER PROPERTIES FROM INVENTORY DATA

Earlier studies on the morphology, growth and wood properties of Norway Spruce (Houllier et al. 1995; Leban 1995) have resulted in statistical models which have been introduced in a software, Win-EPIFN (Saint-André et al. 1995). For models constructions we have sampled 96 trees in eight stands. Their age vary from 53 to 130 years and their dbh from 25 to 48 cm while in the existing forest resource Norway spruce age vary from 10 to 190 years and dbh from 10 to 60 cm.

The software Win-EPIFN simulates the visual properties of boards sawn from trees for which minimum inventory data are available. Predicted outputs, i.e. board average ring width, average wood density and knotiness, have been compared to observations on an independent data set of 213 boards sawn from 62 Norway spruce trees. The results of this validation procedure were promising and suggested that Win-EPIFN could be used to assess timber quality of forest resources at a regional level (Daquitaine 1994; Leban 1995; Leban et al. 1996).

Input data of Win-EPIFN are a list of standing trees described by their age, height, dbh and their statistical weight, i.e. the number of trees represented by each sample tree. The models consist in a set of equations and submodels which predict, for each sample tree: past height and dbh growth; bark thickness, stem taper and stem inner ring width distribution (ring age and ring width); past crown recession with the evolution of the height to the first dead branch, the first living branch, and the first living whorl; branch characteristics (number per annual shoot, position, size and insertion angle); the variation of wood density within the stem. For each 'reconstructed' sample tree, Win-EPIFN simulates log cutting and log grading, and finally board sawing in each log.

In its present version, the sawing pattern implemented in Win-EPIFN is based on a single board size excluding wane. The board section was chosen from among the most usual commercial board size (50x150x3000 mm^3). The sawing pattern is realised in order to maximise the number of such boards. Each simulated board is described by its (predicted) average ring width, average wood density and KAR (Knot Area Ratio, Tredwell, 1973). Board grading is not yet available in the software, so that the results which are presented below concern only these three board characteristics. Because of the unique size of boards, all results are presented as a number of boards. A flow chart diagram of the Win-EPIFN structure is presented in Annex 1.

DATA ANALYSIS

The data were obtained from the French National Inventory data base. For this study, they were restricted to the pure spruce and fir even-aged stands. Data were available for three successive inventory dates: 1973, 1981 and 1992, respectively noted C1, C2 and C3 (i.e. cycle number 1, 2 and 3). The sample plots were not permanent but randomly and independently selected at each inventory date, using a 3-phase stratified sampling strategy (I.F.N., 1985): (1) interpretation of aerial photographs and forest mapping which results in a stratification, (2) field checking of the selected strata, (3) field measurement of sample plots and sample trees therein. The total number of sample plots and trees vary according to the inventory date (see Table 1).

For each sample stand (in fact, each sample plot), the age, the dominant height, and the average dbh were available. In each plot, we had a list of sample trees with the following basic data: tree age, dbh, total height, height of the first dead branch, radial increment (i.e. width of the last 5 annual rings) and height increment (i.e. length of the last 5 annual shoots). Height and dbh increment data were further used to estimate tree and stand annual volume increment (AVI) over the 5 years which preceded the survey. Each sample plot and each sample tree within were given a statistical weight as per the sampling strategy.

Table 1. Number of stands and trees measured at each inventory date.

	Spruce (*Picea Abies* Karst)		Fir (*Abies alba*)	
Year	Plots	Trees	Plots	Trees
1973(C1)	163	2896	393	4765
1981(C2)	260	4577	296	3425
1992(C3)	209	3850	286	3315

Tables 2 and 3 provide the forest area under pure spruce and fir even-aged stands, the volume of these two species in these stands, as well as the average age, mean dbh and annual volume increment per ha. In 1992, the pure even-aged Norway spruce stands represent more than 55% of the total forest area dominated by spruce and the spruce volume in the pure even-aged spruce stands is more than 61% of the total standing volume of spruce in the district. For fir, these figures are slightly different: 52% for the forest area and 53% for the volume.

Between 1973 and 1981 (i.e. C1 and C2), the area of pure even-aged spruce stands has doubled. It has then remained stable during the next decade. Between each inventory date, the total standing volume has strongly increased, with more than 3 millions m^3 more at each inventory cycle. The mean age has remained stable for C1 and C2 and slightly decreased between C2 and C3. The mean diameter has remained stable between C1 and C3 (about 28 cm). The calculated annual volume increment has considerably decreased at C2 (9.1 m^3/ha/year against 13.7 at C1 and 14.3 at C3) probably mainly because of the drought period which had occurred in 1976 (Becker et al. 1995). A similar reduction in production at C2 can be noticed for fir.

The annual volume increment is always lower for fir than for spruce mainly because of the mean age which is higher for fir than for spruce. Between C1 and C3 the fir total standing volume has decreased by about 30% and the total forest area has slightly decreased between C2 and C3. Meanwhile, both mean age and dbh have reduced by ca. 10%. During this relatively short period of 20 years, the forest resource in the 'Vosges' district has thus been modified by both silvicultural decisions and affected significantly by a severe drought during a couple of years.

For each species and each inventory date, we represented the distribution of the total standing volume by age and dbh classes (Figures 1a to 1f). For Norway spruce, the comparison between the three successive inventories shows that the volume of the

Table 2. Volume and area of Norway spruce *(Picea abies* Karst) in 'Vosges' district. At 5% level of confidence, the precision for the inventory data is about 6.5% for the volume and 13.6% for the area. DBH is a weighted mean. Each individual tree DBH measurement has a weight in number of stems per ha.

Year	Volume(m^3)	Area(ha)	Age	DBH(cm)	AVI(m^3/ha/year)
1973(C1)	3387900	15760	48.0	28.0	13.7
1981(C2)	6726500	32680	48.8	27.9	9.1
1992(C3)	9819200	32450	43.5	28.2	14.3

Table 3. Volume and area of fir (*Abies alba*) in 'Vosges' district. At 5% level of confidence, the precision for the inventory data is about 6.5% for the volume and 13.6% for the area.

Year	Volume (m^3)	Area(ha)	Age	DBH(cm)	AVI(m^3/ha/year)
1973(C1)	13416300	38280	101	44.9	8.0
1981(C2)	12353100	38040	105	44.9	4.6
1992(C3)	10018400	33660	95	42.9	9.0

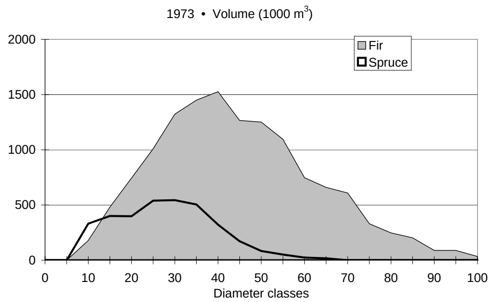

Figure 1a. Volume per dbh classes in Vosges, in 1973

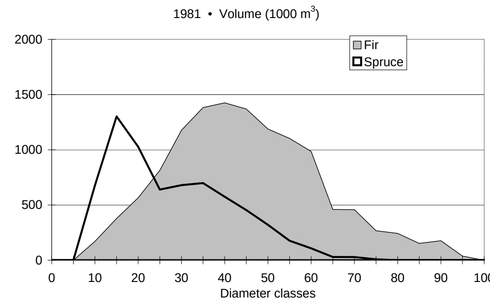

Figure 1b. Volume per dbh classes in Vosges, in 1981

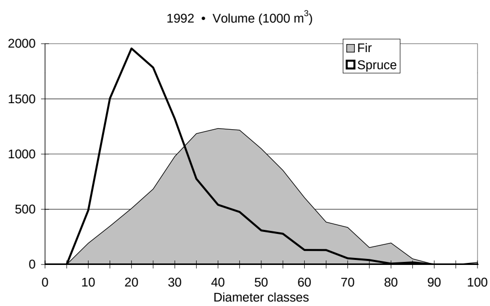

Figure 1c. Volume per dbh classes in Vosges, in 1992

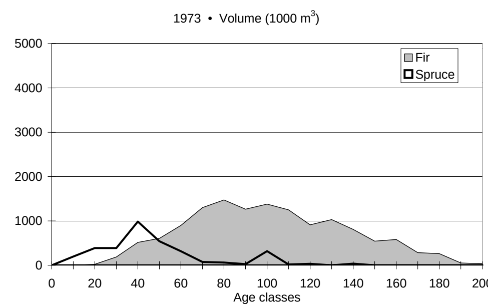

Figure 1d. Volume per Age classes in Vosges, in 1973

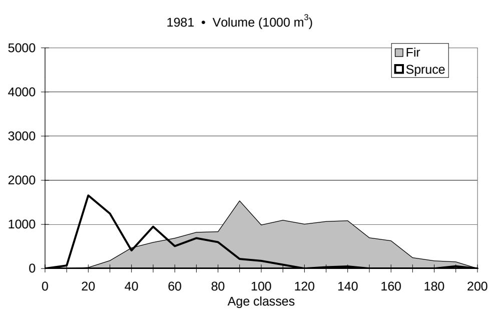

Figure 1e. Volume per Age classes in Vosges, in 1981

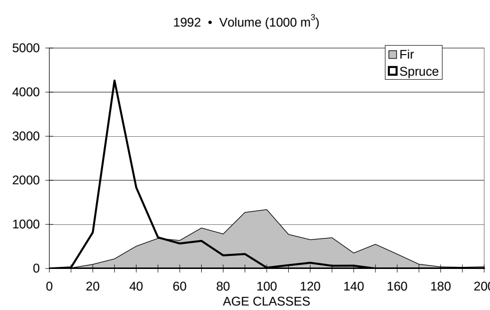

Figure 1f. Volume per Age classes in Vosges, in 1992.

younger age classes has sharply increased: this comes from the great effort of plantation made thank to the 'Fonds Forestier National' between 1945 to 1960 (De Rochebouet 1987). These plantations are different from the older stands: (i) their silviculture is different, e.g. the initial spacing has increased resulting in less stems/ha at young ages; (ii) most of the young stands were planted in the plains on former agricultural land whose fertility is higher than the fertility of the older stands.

As a result of this generation effect, there is an apparent overall change in site quality (Ottorini 1984). We used the dominant height and age, and the yield tables by Décourt

Table 4.1. Spruce standing volumes (1000 m^3) displayed by fertility classes (dominant height at 50 years). The number of stands available in the data base is in brackets.

	Site index (H0 at 50 years)			
YEAR	30 m	27 m	24 m	21 m
1973	1030(54)	1044(57)	468(21)	187(12)
1981	1445(51)	1903(105)	814(43)	192(19)
1992	4021(64)	3079(72)	1053(37)	259(10)

Table 4.2. Spruce area (ha) represented by the number of sampled and measured plots (in brackets) and displayed by fertility classes (dominant height at 50 years) for each inventory date

	Site index (H0 at 50 years)			
YEAR	30 m	27 m	24 m	21 m
1973	5704 (54)	6000(57)	1840(21)	983(12)
1981	6970(51)	12689(105)	6022(43)	2213(19)
1992	11014(64)	11511(72)	5715(37)	1288(10)

Table 5. Dominant dbh (cm) per dominant age classes for spruce. The number of stands available for each age class in the data base is in brackets.

	Dominant Age classes					
Year	20	30	40	50	60	70
1973	17.0(37)	27.3(16)	33.4(24)	39.1(13)	40.5(8)	39.1(2)
1981	16.7(104)	22.7(44)	28.7(17)	36.2(23)	40.8(12)	43.2(15)
1992	17.8(43)	27.6(74)	33.8(37)	42.3(14)	45.3(9)	44.9(10)

Table 6. Dominant height (m) per dominant age classes for spruce. The number of stems per hectare for each age class is represented in brackets.

Year	Dominant Age classes					
	20	30	40	50	60	70
1973	11.1(1899)	18.5(1181)	22.2(1078)	26.6(595)	26.7(492)	28.4(519)
1981	11.3(1679)	15.9(1733)	19.9(1086)	24.6(709)	24.9(668)	28.2(449)
1992	12.5(1578)	19.6(1454)	22.4(986)	25.9(734)	29.1(465)	28.9(394)

(1971) to assess the distribution of standing volume per site classes (Table 4.1). There is a sharp increase of the volume in the best site index classes, which can be explained by the increase of forest area of these classes (Table 4.2). While the reduction of the number of stems per hectare is much less significant (data are not presented here because of the low number of stands available for some cases). As a complement, we have computed at each inventory date the average value of (1) the dominant height and (2) the dominant dbh in each age class. These results are reported in Tables 5 and 6.

There is a slight, but consistent, increase of these variables between 1973 and 1992. But these values are significantly lower in 1981 probably because of the above mentioned drought period in 1976. In Table 6 we have also reported the number of stems per hectare for each dominant age class. As an example, for the dominant age class of 30 years, the number of stems per hectare is higher in 1981 (1733 stems/ha) and 1992 (1454 stems/ha) than in 1973 (1181 stems/ha). This illustrates that thinnings were probably delayed and by consequence a possible positive trend for growth should be then limited when these stands will be older. For the youngest age class (20 years), the number of stems per ha has decreased from 1899 in 1973 to 1578 in 1992. Then, for the same fertility class, the consequence would be an increase of the dbh in the future.

ASSESSMENT OF CHANGES IN TIMBER QUALITY

The total volume sawn in the trees may seem surprising. In fact, it has been obtained by virtually sawing all the available resource which is, of course, unrealistic. If we wanted to estimate the sawtimber quality of the wood available cut, we should correct these estimates by ratios which would depend on age or dbh class and on the management guidelines which are in force. Anyway, our results can be considered as the maximum lumber recovery of the forest resource (for the single cutting and sawing patterns used in this study) at a given date. The yield of sawing is about 50% of the saw logs whose top end diameter allows the sawing without wane of a 50 x 150 mm^2 section.

The total volume of simulated boards is distributed according to board ring width classes (Figure 2). The consequences of the changes in spruce resource are illustrated by the increase of the volume of boards in the highest ring width classes in 1992. As a consequence, there is also an increase in the volume of boards in the lower wood density class (Figure 3). Even though the difference in mean value of board ring width distribution is small between 1973 and 1992 (3.8 mm against 4.2 mm: see Table 7), this difference might increase in the future when (1) these plantations will reach a bigger dbh and when (2) the old slow-grown stands will have been harvested.

The comparison with fir was made in order to underline the better timber properties of fir timber for the 3 selected physical properties: ring width (lower than for spruce), wood density (higher than for spruce) and KAR (lower than for spruce for the same type of boards). There is no trend in KAR through the three inventory dates, which can be explained by the poor self pruning process for these two species. As a consequence, the strong increase of young spruce stands did not affect the mean value of spruce KAR. The distribution of board volume per KAR classes is peculiar, i.e. it is smoothly bell-shaped, in 1973 (Figure 4): this is due to the fact that the height of the first dead branch was not recorded in 1973 and that we used a statistical model to determine this value (Colin & Houllier 1992). In the following surveys (C2, C3), this value was measured for trees whose dbh was higher than 37.5 cm and it appears that the shape of the distribution is modified, namely by an increase of the clear timber volume (i.e. lower KAR values). The distributions for the second and the third inventory are therefore comparable to each other: the increase in volume between C2 and C3 is mainly

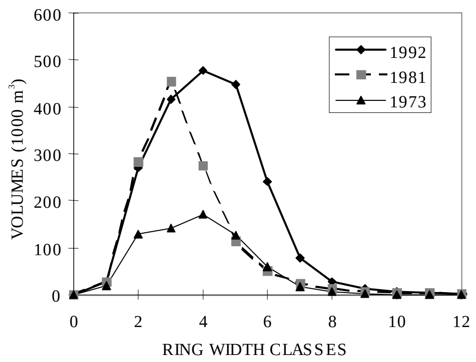

Figure 2. Simulated distribution of boards ring width for spruce.

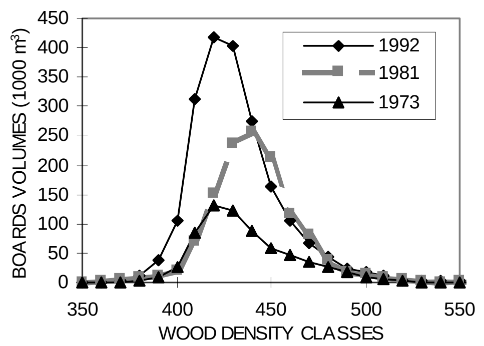

Figure 3. Simulated distribution of boards wood density for spruce.

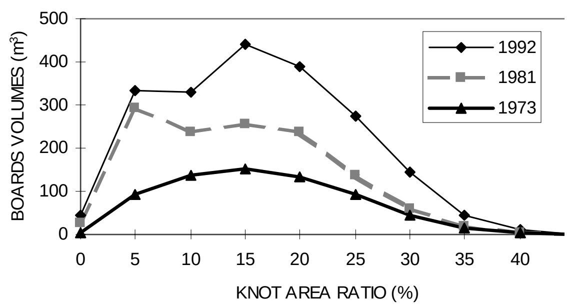

Figure 4. Simulated distribution of boards KAR for spruce.

Table 7. Mean values of the simulated boards properties. The distribution of boards properties from which these means are calculated are all significantly different between two inventory dates. The calculated p(Chi 2) are always lower than 0.001.

	Ring width (mm)		Wood density (kg/m^3)		KAR(%)	
Year	Spruce	Fir	Spruce	Fir	Spruce	Fir
1973	3.8	2.1	437	475	16.3	13.6
1981	3.5	1.8	441	485	14.6	13.6
1992	4.2	2.2	431	479	16.2	12.1

allocated to the higher KAR classes which are unfortunately bad for the timber quality, as it could have been predicted by using for instance a modelling approach! By chance, this trend could be balanced in the 'Vosges' district, by the better quality (in terms of ring width, wood density and knots) of fir timber if its forest area and age structure were to remain stable in the future.

In order to illustrate another sawmill-oriented point of view, we have focused on stands whose dominant dbh varies between 27.5 and 32.5 cm and have studied the properties of boards sawn therefrom (Figures 5a, 5b and 5c; for each of these three figures, the distributions simulated at each date are significantly different between them: the p(Chi 2) is always lower than 0.001). For a stand whose dominant dbh is 30 cm, there is a wide range of tree dbh. This must be noticed in order to avoid a direct comparison with Figures 1b, 1d and 1f, for which we have added all the trees from a same dbh class together. The simulated properties of boards sawn from the stands whose dominant dbh lies between 27.5 and 32.5 cm were displayed in terms of cubic meters of boards/ha per board property classes. The above-mentioned increase of stand volume appears between the second and third inventory, mainly for ring width greater than 3 mm and for board wood density lower than 430 kg/m^3. For KAR, the board volume per ha has increased in 1992 for KAR higher than 10%. The increase of board volume per ha, between 1981 and 1992, is explained by a higher number of stems per ha in 1992 in this stand dominant dbh strata which is represented by 34 stands in this data set. However, we must keep in mind that the general trend in number of stems per ha is globally decreasing in younger stands because of wider initial spacing at plantation. On the other hand, delayed thinnings may limit the effect of this trend when the most recent stands get older.

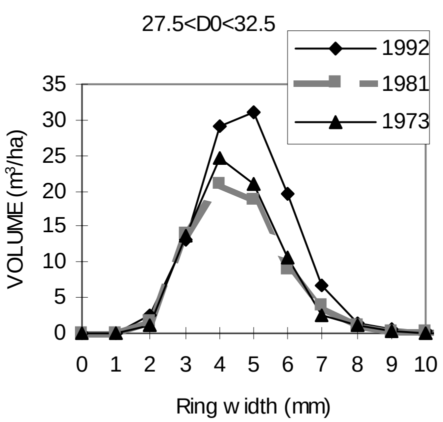

Figure 5a. Boards volume per ha by ring width classes. Means and standard deviation for ring width
1973 M=4.53, SD=1.22
1981 M=4.57, SD=1.38
1992 M=4.80, SD=1.31

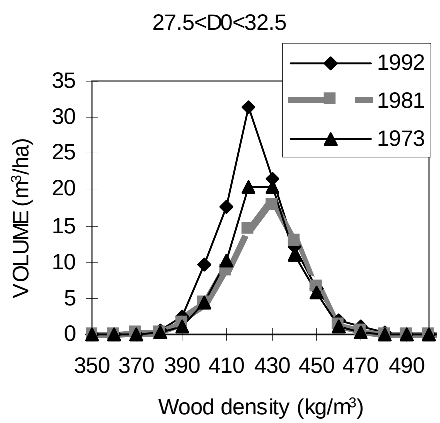

Figure 5b. Boards volume per ha by wood density classes. Means and standard deviations for wood density.
M=425.9, SD=14.67
M=426.8, SD=16.60
M=423.05, SD=15.94

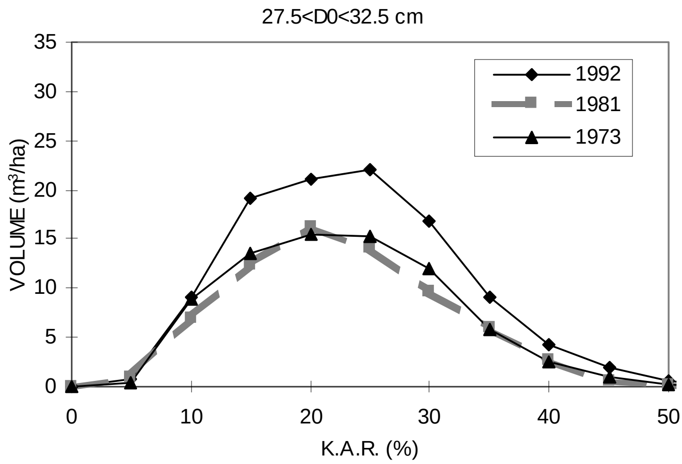

Figure 5c. Boards volume per ha by KAR classes. Means and standard deviations for KAR
1973 M=22.63, SD=8.48
1981 M=22.73, SD=8.52
1992 M=22.52, SD=8.73

GROWTH SIMULATIONS

In order to provide an insight into the respective role of changes in site quality and silvicultural regimes on timber quality, we have also used an average tree growth model (or stand growth model) developed for Norway spruce (Houllier et al. 1995). We have considered 4 contrasted situations:

1. a widely spaced (column A in Table 8) stand on a poor site where the maximum dominant height is 36 meters;
2. a densely planted stand on a better site (column B in Table 8, e.g. a typical stand planted at the beginning of the century): the maximum dominant height is 44 meters;

Table 8. Silvicultural schedules in number of stems per hectare per stand dominant height values.

H0(m)	A(stems/ha)	B(stems/ha)
0-5	1500	4500
5 to 10	1450	4200
10 to 15	1000	2600
15 to 20	700	1600
20 to 25	700	1000

3. a widely spaced stand on the same better site (e.g. a typical stand planted on a former agricultural land and submitted to a ‘modern’ silviculture);
4. a widely spaced stand on a poor site, whose quality is progressively increasing (dominant height is 7 cm higher per year than for case 1) because of long-term changes in ecological conditions.

The growth is simulated to 25 meters dominant height for each of the four cases. The number of stems per ha is reported in Table 8: widely spaced scenario is A and the densely spaced one is B.

The results of these simulations are illustrated on Figures 6.1 (cases 1 and 4) and 6.2 (cases 2 and 3).

In these figures, one can see that the juvenile period during which the ring width increases is followed by a decrease of ring width due to the competition for space and light. Each thinning is followed by an increase in radial growth.

The average simulated ring width at breast height is 3.9 mm for case 1 and 4.1 for case 4. In this simulation, the difference between the two average ring width is only due to growth trend and it can be compared to the difference in the average ring width of the simulated boards in 1973 and 1992 (3.8 and 4.2 respectively, Table 7).

For cases 2 and 3, the simulated ring width at breast height are respectively 3.4 mm and 4.8 mm. This difference is only due to the difference in the silvicultural schedules selected for the simulation.

These results illustrate (i) that, as expected, the ring width is strongly sensitive to both site conditions and stand density and (ii) that these variations could be similar or most important than the variations observed for the simulated boards ring width between 1973 and 1992 (Table 7).

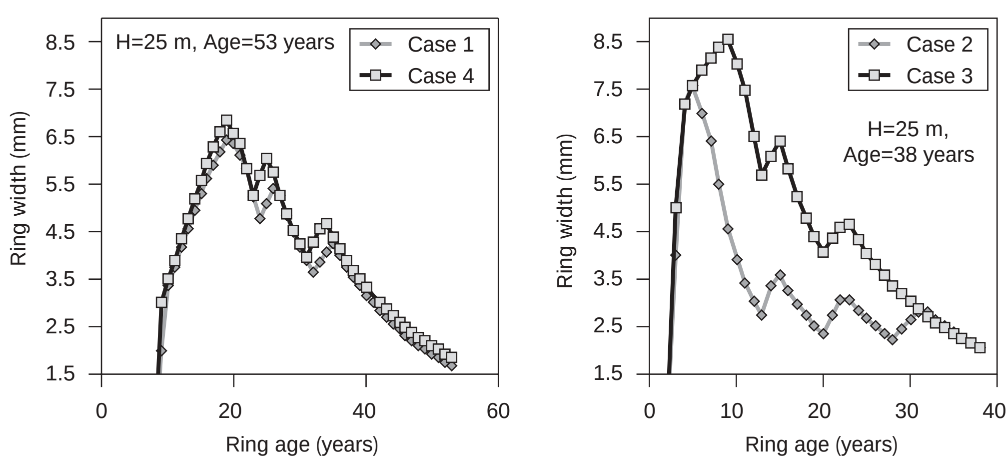

Figure 6. Simulated ring width at breast height. H=25 m, Age=53 years (left); H=25 m, Age=38 years (right).

CONCLUSIONS

In this paper, we have illustrated how the national forest inventory data can contribute to the global assessment of changes in forest productivity and timber quality. Because of the complex nature of the sampling strategy of the French National Forest Inventory, it was not possible to test the statistical significance of the differences observed in the Vosges forest area among the successive survey cycles. This point should be further investigated in a combination with a statistical analysis of error propagation along the chain of growth and wood quality models included in Win-EPIFN. But the simulation of the boards distributions properties from the 11 323 spruces are significantly different between the successive survey cycles, because of the huge amount of simulated boards per class of property.

The combination of various types of data analysis, using age, site index, dominant height and dbh, number of stems per ha, and of growth and wood quality models helps understanding the changes in the distribution of forest resources in terms of forest area, standing volume and wood quality. The possible causes of such changes are indeed numerous: generation effects can be superimposed on smooth long-term ecological trends and short-term ecological variations. Generation effects (see Alvarez-Marty,1989 for *Pinus pinaster*) include changes in silvicultural regimes (e.g. decrease of stand density at plantation for spruce, fertilisation for *Pinus pinaster* in south-western France) as well as changes in the average quality of sites on which afforestation takes place (e.g. new plantations of Norway spruce on former agricultural land in north-eastern France).

In fact, generation effects are spatial in nature: the progressive ageing and renewal of forest stands lead as well as forest plantation or natural colonisation of former agricultural land, to temporal changes when forest resources are considered at a regional level. On the other side, the changes in ecological conditions are, most often, temporal in nature (e.g. the loss of productivity caused by the severe 1976 drought, or the progressive increase of CO_2 air content), but the detection of their effect needs to compare stands and trees of different ages and situated on different sites. It would therefore be worth to combine regional forest inventory data with both growth and yield models and Geographic Information Systems (GIS).

Because of the strong relationships between timber quality and growth processes, which determine the inner structure of logs (knots, ring width, log taper, etc.), changes in forest productivity may have a strong influence on timber quality. In the case of the ‘Vosges’ district, a global analysis does not show a major change in the overall saw timber quality of Norway spruce over the last two decades. However, a more detailed analysis focused on a given type of product or stands (e.g. stands with a given size for dominant trees) demonstrates that changes are indeed taking place, with an increase of board average ring width, a decrease of board basic density and an increase of board knotiness. Such results may interest both the forest managers and the sawmillers, as well as the papermillers.

This paper paves the avenue for further studies along the same line: (i) it would be possible to directly simulate log grading according to predicted stem taper, average ring width and branchiness characteristics; (ii) it would be also possible to include boards grading rules into Win-EPIFN and to use them in order to assess changes in timber quality; (iii) it would then possible to provide an economic evaluation of the changes;

(iv) it would be also possible to simulate harvesting strategies (instead of virtual harvesting every tree). There are plenty of methodological perspectives that can now be explored. There is also a need for duplicating such a study on other species and in other forest area, in order to get more general results.

Acknowledgements

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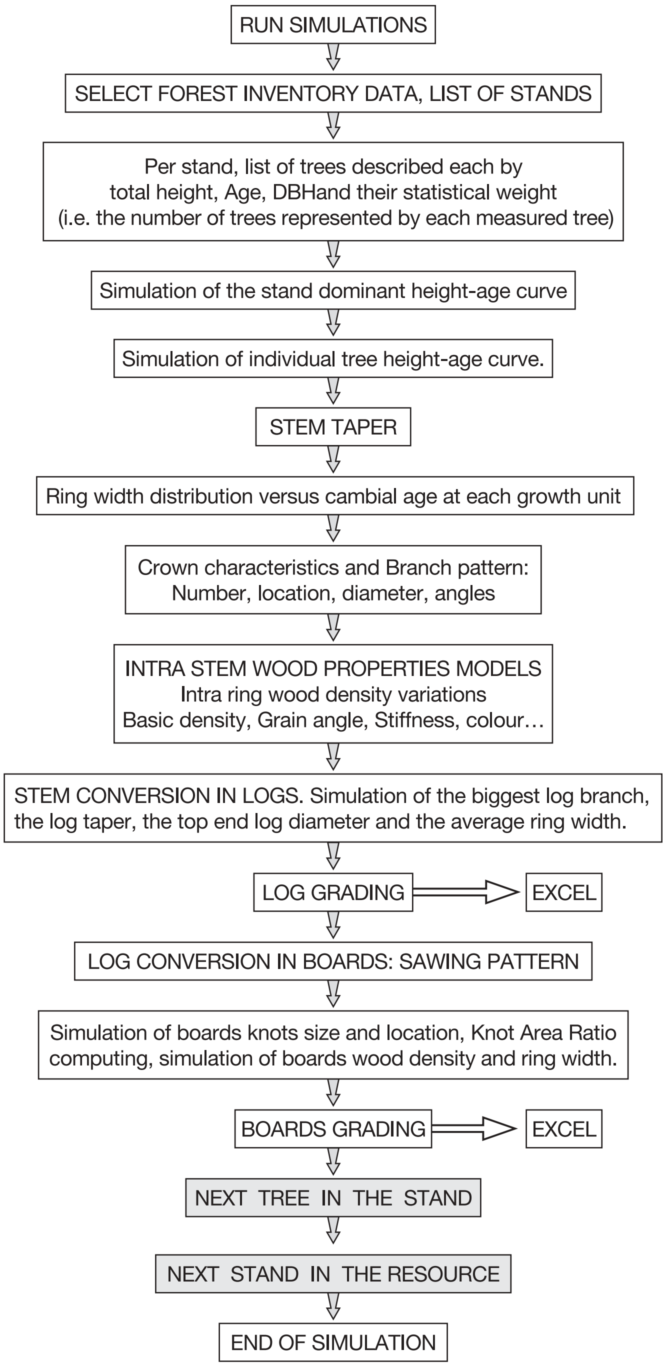
ANNEX 1. WIN-EPIFN SIMPLIFIED FLOW CHART DIAGRAM



CONSEQUENCES OF ACCELERATED GROWTH FOR THE FORESTS AND FOREST SECTOR IN GERMANY

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ABSTRACT

The forest scenario studies at the European Forest Institute aim at long-term projections of the development of European forests. The current baseline study analyses the forest resources until 2050 under different management regimes and forest policies.

In this paper, we have applied the scenario study methodology to the specific case of an increased growth for all species in Germany. We assumed a sudden growth increase of 30%. The impact which this has on the forest development was used as input to a forest sector analysis under this growth increase. We determined the impacts on prices and demand for wood products.

It was shown that the assumed growth would have a large impact on the forest resource development. The prices of sawnwood increase by 16% compared to 1994 in the accelerated growth scenario, against 25% in the baseline projection with capacity expansion. Therefore, under the accelerated growth, the expected price increase in the future is dampened with 36%.

For the present paper we have only build in a sudden growth change and did not take into account any changes in mortality because of high growing stocks, nor did we take into account impacts on trade flows between countries. In the future, the forest scenario model will be improved in such a way that growth changes due to climate change can be taken into account in a transient way.

Keywords: accelerated growth, Germany, forest resource, forest sector

1 INTRODUCTION

European forests belong to the most intensively managed forests of the world. They cover about 4% of the world's forests but provide 13% of current global harvest of wood products. Within Europe they are a refuge for nature and are of high importance

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as a recreational area for the urbanised European population. Given this importance of European forests and the fact that they are scattered over 30 countries, generates a need for long term projections of the European forest resource under different management regimes and forest policies (Nabuurs and Päivinen 1996). These projections are a tool to foresee the long term impact of current changes in management or changes in environmental conditions.

In Spiecker et al. (1996), it was shown that the growth of European forests has increased on many sites, especially in central Europe. This may have been caused by a complex of environmental changes as N deposition, CO_2 increase, a longer growing season, but also by improved forest management, and recovery of earlier degraded sites.

The aim of this paper is to analyse what the effects of an increased growth rate of the forests in a central European country may mean for the long-term development of this forest resource. We also analyse what these changes may mean for the forest sector in terms of removals and prices.

2 METHODOLOGY

For the analysis of forest resource development under changing growth a model which was developed in the early 1980s by Sallnäs (and used for the IIASA forest study for European forests) was chosen (Nilsson et al. 1992). This large-scale scenario model generates projections of growing stock and timber harvest volumes over time by country, species group and age. It requires several variables to characterise the forest types and forest management regimes by country. At present, the model can simulate varying aspects of forest management on the existing forest and forest policy impacts of new afforestations. Furthermore, the growth of the forest can be adjusted according to assumed effects of forest decline, or other changes in forest growth.

The model is a matrix type model. A matrix is defined by 10 intervals for the volume dimension and 6-15 intervals of the age dimension. The forest state is then depicted by the matrix generator as an area distribution over this matrix. Dynamics of volume increment are expressed as transitions of areas between specific fixed states in the matrix. For a more detailed description, we refer to Sallnäs (1990), Nilsson et al. (1992), and Päivinen et al. (1999)

To run a scenario, assumptions must be made on future total demand for wood products by coniferous and deciduous species. Under the defined management regimes, the model will simulate the forest development and will try to find the requested harvesting volumes. The output gives information on the actual volumes which were harvested, and the state of the forest resource e.g. in terms of age class distribution, standing volume, and increment.

For the forest sector analysis a regionalized partial equilibrium model based on the IIASA/Kallio GTM model, adapted to the GAMS framework (Ronnila 1995; Trømborg and Solberg 1996) was used. This modelling approach aims at finding the optimum balance between demand and supply of wood products under which the welfare for the forest sector is maximised. Based on demand and supply curves per commodity (a reflection of price elasticity's), the growth of the forest resource, and a demand which is mainly driven by development of population, GDP and prices of wood products, the model tries to find the optimum quantities of wood products produced by the industry. These quantities also depend on processing, transport, and harvesting costs and e.g. trade barriers. When it is profitable for an industry to expand, this expansion can be taken into use. New capacity will enter whenever total costs (including a profit margin) of new investments are below product price. Old capacities are taken out of use when variable costs exceed product price.

The scenarios for the forest sector analysis consisted of two versions of the baseline growth: one in which capacity expansion of the forest industry is not allowed, and one in which capacity expansion is allowed. This latter scenario will then show the impact of increase in GDP, population and growing stock on removals and prices. The third scenario then re-runs the capacity expansion scenario but now with accelerated growth in the forest.

3 INPUT DATA AND INCORPORATED GROWTH CHANGE

For the forest resource development, the initial state is described by the dataset from the German Federal Forest Inventory 1986-1990 (Bick and Dahm 1992; Förster et al. 1993). The data distinguish forest types by 9 tree species and 13 Bundesländer. For these 117 forest types the data consist of area, growing stock and increment (for the baseline growth from yield tables) for 12 age classes. For the forest resource projection we assumed that the harvesting levels would increase by 2% per year for the next 20 years and then stabilise at that level. We also assumed that there would be more interest in the future for nature values. Therefore we’ve taken out of production all forests of

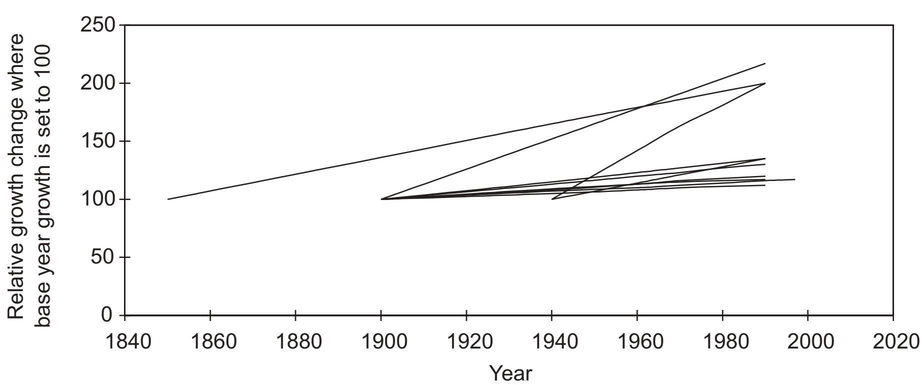

Figure 1. Relative growth changes as given for the central European case studies concerning Norway spruce (*Picea abies* (L.) Karst.) by several authors in Spiecker et al. (1996). Those reported changes have been linearly interpolated for the time period which was studied. Only spruce is shown as an example. The other species studied for central Europe showed comparable trends.

oak and beech older than 150 years and all forests consisting of ‘other hardwoods’ older than 110 years. Furthermore we increase the share of thinnings from total harvests, i.e. we simulate the emphasis on selective felling regimes instead of clearcuts.

For the forest sector analysis, data which were gathered in a European wide project on ‘Structural changes in roundwood and forest product markets in Europe’ were used (Solberg and Moiseyev 1997). Data were incorporated by region (Europe by countries, North America, Latin America, Oceania (Australia and New Zealand), Asia, and Africa) and four types of primary (raw) products, and eleven types of commodities (e.g. Coniferous sawnwood, printing and writing paper). For each of these commodities existing capacity is defined for the countries and regions in the model.

Demand for product categories sawnwood and paper and paperboard were estimated as in the FAO provisional outlook for global forest products consumption, production and trade to 2010 (FAO 1997). For the other product categories (wood based panels and fibre furnish), demand is derived from demand for final products.

For each of the commodity groups, the costs are based on input/output coefficients for fibre and other material input (m^3 input per m^3 output) and production costs (costs per ton or m^3 output) specified by labour, energy, and variable capital costs. To incorporate the willingness of forest owners to supply at certain prices, supply elasticities are based on existing studies (Trømborg and Solberg 1995). Transport costs are estimated based on generalised cost functions for costs per tons per km divided by short and long transport, and the average distance between regions and countries. We estimated for trade inertia a maximum 3% change allowed in trade flows per 1-year period. For economic growth data we used in all scenarios for Germany 2% GDP growth.

To choose a growth change the papers concerning central European case studies in Spiecker et al. (1996) were reviewed. An overview of the reported growth changes for Norway spruce is given in Figure 1. For clarity only spruce is given. The other species studied for central Europe showed comparable trends. From those changes we derived a general growth increase of 30% regardless of species and age of the forest. The increase is incorporated as a sudden change starting in the initial year 1990.

4 IMPACTS OF ACCELERATED GROWTH ON THE FOREST RESOURCE DEVELOPMENT

In the forest resource simulation, a total requested felling level was incorporated to run the scenario (see Figure 2). Based on the defined felling regimes the model outcome then shows if the requested volumes can be found. Figure 2 shows that the requested volumes cannot be met between 2005 and 2030 under the baseline growth. This does not directly mean that a shortage of wood will occur, but under the assumed quick rise of felling levels and the specified regimes, those volumes cannot be found in the growing stock. Under accelerated growth the difference is much smaller and amounts to 6.4 million m^3 at the maximum.

Although age development under baseline growth and accelerated growth do not differ, Figure 3 shows some minor changes between base growth and accelerated growth. This is caused by the fact that under the increased growth higher average standing volumes develop. This results in a higher yield when a clearcut is carried out and therefore requires a smaller area for clearcutting to reach the total volume of removals. A smaller area in the young age classes can therefore be seen in Figure 3 under the increased growth scenario.

Main impact of the accelerated growth can be seen in Figure 5. Under the accelerated growth the growing stock increases with another 36% compared to the base growth (under the felling levels of Figure 2). However, this is under the assumption that the

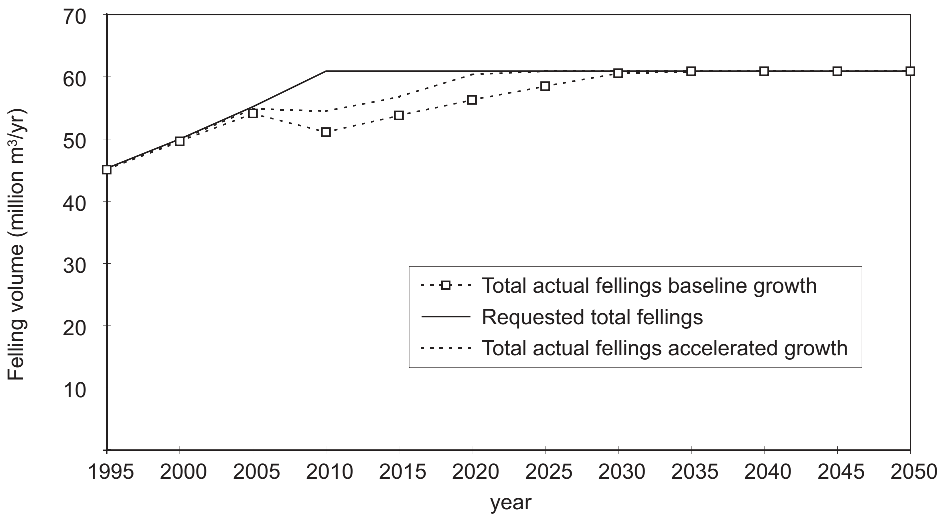

Figure 2. Development of requested felling volumes and actually harvested volumes.

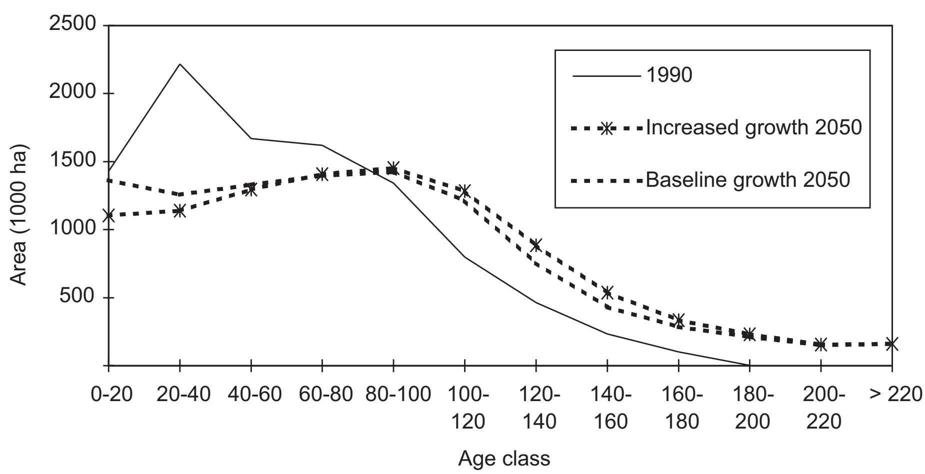

Figure 3. Age class distribution in the German forests in 1990 and in 2050 for baseline growth and increased growth.

accelerated growth is sustainable and that these very high growing stocks are stable forest ecosystems. This development of growing stock also shows that there is no real shortage of wood occurring as may seem from Figure 2. The shortage of wood is clearly caused by the way the theoretical final felling regimes (constraints) have been specified.

5 IMPACTS OF ACCELERATED GROWTH ON THE FOREST SECTOR

The results for the forest sector analysis concerning volume of removals and price development (calculated on the basis of the average of import and export value) of some primary products are given in Figures 6 to 8.

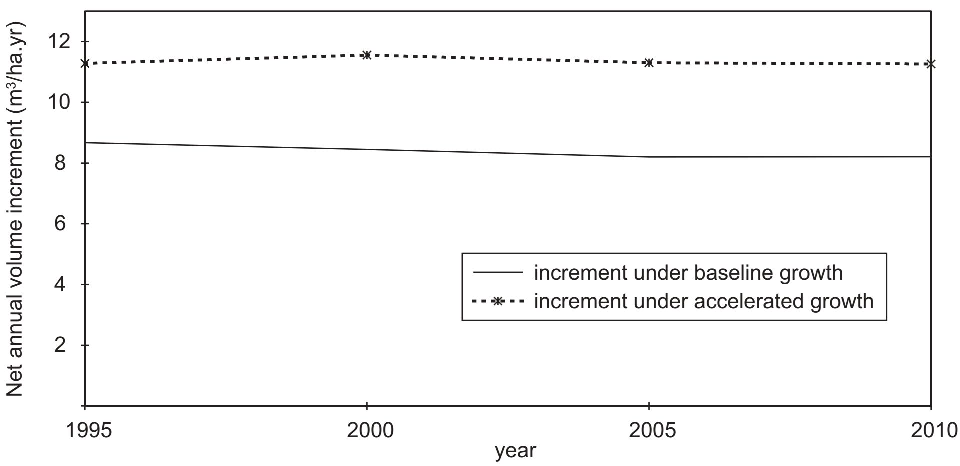

Figure 4. Development of average increment in German forests under base growth and accelerated growth.

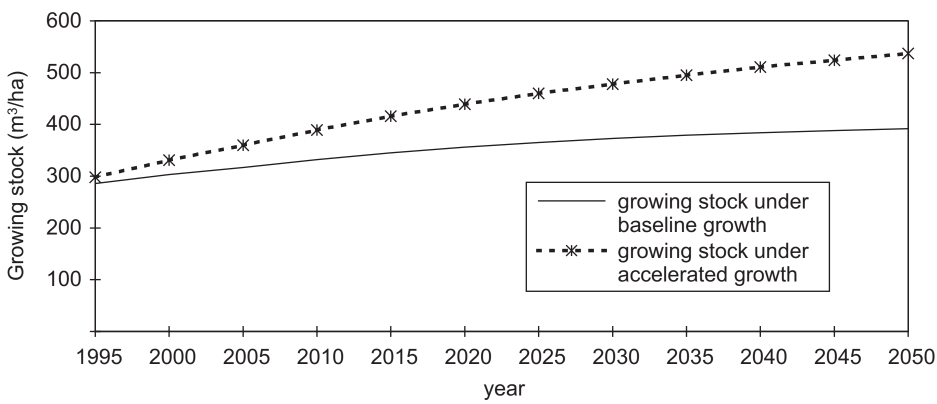

Figure 5. Development of growing stock in German forests under base and accelerated growth.

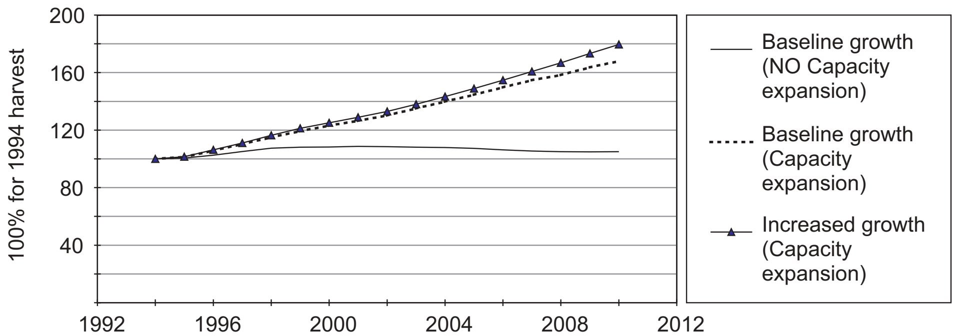

Figure 6. Relative change in removals of industrial logs in Germany as influenced by capacity expansion possibilities and growth rate changes.

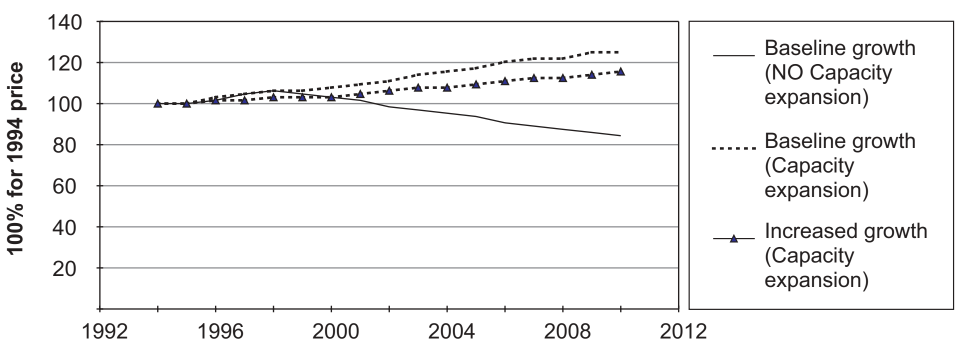

Figure 7. Relative change in price index for coniferous sawlogs in Germany as influenced by capacity expansion possibilities and growth rate changes.

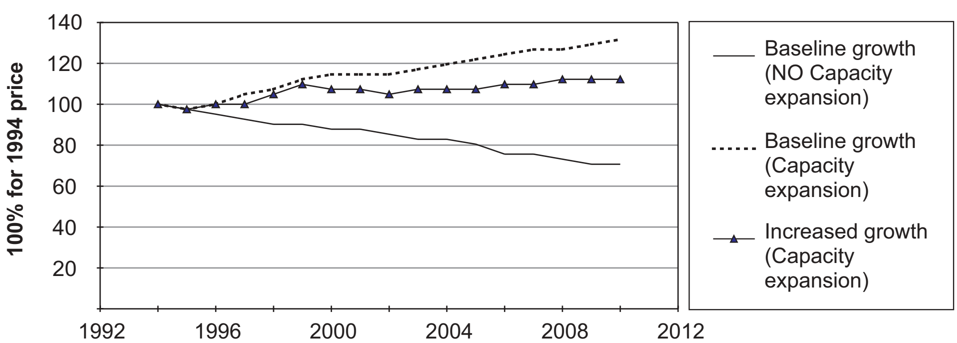

Figure 8. Relative change in price index for pulpwood in Germany as influenced by capacity expansion possibilities and growth rate changes.

Figure 6 shows that development of GDP, and population have their largest impact on the level of removals. When capacity expansion is allowed in the model (i.e. the industry expands when it is profitable to do so; indirectly that is an effect of demand thus GDP development), the removals quickly increase with 68% by 2010 compared to the levels in 1990. Profitability in the forest sector is mainly determined by these demand determining factors. The declining price index for coniferous sawlogs in the 'no capacity expansion' scenario in Figure 7 is caused by the fact that no more investments in new industry are allowed. Therefore, prices go down.

The accelerated growth leading to a higher growing stock has a significant impact as well: it leads to somewhat higher removals (an additional 12%), mainly determined by the reduced rise of prices (Figure 7 and 8). The projected price reduction in the increased growth scenario is an effect of the larger growing stocks available in the forest. The prices of coniferous sawnwood increase by 16% compared to 1994 in the accelerated growth scenario, against 25% in the baseline projection with capacity expansion. So under the accelerated growth, the expected price increase in the future, is dampened with 36%. Pulpwood prices are envisaged to be reduced even further.

6 DISCUSSION

An increasing growth has been shown for many case study sites in Europe. However, it is still uncertain to what degree or whether these sites are representative for all of Europe. From Spiecker et al. (1996) it at least appears that regional differences within Europe exist. This, and the fact that the causes of the accelerated growth are uncertain, make long-term projections of the impact rather risky. Therefore, the results above should always be seen as 'what-if' scenarios.

In the scenarios it was assumed (deducted from Spiecker et al. 1996) that the average growth increase would amount to 30%, regardless of species and age class. In addition, we have assumed that the growth stimulation will continue in the future and the growth change has been incorporated as a sudden change. A method to incorporate a more gradual growth change due to climatic change in Europe is under development now (Mohren et al. 1997).

Especially on the point whether the growth change will continue in the future, there is uncertainty. In addition, the modelling approach for the forest resource does not take into account increased mortality at high growing stocks. Therefore, the uncertainty in the forest resource projection mainly lies at the higher growing stocks, which are reached under the accelerated growth scenario. It is unlikely that those very high growing stocks will be reached in practice. On the other hand, growing stocks reported in forest inventory results from parts of Germany, Switzerland and Austria with average values sometimes over 400 $m^3\ ha^{-1}$ do not seem to give large scale forest stability problems. Very little experience exists in Europe now, on what maximum growing stocks could be on different sites.

The input data for the forest sector model are not yet calibrated through a sensitivity analysis of the model. A validation based on historic developments of prices and removals, will be done in the future. Therefore, results on the sector analysis must be seen as preliminary. They have been presented as relative changes to the 1994 level. A validation of the forest resource model is under progress based on historic forest inventory data from Finland dating back to 1921 (Schelhaas and Nabuurs, in press).

At the moment the link between the forest resource model and the forest sector model was only incorporated by supplying the output from one model to the other model. A general shortcoming of these two modelling approaches is that the resource models often incorporate very simple assumptions on the demand development and that sector models have very simple assumptions on the forest resource. This is also the case in the current paper. However, the assumption we made on the quick rise in demand development in the forest resource model seems rather good, because the sector model also predicts a comparable quick rise in demand. Still the results could be improved considerably when these two modelling approaches were combined in a dynamic way.

An example of the importance of that dynamic combination of modelling approaches can be seen in Figure 2. There the forest resource model predicts a shortage of wood starting around 2005 (given the specified final felling ages) under the quickly increasing demand. This shortage does not occur in the forest sector model. We have assumed in the forest resource modelling that the increasing demand levels off around 2010 and therefore the shortage is reduced after that, but this stabilisation of demand may not occur in reality.

A comparable study as what we report here has been carried out by Sohngen and Sedjo (1996). They test two types of timber models (econometric and optimisation) against exogenous shocks, of which one is a gradual growth increase of 1% per year continuing for 50 years. The econometric model predicts at first only a moderate price decline which then increases after year 30. The optimisation showed a sudden price decline because forest owners and industry are in this approach aware of future increasing growing stocks in the future. They try to prevent price decline later, by taking additional growing stock away now. That results in a smaller decline of prices in the optimisation approach in the long term. Because of this possibility to foresee future developments in the optimisation approach, the growing stock increases less in this approach than in the econometric approach. In general, the optimisation approach seems to dampen the effects of changes.

Despite current shortcomings in our own study, we are confident that the magnitude of the impacts of accelerated growth under these ‘what-if’ scenarios is presented in a satisfying way. As expected the growth increase leads to a faster build-up of growing stock which has a decreasing effect on prices and a small increasing effect on removals. These impacts are rather small because the present situation in Europe already shows a sufficiently large growing stock and increment. Europe is now self sufficient for 65% and of the total increment around 70% is harvested. If the growth increase is sustainable, the self-sufficiency of Europe could increase (assuming forest owners are willing to harvest under decreasing prices) while still felling only three quarters of the increment.

Acknowledgements

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POSSIBLE EFFECTS ON WOOD QUALITY TO EXPECT FROM ACCELERATING TREE GROWTH IN EUROPE: TENTATIVE ANSWERS AND QUESTIONS TO ACCOMMODATE

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ABSTRACT

Modern and interactive evaluation of wood quality from a tree population requires the availability of two sets of data: 1) the ring width profiles from pith to bark and from the bottom to the top of the resulting commercial logs (data provided or to be provided by individual tree growth models) as well as 2) statistical adjustments giving the determinants of the wood quality (i.e. branchiness and basic wood properties) from growth attributes (mainly ring width, RW and age from the pith, AGE), the structure of the variability/covariability of branchiness and basic wood properties being taken into account. In this paper, these adjustments will be called P = f (RW, AGE).

To predict the possible effects on wood quality expected from a possible acceleration of tree growth in Europe, the effect of accelerating tree growth on ring width profiles and on P = f (RW, AGE) needs to be known

Under the hypothesis that an accelerating tree growth will lead to earlier harvest of trees having the same diameter than at present (i.e. younger trees), firstly the author indicates the consequences which can be expected for branchiness and basic wood properties (and thus for wood quality) if P = f (RW, AGE) does not change with climatic change. The cases of softwoods and hardwoods (mainly *Picea abies* and *Quercus petraea*) are considered.

In the second part of the paper, the possible long term change of P = f (RW, AGE) is discussed using two types of results drawn from data already published, to be published or by re-analysing available data: 1) comparison of the P = f (RW, AGE) established separately for tree populations from contrasting pedoclimatic areas (rings initiated during the same climatic years); and 2) comparison of P = f (RW, AGE) established on the same trees from contrasting climatic periods, the effect of age from the pith having been corrected (rings initiated recently and rings initiated in the past).

In the conclusions, future research is suggested mainly in the field of relationship between growth and wood quality models and resulting simulating software.

Keywords: basic wood properties, predictive models, simulation, long term effect

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INTRODUCTION

When considering wood quality it is reasonable to assume that for a given piece of wood its quality (as seen by the possible end-users: visual grading, mechanical behaviour, warp, appearance etc.) is completely determined when some *attributes* are known in each part of this piece. These attributes are mainly the following: ring width, grain angle, knot occurrence and, if any, type (living/dead), size, angle, basic wood properties (density, shrinkage/swelling, colour attributes, etc.), age from the pith, from the cambium or/and from the limit between heartwood and sapwood, as well as anatomical traits (vessel size, fibre dimensions, etc.).

The list of the attributes necessary depends on the requirements of the end-user in terms of "wood quality" e.g. fibre dimensions, density and sapwood proportion for pulp and paper making; knottiness, shrinkage/swelling, colour and sapwood occurrence in furniture making; knottiness, ring width, grain angle as well as (sometimes) wood density for structural use (visually graded timber).

As a result, and in addition to knowledge of the sawing patterns (if such log processing is considered), the evaluation of the quality for a set of boards coming from a tree population (with a modern and interactive approach) requires *the availability of two sets of data/models* (Nepveu 1996; Nepveu et al. 1996a; Nepveu 1997a; Nepveu 1997b):

1. the ring width profiles from pith to bark and from bottom to the top of the resulting commercial logs (data provided or to be provided by *individual* tree growth models); and
2. the statistical adjustments giving branchiness and basic wood properties from growth attributes (mainly from ring width RW and age from the pith AGE as a result of the generally poorly significant effect of height in the commercial log when RW and AGE have been taken into account). For simplicity, these adjustments will be called: P = f (RW, AGE) in the text. Note that due to the huge tree effect on basic wood properties at fixed growth patterns (Nepveu 1996; Nepveu et al. 1996b; Guilley et al. 1999) these statistical adjustments have to take the structure of the variability/covariability of branchiness and basic wood properties into account in order to make further simulation of the quality traits of wood pieces coming from the relevant tree population(s) possible in terms of average and distribution (Nepveu et al. 1996a; Guilley et al. 1997).

From the above-mentioned sets one and two, to evaluate/simulate the possible effects of accelerating tree growth on wood quality, two situations have to be considered:

1. the ring width profile from pith to bark will change and
   P = f (RW, AGE) will not change.

In this case, in order to evaluate/simulate the change in wood quality the" present" statistical adjustment P = f (RW, AGE) has to be run with the" future" ring width profile;

2. the ring width profile from pith to bark will change and
   P = f (RW, AGE) will also change.

In this case, in order to evaluate/simulate the change in wood quality the "future" statistical adjustment P = f (RW, AGE) has to be run with the "future" ring width profile. In the present paper, two points will be considered:

1. what is the change in wood quality, if a change in ring width profile occurs (P = f (RW, AGE) remaining unchanged) and
2. does as any evidence or prediction exist for possible changes of P = f (RW, AGE) in relation to long term climatic change?

What is the change in wood quality if a change in ring width profile occurs (P= f (RW, AGE) remaining unchanged)?

In the context of higher fertility of the site considered here, answering this question requires one to accept some hypotheses regarding the silvicultural schedule applied. In the present paper we accept the following: 1) the same initial spacing; 2) the same curve "tree number/ha = f (dominant height)"; and 3) trees cut at same dbh as at present. Under such conditions it is expected that *younger trees* having *larger rings* than at present would be harvested in the future (but note that other silvicultural conditions could be accepted leading to different consequences in terms of wood quality: to maintain the same harvest age than presently and to cut thicker trees, etc.).

Based on present knowledge of the effect of radial growth (mainly age from the pith and ring width) on wood quality attributes and in the context of the above-mentioned silvicultural conditions, the following consequences can be expected (see Nepveu 1994):

1. consequences for softwoods (rather firmly established):
   - less branches and knots;
   - thicker branches;
   - lower branch angle;
   - shorter fibres;
   - lower wood density;
   - higher spiral grain;
   - lower mechanical properties;
   - lower dimensional stability;
   - higher amount of sapwood.

2. consequences for softwoods (not yet or still poorly investigated):
   - drying time (probably better);
   - natural durability (probably less);
   - impregnability (probably better);
   - sensitivity to pests in the forest (?);
   - shape of the tree (ovality, straightness) and associated reaction wood (?).

3. consequence for hardwoods (firmly established: the case of Sessile oak (*Quercus petraea* Liebl.); Nepveu and Dhôte 1998):
   - higher wood density;

- higher shrinkage/swelling;
- less spiral grain;
- probably better dimensional stability (to be confirmed!);
- higher amount of sapwood;
- lower content and thickness of multiseriate wood rays;
- better colour (lighter wood).

4. consequence for other hardwoods (rather firmly established):
   - higher amount of sapwood;
   - less false heart in Poplar, Ash, Beech (younger trees harvested);
   - less defects such as rot in heartwood (younger trees harvested);
   - shorter fibres.

5. consequence for hardwoods (not yet or still poorly investigated):
   - amount of clearwood in the commercial log (probably less ?);
   - wood shrinkage/swelling, wood density and spiral grain in hardwoods other than Oak ... and their implications for dimensional stability;
   - stem shape and associated growth stresses and tension wood ... as well as their heavy technological implications (probably less ?);
   - natural durability;
   - impregnability;
   - drying time.

Before completing point 1, we must emphasise two points regarding the hypotheses accepted: 1) we have considered that only the ring width profile (younger trees with larger rings harvested) will change with climatic change (i.e. no change for P = f (RW, AGE)); and 2) we have taken as a hypothesis that the silvicultural schedule would have to be adapted (i.e. more dynamic silviculture) to the increasing fertility of the site due to the climatic change. It is one hypothesis among other alternative ones!

Does evidence or any prediction exist for possible changes of P = f (RW, AGE) in connection with long term climatic change?

Two ideas can be put forward to try to answer this question:

1. Does P = f (RW, AGE) vary according tree populations from contrasting pedoclimatic areas/conditions? In this case, we consider rings initiated during the same climatic years by different (and sufficiently large) tree populations;
2. Does P = f (RW, AGE) vary according contrasting climatic years? In this case we consider rings initiated recently and in the past by the (statistically) same tree population.

Testing Idea 1. If for the group of rings initiated during the same climatic years P = f (RW, AGE) varies according to pedoclimatic areas/conditions, it is realistic to expect that P = f (RW, AGE) will change if the climate changes in the future on the same place.

The experience in this field gained by our Wood Quality Research Team in softwoods (mainly for wood density in Norway spruce, Silver fir and Scots pine (Mazet et al. 1989; Mazet et al. 1990)) and in Sessile oak (for wood density traits, swelling, colour, spiral grain and multiseriate ray characteristics (Nepveu et al. 1996b; Nepveu and Dhôte 1998)) leads us to conclude that:

1. the effects of the region, fertility class and other environmental factors on P = f (RW, AGE) are not significant or only slightly significant;
2. the only effects which appear significant on P = f (RW, AGE) are those of altitude (and latitude) on wood density in Norway spruce, Silver fir and Scots pine: when altitude and latitude increase, and ring width and age from the pith be remain fixed, wood density decreases.

Figure 1 (Fertility class has no effect on P = f (RW, AGE) for wood density in Norway spruce in North-Eastern France) and Figure 2 (Altitude has a significant effect on P = f (RW, AGE) for wood density in Norway spruce in France) partly illustrate these observations. Related to Idea 1, a presumption of change in P = f (RW, AGE) concerning long term climatic change is supported by results of experiments under strictly controlled conditions in terms of environment (and genotype). For example, recent results gained by INRA in Nancy-Champenoux (Unité d'Ecophysiologie Forestière) by Picon et al. (pers. comm.) on 4-5 year old maritime pines under high CO_2 concentration have demonstrated no change for wood density in spite of high increase for radial growth (i.e. change for P = f (RW, AGE)).

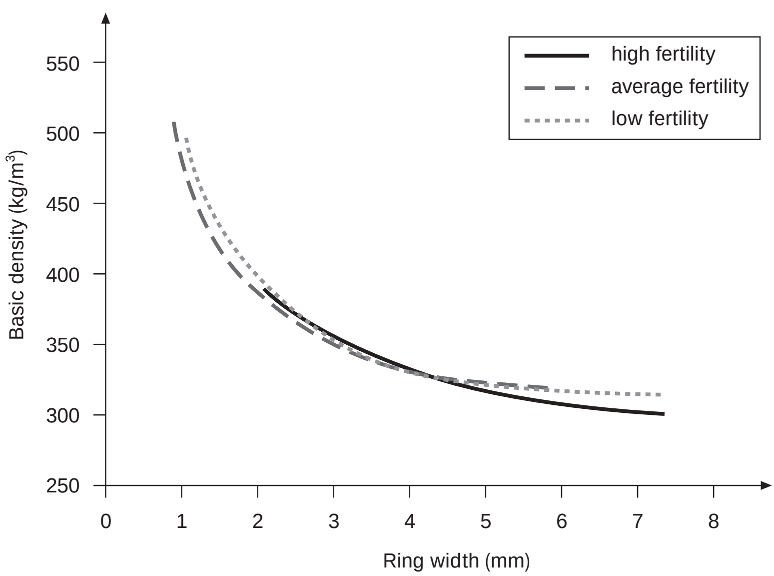

Figure 1. Fertility class has no effect on P = f (RW, AGE) for basic wood density of Norway spruce in North-Eastern France (after Mazet et al. 1989). Sampling used: 244 trees from 61 stands.

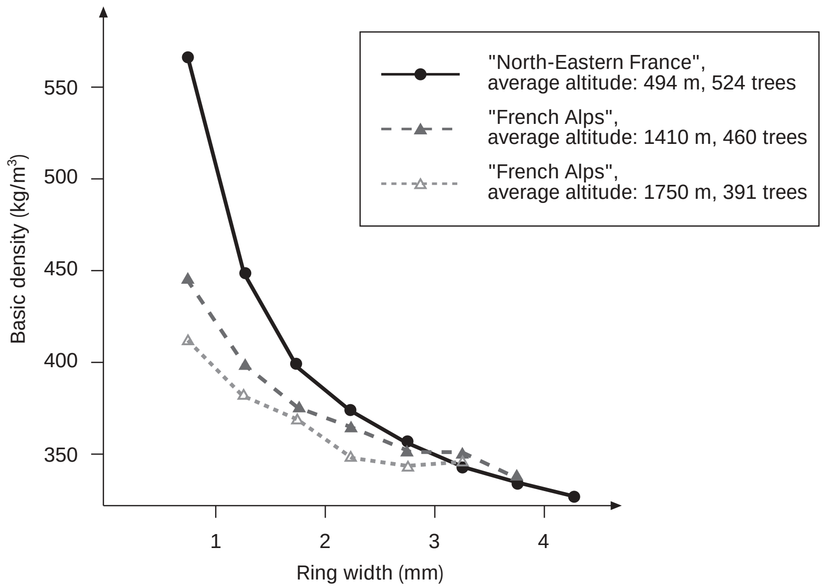

Figure 2. Altitude has a significant effect on P = f (RW, AGE) for basic wood density of Norway spruce in France (from Nepveu, unpublished data).

Testing Idea 2. The possible change of P = f (RW, AGE) according to contrasting climatic years (rings initiated recently and rings initiated in the past) has been investigated (among many other factors) by Laurent Bergès (1998) in his PhD work devoted to Sessile oak.

The method used by Laurent Bergès consisted of comparing wood density (as well as earlywood and latewood width and density, obtained using microdensitometry) for rings having the same age from the pith and width but initiated during contrasting periods of time.

The sampling involved 297 sessile oak trees aged 56 to 187 years sampled (increment cores at bh) in a wide variety of sites (Paris Basin and Eastern France). Four ring samples were considered (samples A, B, C and D) with high ring number in each: from 11906 (sample D) to 29545 (sample A).

From his data interpretation Laurent Bergès concluded that for same age from the pith and ring width, rings initiated in the past exhibit higher wood density. It means that the long term effect on P = f (RW, AGE) can be accepted for wood density in Sessile oak. Figure 3 (3a, 3b, 3c, 3d) illustrates the results by Bergès (1998).

Lot of references related to works having investigated the effect of the environmental conditions on wood properties (mainly wood density) and sometime on wood anatomy traits exist in the literature but up to now such studies did not test explicitly the effect of the environment on the statistical *adjustment* P = f (RW, AGE). For this reason it is not possible to use these works to test the above-mentioned Idea 1 and Idea 2. Under condition to be re-analysed using“ statistically correct“ methods some of the relevant data bases (often established on very large sampling) could be used in that perspective.

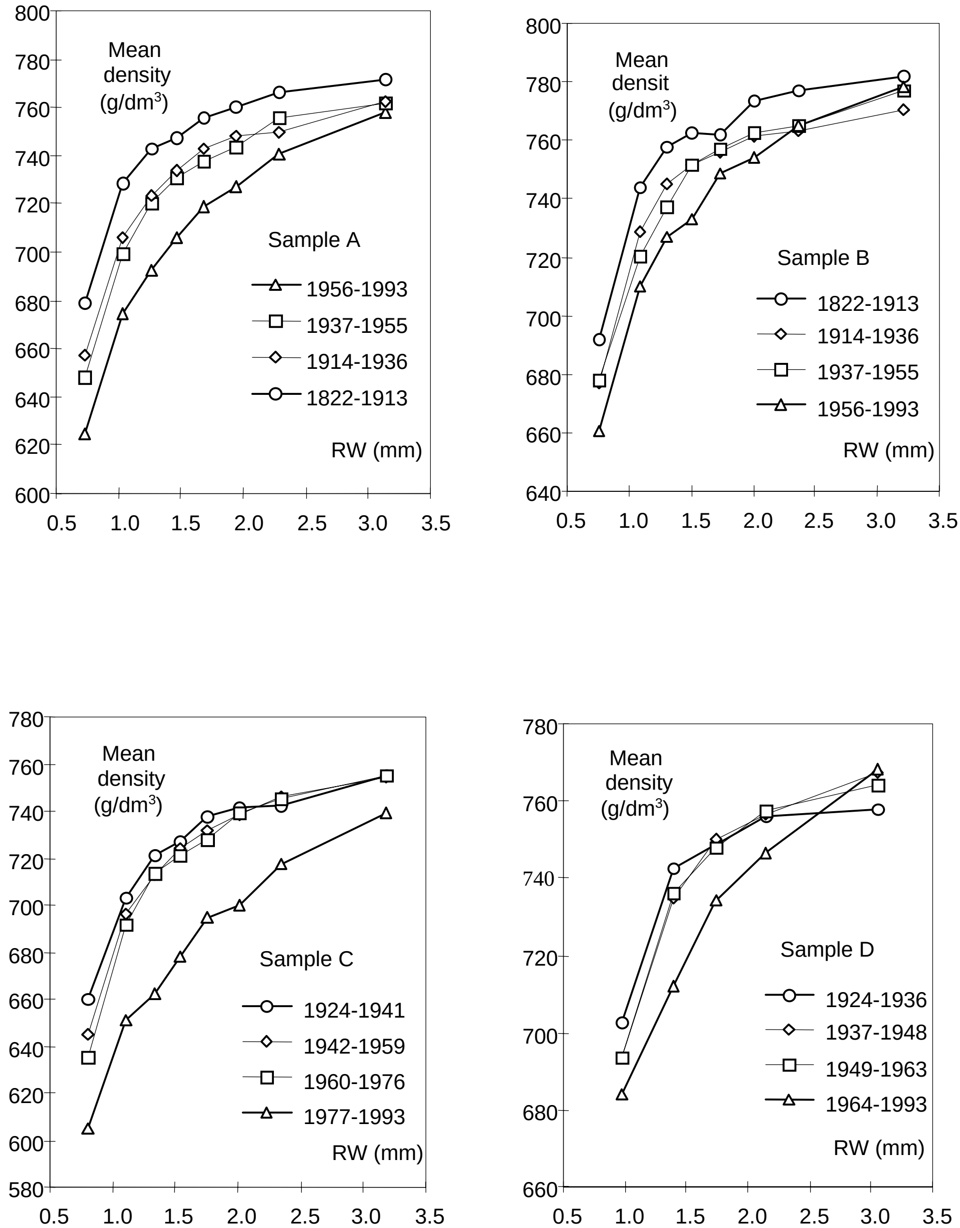

Figure 3. Effect of ring width on wood density in Sessile oak for contrasting periods of time (after Bergés 1998). All the points correspond to the same average age from the pith.

Sample A: 29545 rings, one point: 923 rings on average
Sample B: 18246 rings, one point: 572 rings on average
Sample C: 20381 rings, one point: 637 rings on average
Sample D: 11906 rings, one point: 595 rings on average

CONCLUSIONS

When investigating the possible effect on wood quality to be expected from accelerating tree growth in Europe using data/results available in the literature we are forced to accept that at present we are faced with more questions than answers. The main problem in drawing conclusions is ensuring that the processing of the available data set can isolate the effect of a long term climatic change without bias. The two basic questions must be solved in order to predict wood quality:

1. By how much the fertility class of the site change (and, as a result, the ring width profile)?
2. How will P = f (RW, AGE) change? (at present some predictions exist for this change).

Even if an enormous amount of work remains to be done in order to answer these questions properly realistically we can be optimistic because: 1) at present we know what we have to do to answer these questions; 2) we know the tools we need to achieve it; iii/ the building of such tools is in progress (even if they are for other purposes than answering the questions asked in this paper).

The tools which are needed are simulating softwares fed by growth and basic wood property models to simulate wood quality from silviculture 1) when the fertility class of the site changes (due to the climatic change); and 2) when the basic property model P = f (RW, AGE) changes (due to climatic change).

The paper by Leban et al. (1999) in these proceedings gives an example of such simulating software and the type of results we can get from it in relation to the topic considered in this seminar.

Due to the number of situations imaginable in the future as a consequence of the changing climate (change in the genetic stock due to the climatic pressure or due to the forest manager; adaptation of the forest and industry management to the changing resource; etc.), such softwares are the only tools able to simulate the consequences of climatic change in terms of wood quality. When such tools are available, the (only) requirement to simulate the effect of climatic change using the software will be: 1) to change (if necessary) the fertility class of the site (which will result in a change by the software in the ring width profile from pith to bark); and 2) to change (if necessary) the parameters of the model P = f (RW, AGE). Fed with this information the software in progress will run.

In France, tree growth and wood quality modellers are working hard to build these simulation softwares and to feed them with the required models (Nepveu 1997b). No doubt the prospect of being able to use them – in addition to several other applications – in order to simulate the possible effects on wood quality due to accelerating tree growth in Europe is encouraging them in their task.

Acknowledgments

The author would like to thank Catherine Picon-Cochard et al. for the early communication of their results on the effect of CO_2 concentration on wood density profile in young maritime pines (paper in preparation), as well as Laurent Bergès for communicating the results in his PhD work "Variabilité individuelle et collective de la croissance et de la densité du bois de *Quercus petraea* (Matt.) Liebl. en relation avec les facteurs écologiques" (December 18, 1998).

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CHANGED GROWTH PERFORMANCES IN GERMANY EXEMPLIFIED BY SPRUCE, AND CONCLUSIONS FOR FORESTRY

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ABSTRACT

In many German regions, forests seem to be characterised by rising increment rates because of environmental changes. The growth behaviour of spruce is investigated for two regions. In South Bavaria (sites of high productivity) mature spruce stands achieve growing stock volumes of up to 1600 m^3 ha^{-1} as well as current volume increments of more than 18.0 m^3 ha^{-1} y^{-1}. Analyses of sample trees show that the phase of hypertrophic growth has begun in 1960. The increase of growth is readily apparent from the comparison of the preceding and succeeding generations. In Erzgebirge (sites of medium productivity), increment decline and losses of forest covered areas due to air pollution are ascertainable in spruce stands on mountain ridges. Because of the decrease in air pollution since about 1986 in the rest of the Erzgebirge, the stands are recovering and currently achieve increment performances at normal level.

Keywords: Norway spruce, growth trends, production level changes, site class

1 INTRODUCTION

In Germany, forest growth is enhancing in many regions which are free from or only slightly affected by air pollution, drought or frost (Kenk et al. 1991; Pretzsch 1992; Röhle 1995). The development of the climatic processes as well as nitrogen inputs into the atmosphere and raising CO_2 concentrations are regarded as important factors for the altered growth conditions (Kellomäki et al. 1988; Kreutzer 1989; Fabian 1991; Menzel 1997). Increment decline and area losses are identifiable merely for areas with high inputs of noxious substances. Alterations in growth behaviour are described in closer detail based on investigations conducted in spruce stands of two regions with different site conditions:

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- South Bavaria (Röhle 1995), distinguished by highly productive sites, and
- Erzgebirge in Saxony (Röhle et al. 1997), where medium-quality sites are dominant.

Growth of spruce in South Bavaria was investigated on 26 plots of 9 experimental areas. The investigations in Erzgebirge Mountains are based on 9 trial plots located on ridges and on 35 trial plots at medium and lower altitudes.

2 GROWTH OF SPRUCE IN SOUTH BAVARIA

2.1 Basal area and volume

In South Bavaria, maximum basal areas of up to 90 m^2 ha^{-1} and maximum growing stock of 1600 m^3 ha^{-1} have accumulated on the unthinned plots of 3 experimental areas with more than 120-yr-old spruce stands over the past 30 years (Table 1). The basal area densities and the growing stock volume were only slightly less on the moderately thinned plots of these 3 experimental areas. These enormous performances, which by far exceed the values given in the Assmann/Franz spruce yield table (1963), were mainly facilitated by the accelerated diameter and height increment, but also by the low mortality rates over the past few decades.

On the other 110- to 122-yr-old experimental areas, growing stock volumes between 1013 and 1539 m^3 ha^{-1} and basal areas between 57 and 89 m^2 ha^{-1} were identified.

2.2 Development of top height

A comparison of the top height development on Sachsenried 67 experimental area (age 131 in 1990), represents the conditions found on the other experimental areas, with standard curves of the Assmann/Franz yield table shows that a growth behaviour close to the yield table was achieved up to the age of 100 (as of 1959) on plots B and C (Figure 1). Subsequently, an accelerated height growth is discernible, and until 1990 the site class improved from 38 to 42 (top height at the age of 100), thus clearly exceeding the height growth of the best site class of the table, as was proven by analyses on sample trees. While according to the yield table the top height increment of site class 40 at ages over 120 years is below 10 cm y^{-1}, the sample trees up to the age of 143 have achieved average annual height increments of 15 cm during the past decades.

2.3 Current volume increment

The Assmann/Franz yield table, which is used for estimation of growth on highly productive sites, gives the 120-yr-old spruce stands a current volume increment of 12.6 m^3 ha^{-1} y^{-1} for the best site class (site class 40) at optimal density (corresponding to stocking density 1.0 given in the table). In contrast to the majority of the investigated plots, the

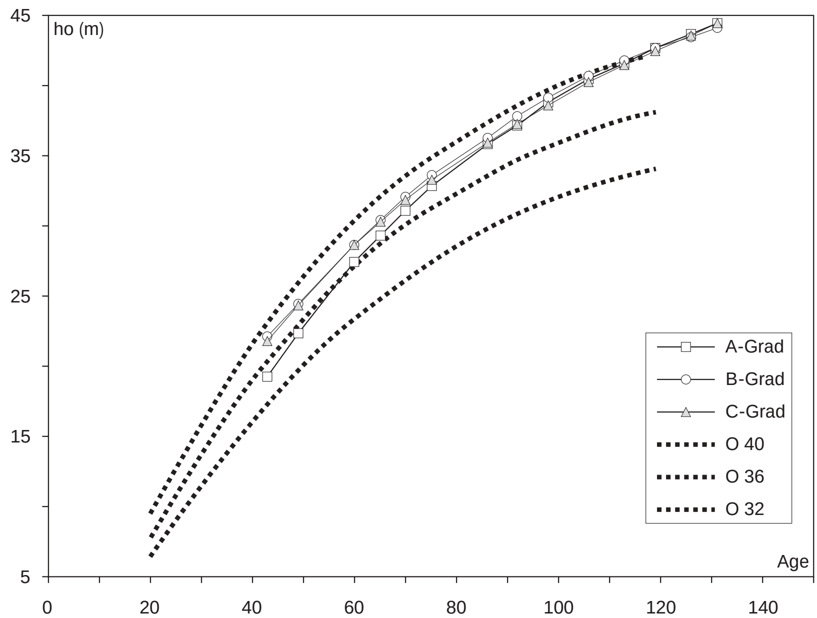

Figure 1. Development of top height on Sachsenried 67 experimental area in comparison to the Assmann/Franz yield table, site classes 40, 36 and 32, plotted against the age. A-Grad: unthinned; B-Grad: moderate thinning; C-Grad: heavy thinning

current volume increments exceed the yield table values from 2 to 6 m^3 ha^{-1} y^{-1}. In 1990 the maximum current volume increments of the more than 120-yr-old plots (Table 1) lay between 16.3 m^3 ha^{-1} y^{-1} (Sachsenried 68 experimental area, plot B, 130-yr-old stand) and 18.5 m^3 ha^{-1} y^{-1} (Sachsenried 67 experimental area, plot A, 131-yr-old stand).

If stocking density exceeds that of fully stocked stand according to Assman/Franz growth and yield table, also respective increment levels should be achieved. This may not necessarily be the case, since increment losses due to high density seem to be very likely. However, density-dependent increment losses are not recognisable on the unthinned plots of the majority of the experimental areas. So on the experimental areas Sachsenried 67 and 68 the increment values of the 3 different treatments (unthinned, moderate and heavy thinning) ascertained during the last observation period (age 126 to 131) have been found to be nearly at the same level. Even a superiority of the unthinned control plot was detected on the experimental area Denklingen 05: during the last observation period (age: 138 to 143) 18.2 m^3 ha^{-1} y^{-1} of the unthinned plot A are compared with 16.9 m^3 ha^{-1} y^{-1} of plot B (moderate thinning) and 16.60 m^3 ha^{-1} y^{-1} of plot C (heavy thinning), respectively.

Furthermore, the current volume increment recorded on the 26 plots indicates a considerable change in growth conditions during the past decades (Figure 2). Since the establishment of the 26 plots at the end of the last century up to 1940, the current volume increment generally corresponds to the Assmann/Franz yield table. Since 1950, current volume increment has increased rapidly, with values between 200 and 240 % of the yield table reference. This result underlines that during the last 4 decades a

Table 1. Yield characteristics of 9 selected spruce plots from 3 experimental areas in comparison to the Assmann/Franz spruce yield table (1963).

Experimental area and plot	Year	Age	N	G	dm	ho	V	iV
Denklingen 05								
A – unthinned	1990	143	508	89.2	47.3	42.6	1623	18.2
B – moderate th.	1990	143	388	88.9	54.0	42.8	1597	16.9
C – heavy th.	1990	143	276	74.0	58.4	42.8	1325	16.6
Sachsenried 67								
A – unthinned	1990	131	443	89.5	50.7	44.4	1637	18.5
B – moderate th.	1990	131	344	79.8	54.4	44.1	1453	18.2
C – heavy th.	1990	131	252	72.8	60.7	44.4	1355	18.1
Sachsenried 68								
A – unthinned	1990	130	544	87.8	45.3	43.0	1614	16.9
B – moderate th.	1990	130	376	74.4	50.3	43.2	1365	16.3
C – heavy th.	1990	130	232	67.2	60.7	43.6	1230	16.4
Yield Table Assmann/Franz (1963)								
Site Class O 40		120	376	75.6	50.6	42.5	1327	12.6

Year	year of observation	dm	mean diameter (cm)
Age	age of stand	ho	top height (m)
N	number of trees (ha^{-1})	V	standing volume (m^3 ha^{-1})
G	basal area (m^2 ha^{-1})	iV	current volume increment (m^3 ha^{-1} y^{-1})

Table 2. Yield characteristics (results of measurements) of successive crops on the experimental areas Sachsenried 03/Sachsenried 602 and Ottobeuren 08/Kaufbeuren.

Experimental Area	Year	Age	N	G	dm	hm	ho	V
Sachsenried 03 (preceding crop)	1882	33	7428	43.3	8.6	10.6	13.8	180
Sachsenried 602 (succeeding crop)	1992	29	4708	59.5	12.7	12.5	14.5	339
Ottobeuren 08 (preceding crop)	1882	32	4232	54.8	12.8	14.0	17.1	356
Kaufbeuren (succeeding crop)	1992	25	3175	48.3	13.9	14.7	17.1	341

Year	year of observation	dm	mean diameter (cm)
Age	age of stand	hm	mean height (m)
N	number of trees (ha^{-1})	ho	top height (m)
G	basal area (m^2 ha^{-1})	V	standing volume (m^3 ha^{-1})

continually widening gap opened out between the increment trend of the yield table and the actual growth behaviour of spruce in South Bavaria.

2.4 Sample tree analysis

For six sample trees each on the experimental areas Denklingen 05 (143-yr-old in 1990) and Denklingen 84 (110-yr-old in 1990), the phases of typical growth behaviour are delimited and described by means of regression functions (Figure 3). It is obvious that the period of growth taking place corresponding to yield table standards (increasing increment before and decreasing increment after culmination) had ended on both experimental areas in about 1960 despite the different ages. This was followed by a totally atypical phase of hypertrophic growth which continued until the felling of the sample trees in 1990. During this period, the increment curves of all sample trees reach a level which by far exceeds the first maximum (culmination age according to Assmann 1961). These findings confirm the suggestion first brought forward by Franz (1983) that

- there is an widening gap between the actual increment since the mid-50s and the general ideas of the processes of forest growth reflected by models (yield tables) which were still applicable until recently, and
- a new move towards standard behaviour deduced from yield tables is not yet detectable.

2.5 Growth of preceding and succeeding generations

Growth-stimulating alterations of site conditions are reflected in older spruce stands by a decrease or even a reversal of the age trend, i. e. by a second increase of increment after having passed the culmination. Younger stands respond to it as is obvious from an increment curve having a steeper slope in general – a fact which might lead to a considerable improvement in growth performances.

Investigations conducted on two spruce sites in the area of the forest districts Schongau (preceding generation Sachsenried 03/ succeeding generation Sachsenried 602) and Kaufbeuren (preceding generation Ottobeuren 08/ succeeding generation Kaufbeuren) likewise point to an increase in growth performance. Supposedly, this superiority is partly attributable to the lower densities of forest plantation establishments in the succeeding generations, by which even on the unthinned plots more favourable growth conditions were achieved. This, however, explains only the differences of the mean tree values, and not the enormous differences apparent from the other yield characteristics. Moreover, it is obvious that the increase in basal area and standing volume is more pronounced than that in height development. This means that not only the site class has increased, but that the production level itself also seems to have improved.

Figure 4 shows the superiority of the succeeding stands by the example of volume development. The standing crop on Sachsenried 602 experimental area, 29-yr-old in 1992, accounts for 339 m^3 ha^{-1}; compared to this the preceding generation at the age of 33 years (in 1882) reached with 180 m^3 ha^{-1}only 53% of the volume. The accumulation

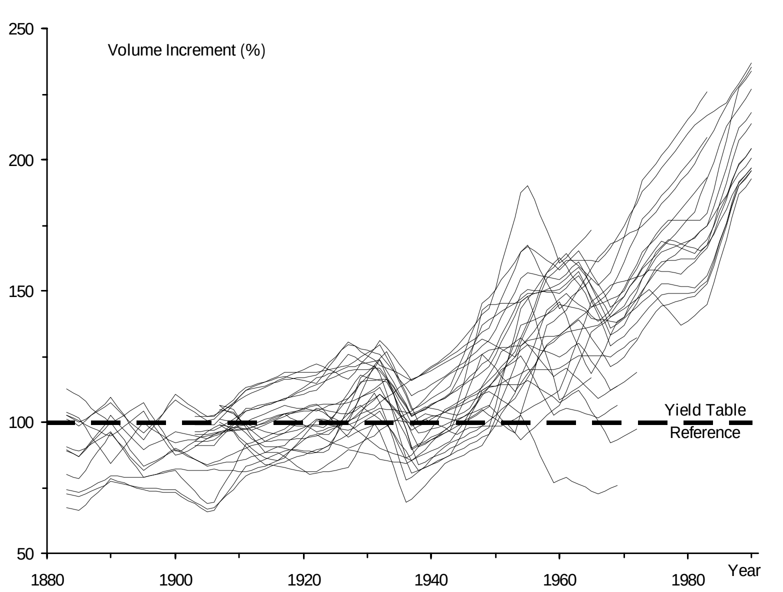

Figure 2. Development of current volume increment (in % of the volume increment of the Assmann/Franz yield table) on the 26 spruce plots in South Bavaria, plotted against the calendar year.

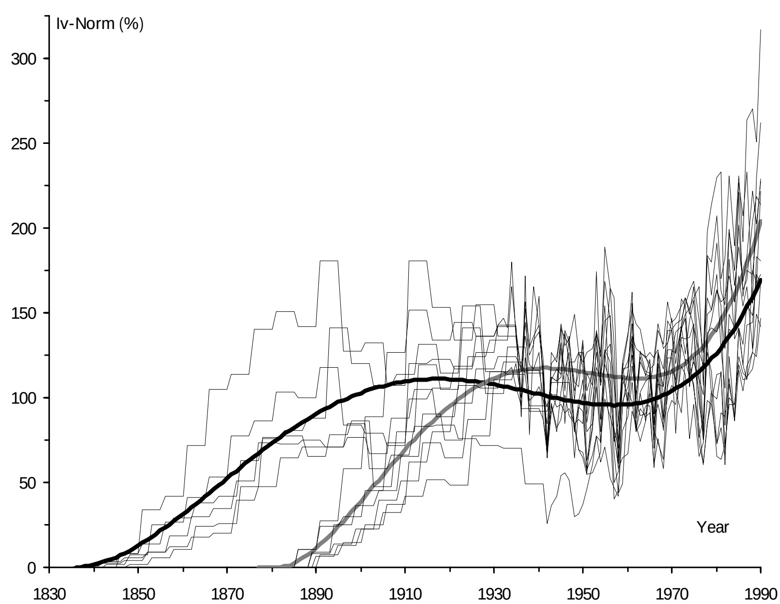

Figure 3. Standardised volume increment of top height trees (annual increment of each tree in % of its mean increment) from the unthinned and moderately thinned plots on the experimental areas Denklingen 05 and 84 (established around 1830 and 1880, respectively), plotted against the calendar year. Single tree curves: narrow lines; Mean curve Denklingen 05 experimental area: bold black line; Mean curve Denklingen 84 experimental area: bold grey line

of standing crop on Kaufbeuren experimental area is at least likewise noteworthy: almost the same timber volume is growing in the succeeding 25-yr-old stand, having a volume of 341 m^3 ha^{-1}, which was achieved only at the age of 32 (in 1882) by the preceding crop with 356 m^3 ha^{-1}. In this context, mention should be made of the fact, that for the establishment of the succeeding stand on experimental area Sachsenried 602 seed material was used, which had been harvested from the preceding crop.

3 GROWTH OF SPRUCE IN ERZGEBIRGE (SAXONY)

The air pollution stress and the pollution type underwent marked alterations on the German part of Erzgebirge Mountains in Saxony due to the political changes and restructuring of the economy. According to Wienhaus et al. (1995), mainly the SO_2 pollution appeared to decrease. In contrast to this, the O_3 concentration increased. Further, the nitrogen input distinctly increased and assumed values of a magnitude between 30 and 40 kg ha^{-1} y^{-1} as they are known from many regions in the former Federal Republic of Germany (Kandler 1994).

In Erzgebirge Mountains spruce growth at the various altitudes has to be assessed in a different way. In the heavily polluted locations on the ridges increment decline and disintegration processes in spruce stands are verifiable, whereas in the medium and lower altitude positions a phase of recovery has been taken place for 10 years.

3.1 Growth on mountain ridges

Seyde trial plot, which is representative of the heavily polluted locations, lies in an exposed ridge position at an altitude of about 800 m a.s.l. The approx. 90-year-old spruce stand located on this plot is subject to gradual disintegration processes due to the input of noxious substances being still rather high. Apart from few vigorous individual trees, the majority of spruces growing here suffered considerable needle losses, in 35 % of the spruces upper crowns died off.

Figure 5 underlines by the example of volume development that a high proportion of spruces failed since 1980 and had to be removed by felling measures. This caused the standing timber to decrease from almost 250 m^3 ha^{-1} to the actual value of 100 m^3 ha^{-1}. However, the development of volume increment (Figure 6) indicates, that already in 1970, one decade before the stand began to disintegrate, a drastic decline had set in. In the period from 1970 to 1980 the volume increment was characterised by a downward trend from approx. 8 m^3 ha^{-1} y^{-1} to values of approx. 1 m^3 ha^{-1} y^{-1}. The fact that this performance has been almost maintained until now despite the great amount of stem number failures, suggests that

- the spruces still stocking on this plot succeeded in using the enlarged growing space for production increase, and
- at least a proportion of these spruces is characterised by enhancing volume increments since 1990.

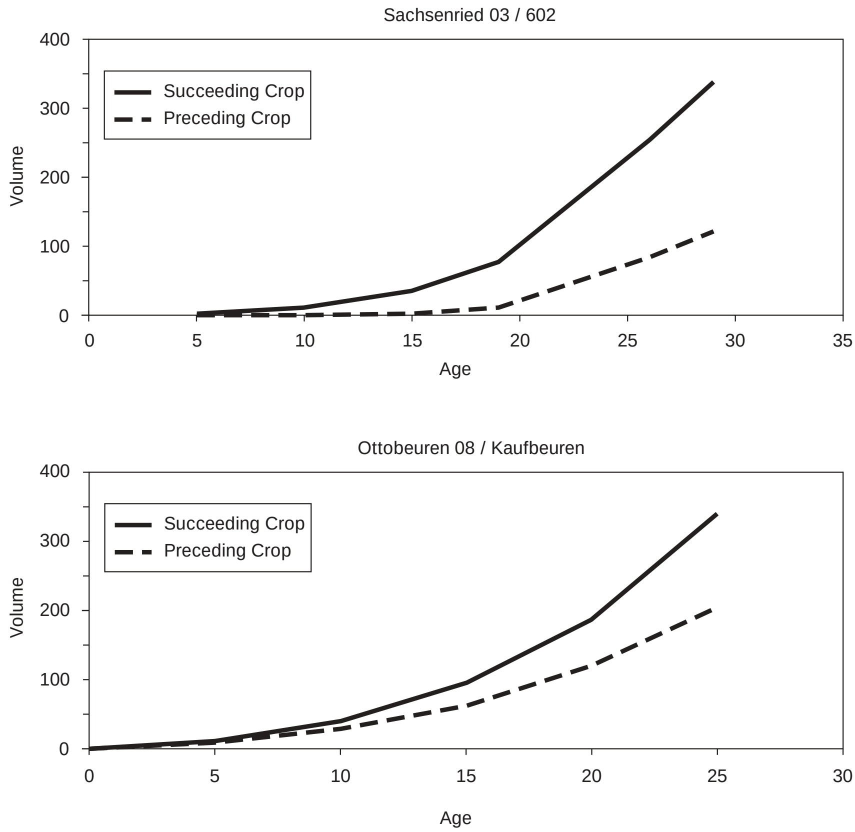

Figure 4. Volume development (m^3 ha^{-1}) of successive crops on the experimental areas Sachsenried 03/Sachsenried 602 (top), and Ottobeuren 08/Kaufbeuren (below).

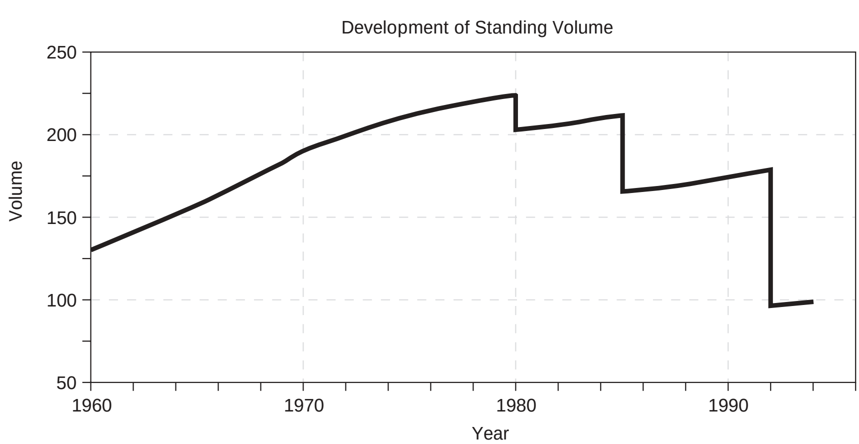

Figure 5. Volume development (m^3 ha^{-1}) on Seyde trial plot.

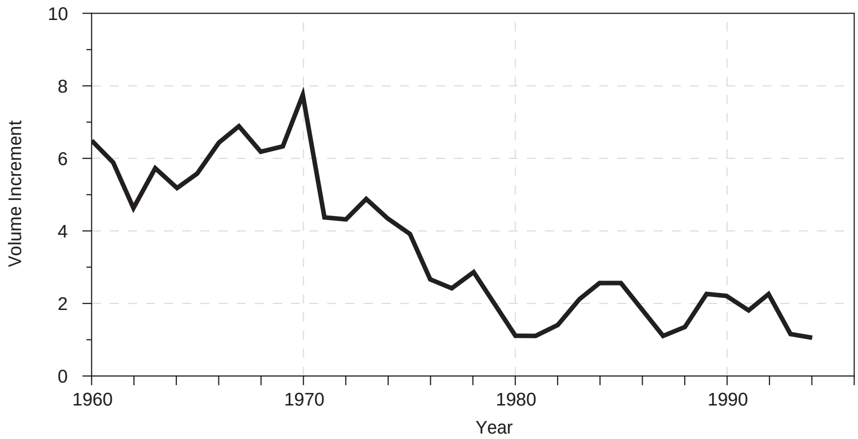

Figure 6. Development of volume increment (m^3 ha^{-1} y^{-1}) on Seyde trial plot.

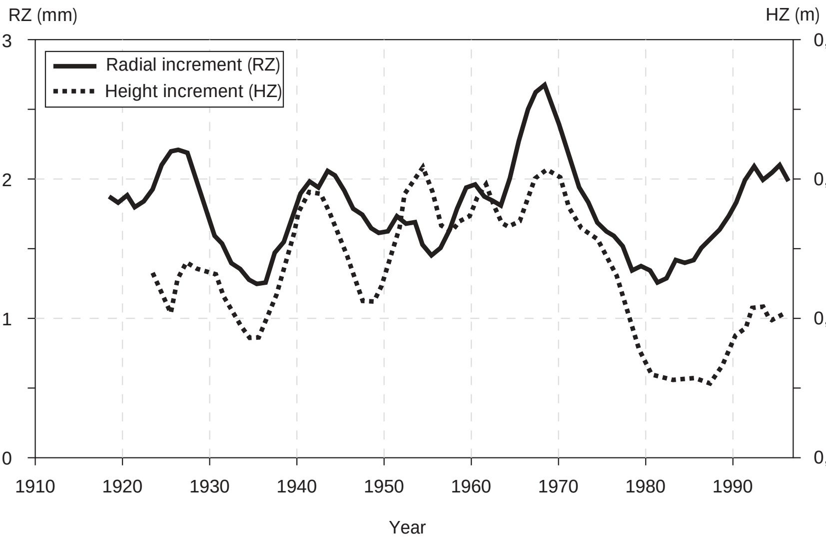

Figure 7. Radial increment (RZ) and height increment (HZ) on Rotherdbach trial plot. The period of recovery starting in the 1980s is readily discernible.

3.2 Growth at medium and lower altitudes

Stem analyses on predominant trees growing on selected trial plots at various altitudes suggest that the change in the type of air pollution led to unequivocal responses in the increment pattern (Figure 7). The top height trees on Rotherdbach trial plot, which is representative of the medium and lower altitude positions, are characterised by nearly a standard pattern of radial increment (RZ) up to 1970. Following this, the performances drop by more than a half until the early 80s, then maintaining this level for a period of about 5 years. Since the mid-80s a conspicuous recovery is observed, the radial increments find their mid-60s level again. A similar trend becomes obvious in height increment (HZ): Here too, following the phase of highest increment performances between 1940 and 1960 (of course also attributable to age), a decrease is observable until the late 80s. Since then height increment performances have been again increasing from values below 10 cm to almost 20 cm per year. However, the rise in height increment is not so distinct as that in radial increment. For some years now also an improvement of the amount of foliage has been recognisable parallel to the recovery in radial and height increment on Rotherdbach trial plot.

4 CONCLUSIONS FOR FORESTRY

From the altered growth behaviour of spruce the following conclusions for forestry can be drawn:

- Site constancy as a precondition of assessment is absent at present: On the one hand, environmental conditions such as air pollution, drought and frost cause increment decline and disintegration processes especially in the higher elevations of the mountains in central and eastern parts of Germany. On the other hand, nitrogen inputs into the atmosphere and raising CO_2 concentrations improve growth conditions in many regions of Germany. The available yield tables used as common planning tools by forest practice do not correspond to the altered growth behaviour. Therefore, revised growth models taking environmental factors into consideration are urgently needed.
- Apart from regions which are much affected by forest damage the accelerated growth of forests in Germany leads to an accumulation of growing stock. This requires that prescribed cuts be raised in order to avoid forest stands with too high densities and unstable structure concerning h/d-ratio. Beyond this, the increased growth performances should give rise to more flexibility regarding the length of rotation periods as well as to integrating into silvicultural practice selective felling methods (exploitable diameter felling): In the first place dominant trees will reach the exploitable diameter within shorter periods of time. In the second place after having harvested dominant trees with the exploitable diameter codominant spruces respond to release cuttings by enhanced diameter increments, thus also being able to achieve the exploitable diameter within acceptable periods of time. This holds also true for poorer sites and medium yield classes, as was shown by Schmitt (1994) for uneven-aged spruce stands in South Bavaria.

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CONSEQUENCES OF INCREASED TREE GROWTH ON FOREST MANAGEMENT PLANNING AND SILVICULTURE

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ABSTRACT

With a present growing stock of over 350 m^3 per hectare in the public forests of Baden-Württemberg, forest inventory methods need to be changed in order to meet the requirements of modern management planning methods especially with respect to changing growth conditions. Systematic sampling methods with highly accurate results meet these demands. It is intended to make full use of the current volume increment and to keep stock volume at the present level in order to limit increasing risks. The programme of nature oriented silviculture ensures economically and ecologically favourable forests.

Keywords: systematic sampling methods, volume of growing stock, cut rates, sustainability

1. INTRODUCTION

During the past years, numerous studies detecting accelerated tree growth were published, one of which was the research report “Growth trends in European forests” by the European Forest Institute in 1996 (Spiecker et al. 1996). Despite the existence of various scientific explanations, knowledge concerning the precise sources of this development as well as the specific impact of these sources on forest growth is still insufficient. It seems obvious that there is not only one single cause but a combination of many different factors which are responsible.

As for atmospheric deposition, the results of our forest research institute in Freiburg show that besides other compounds the annual average deposition of nitrogen throughout the country adds up to approximately 25 kg per hectare per year (Forstliche Versuchsanstalt... 1997; Hochstein and Hildebrand 1992; Hepp and Hildebrand 1993).

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This deposition rate is very likely to be one of the important causes for accelerating tree growth in Baden-Württemberg.

Global changes in climate with rising average temperatures during the vegetation period and a generally rising level of CO_2, which both stimulate photosynthesis, may also be an additional cause.

The devastation of forest soils, due to excessive wood utilisation, forest grazing and litter raking have had long term effects on forest soils. 200 years of forestry have been able to contribute to successive recovery with increasing site productivity of forest soils during recent decades.

In addition management practises such as regeneration methods, tending, thinning and harvesting regimes have effects on site productivity.

All these causes may have positive effects on the growth rates of forest trees, but it has to be kept in mind that there are risks for forest health too. Above all atmospheric deposition does have negative effects on forest soils such as acidification, nutrient losses and imbalances and other additional unfavourable results. Consequently we should be very cautious when interpreting these results. It seems important not only to detect the fact of accelerated tree growth in Europe but also to do more research relating to the share of each of the possible causes and their individual contribution to the phenomenon as a whole.

2. FOREST GROWTH DATA FROM THE FEDERAL STATE OF BADEN-WÜRTTEMBERG

2.1 Growing Stock Characteristics

The findings of studies on changing forest growth are extremely important for forestry in Baden-Württemberg, because the present growing stock in the state owned forests amounts to a total of 353 m³ of standing crop per hectare, according to the forest inventory statistics for the public forests in Baden-Württemberg. Since 1965, the growing stock has increased by 26%.

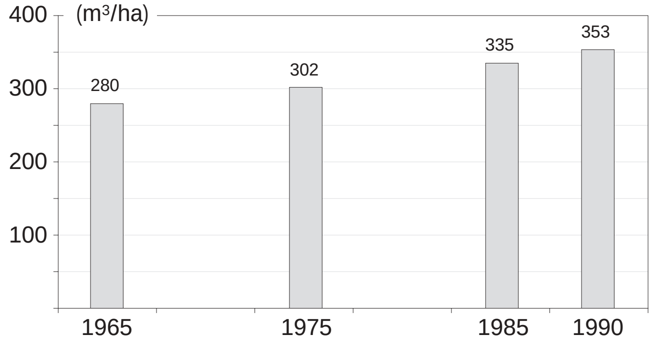

Figure 1. Development of growing stock in the Baden-Württemberg state forest.

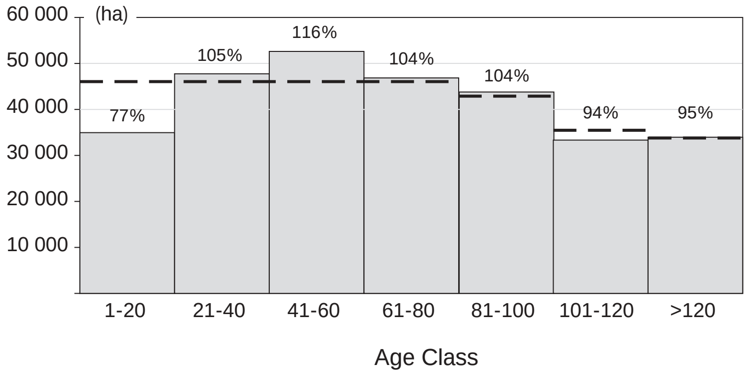

Figure 2. Age class distribution in the Baden-Württemberg state forest.

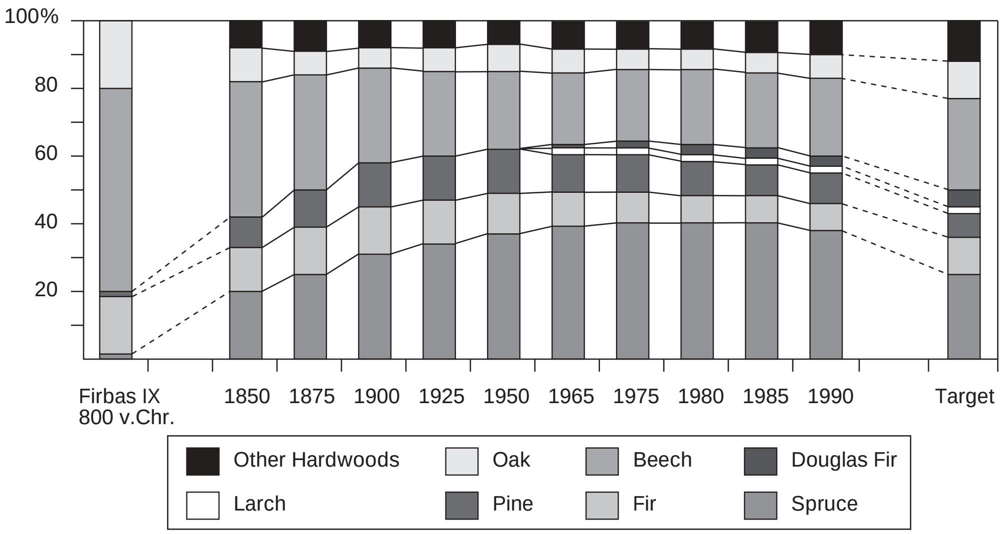

Figure 3. Composition of tree species in public forests in Baden-Württemberg.

Of course, this is partly due to the age class distribution of our forests with an overrepresentation of age classes II and III. The older age classes as well as age class I with a lower current volume increment are below average. A look at the tree species composition shows that there are 60% of conifers, 38% of which consists of spruce (*Picea abies*) alone. This composition of tree species and especially the privileged geological and climatical situation in Central Europe lead to a high level of volume increment and consequently a considerable potential of exploitable growing stock.

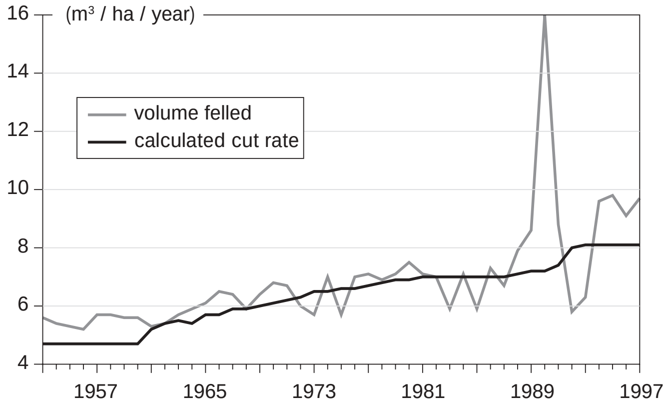

Figure 4. Calculated cut rate in comparison to volume felled (Baden-Württemberg state forest).

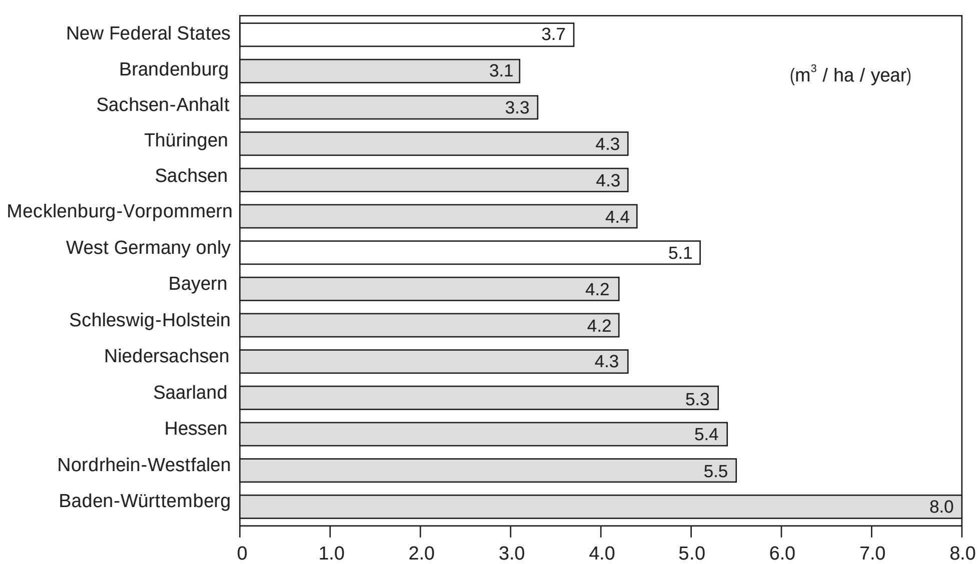

Figure 5. Annual calculated cut rates of the states of the Federal republic of Germany.

2.2 Cuttings

The development of the planned cut rates per hectare per year in the state owned forests shows a continuous increase from 5.7 m³ in the 1950s to 8.1 m³ of timber harvested in 1997. This represents a rise of more than 40% in the past 45 years. In comparison to the other federal states of the Federal Republic of Germany Baden-Württemberg with a cut rate of over 8 m³ per hectare per year timber harvested has the highest cut rates of all federal states.

The economic opportunities arising from these facts do not have to be mentioned. But there are risks in those numbers, that have to be kept in mind as well. For 4 years the annual fellings have exceeded the planned cut rates and add up to approximately 10 m^3 timber harvested per hectare per year in the state owned forests of Baden-Württemberg.

3. CONSEQUENCES FOR FOREST MANAGEMENT PLANNING

In the current situation it is obvious that a close monitoring of changing tree growth is absolutely necessary. In order to meet these demands, forest inventory methods have to be adjusted to meet the requirements of modern forest management planning.

The traditional forest inventory system used by the state forest service in Baden-Württemberg is based on an inventory of data in each stand (Ministerium für Ernährung... 1986). In larger, rather homogenous stands sampling methods (systematic sampling, relascope) are used. Some valuable old growth stands used to be fully callipered, whereas smaller stands (<1 ha) are simply estimated. The management period is ten years. The big advantage of this investigation is a single stand data base, which makes it easy for the local forest personnel to follow the planning instructions. On the other hand, there are some problems connected with the traditional inventory method, such as high costs and lack of accuracy. Moreover, the rate of error is not known unless compartment sampling is applied. Accelerated tree growth requests an inventory, that makes changes apparent in a rather short period of time. This is why the inventory methods should guarantee a relatively small error and this error should be defined precisely.

Recent research suggests that existing yield tables seem to be no longer valid for a reliable prognosis and the control of sustainability in forestry. Therefore new flexible growth models that are adjustable to changing growth condition as well as different managing regimes are needed. Another big task we face, since changing site conditions have become evident, is that site mapping is not a single effort but a permanent job to be repeated in a rotation of some 30 or 40 years.

During the last 2 years the Forest Service has developed a new forest management planning concept using permanent and temporary systematic grid sampling methods for inventory (Ministerium Ländlicher Raum... 1998 unpublished). The single stand as a numerical data base is being deliberately abandoned in favour of groups of stands selected under a silvicultural point of view. For these strata the systematic sample data are analysed. The result is a very accurate data base. With reference to the growing stock, the results have a standard error of around 2%. This is also valid for all other relevant data. Besides that there is a cost reduction for the forest inventory part (not including the planning part) of around 50% as compared to the previous action. One of the surprising outcomes of the first systematic sampling inventory is the fact that, when compared to the traditional inventory, the growing stock in general is 10 to 20% higher, in some cases up to 30% higher. This is due to the rather cautious estimates of previous inventory methods.

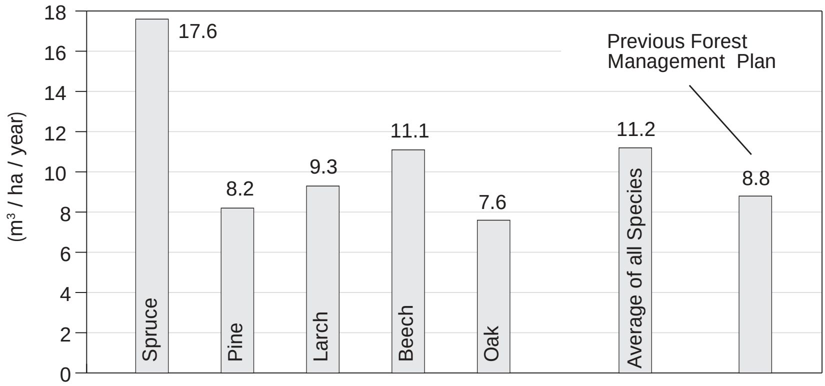

Figure 6. Annual volume increment of growing stock in the Bebenhausen forest district.

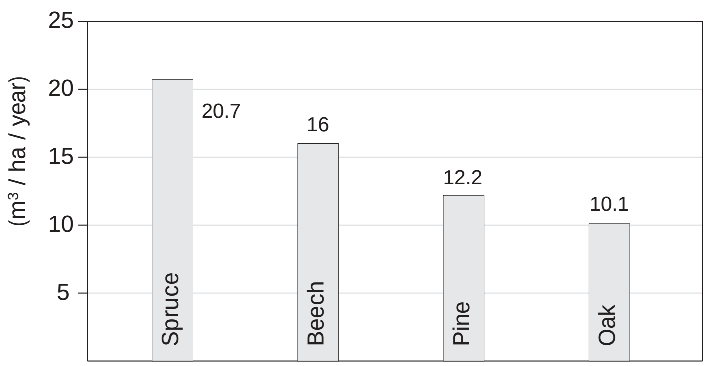

Figure 7. Annual volume increment of growing stock in the Biberach forest district.

The next step of methodological development will be to aggregate the single forest enterprise data in order to run evaluations on a higher level, such as the whole state forest enterprise, regions or other groups of forest districts. It will be very interesting to compare these results with the 2. Federal Forest Inventory expected in the year 2002.

Systematic sampling with permanent sampling plots has been used in Baden-Württemberg for 10 years. Consequently there is a rising number of forest districts which undergo a successive inventory each year. One of the most surprising results of this successive inventory is the high periodical volume increment. The error of these results is less than 5%. For example, in the forest district of Bebenhausen near Stuttgart with average to subaverage site conditions an annual volume increment of 11.2 m^3 of standing crop was detected. According to the available yield tables the expected growth was 8.8 m^3. Spruce showed an annual increment of 17.6 m^3, whereas beech had 11.1 m^3 increment per hectare per year. Even more surprising were the results of the municipal forest district of Biberach with better site conditions with volume increment of spruce

20.7 m³ and beech 16.0 m³. Even oak grew with 10.1 m³ of standing crop per hectare per year.

Other important findings of successive inventories are reliable data on the development of game damage, such as debarking and browsing, as well as information on the amount and the structure of natural regeneration. Thus, effective controlling is possible.

Another big question concerning forest management planning is the definition of sustainability. Though it has been the major principle of forestry in Germany for over 200 years, there still is no exact numerical definition applied in practical forest management and there probably never will be. When dealing with sustainability it becomes obvious, that there is no optimum amount of growing stock, no optimum tree species composition, no optimum assortment of timber in stock and so on. In order to define sustainability there has to be a system of values to refer to. A relatively wealthy society like the contemporary German society will define sustainability in a totally different way than if it were poor. During the past 200 years this has not been a relevant question since there was a common understanding that further accumulation of growing stock was necessary. With a growing stock of over 350 m³ of standing crop per hectare, this is different and has to be looked at carefully.

4. CONSEQUENCES FOR SILVICULTURE

The most important consequences of increased tree growth for silviculture are rising cut rates. This is basically valid for all age classes and for most tree species especially spruce and beech. The economic dimension of this development is tremendous, since the level of cut rates is one of the determining factors of net revenue of forest enterprises. From a timber market point of view, higher felling rates emphasise the importance of Central Europe in global competition for investment of timber processing industries.

A big challenge for the management of the Forest Service is to encourage and develop a mental change of attitude among the employees. Since the existence of professional forestry for around 200 years, foresters in Germany were taught to focus their professional energy on overcoming the negative effects of overexploitation of the forests during the middle ages by building up intact forests. One of the main goals of this big challenge was the accumulation of growing stock. These mental problems should not be underestimated.

Under the present conditions and level of knowledge in the Forest Service of Baden-Württemberg a full use of the periodical volume increment is aimed at. A further increase of standing volume does not seem to make sense, because it would be connected with higher risks for the health of mature trees as well as the susceptability to storm and other damage. On the other hand we do not want to significantly reduce the present level of growing stock. This seems to make sense in recognition of the fact, that in Germany since approximately 200 years foresters have aimed at the accumulation of growing stock. An extreme shift towards reduction of growing stock would find no acceptance. Besides that it is likely that the annual value increment of a higher standing volume of mature trees exceeds the value increment of forests with lower standing volumes. In the long run however, due to the expected change in tree species composition, there will be a reduction of growing stock.

The programme of nature oriented silviculture in Baden-Württemberg meets the demands to reduce the present risks. An important principle is to maximise single tree stability in all stand ages especially in young stands. Unfortunately, there are still a remarkable amount of sites covered with unsuitable tree species. In order to reduce these risks we are planning a significant reduction of spruce and an increase of deciduous trees in general. Another instrument to promote stability is the establishment of richly structured mixed stands.

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IMPLICATIONS OF INCREASED EUROPEAN TIMBER SUPPLY ON GLOBAL MARKETS FOR ROUNDWOOD AND FOREST INDUSTRY PRODUCTS

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ABSTRACT

A partial equilibrium model was applied to the global forest sector in order to assess regional and global impacts of increased timber supply potential in Europe. The model uses recursive price-endogenous linear programming and deals with 8 geographical regions and 16 products. The base line projections of the model gave an average annual increase in global production of pulpwood and sawlogs of 1.0% until the year 2010, and the real price of sawlogs and sawnwood was found to remain approximately constant, whereas the prices of pulpwood and particles increased significantly during the first years, and then declined after year 2000.

In the base line model run, the annual growth of the potential supply of industrial roundwood was assumed to be 1.4%. In two alternative model runs this annual growth was increased to respectively 2.0% and 2.7% to reflect a medium and high increase in forest growth in Europe (except in Scandinavia and Russia). Both increases lowered significantly the equilibrium prices for pulpwood and particles relative to the base line estimates, whereas the price of sawlogs remained stable. The increases did not lead to higher production of paper whereas the import of wood pulp decreased. A somewhat higher production of sawnwood and wood based panels in this region was combined with less imports. Possible improvements of the methodology include introduction of a price responsive timber supply, and empirical estimation of key parameters that determine capacity expansion, trade intertia, and technical change.

Keywords: forest sector, global markets, timber supply, Europe, forest industries, demand, models

1. INTRODUCTION

There are clear indications that the growth of European forests has increased in recent decades. This may have strong impacts on the availability and supply of industrial roundwood, which in turn will influence both the supply and demand of forest industry products. According to economic theory, increased timber supply leads to decreased roundwood prices, lower costs for the forest industries and higher demand of forest industry products. For the long term planning in both forestry and forest industry sectors it is of considerable interest to get an idea of the order of magnitudes of such impacts. The main objectives of this study were to assess how changes in the timber potential in Europe shall affect world market prices, European and global demand and supply, and international trade of timber and forest industry products.

2. METHODS

Modeling methodology

The development of quantitative models for analyses of economic relationships within the forest sector has been an important topic of research in forest economics over the last 20 years. Forest sector models include supply/demand equation systems for forecasting and policy analysis. The SOS-model for the Norwegian forest sector by Randers (1977), the TAMM-model for the North American solid wood sector by Adams and Haynes (1980), the IBRD-forest model applied to Sweden by Nilsson (1981) and for Norway by Gundersen and Solberg (1984), and the model for the global newsprint market by Buongiorno and Gilless (1984) are examples of early forest sector models. Methodological aspects from these models were included in the global trade model (GTM) developed at the International Institute for Applied System Analysis (Kallio et al. 1987).

The global forest products model (GFPM) developed by Zhang et al. (1997) for the FAO outlook study for global forest products consumption, production and trade (FAO 1997), served as the starting point for this model. The model structure is based on the Price Endogenous Linear Programming System (PELPSIII), proposed by Gilless and Buongiorno (1985) and improved progressively into the version of Zhang et al. (1993). The theoretical structure is that of spatial equilibrium in competitive markets. PELPSIII generalizes the problem specified by Samuelson (1952) to represent the production, transport, transformation, and consumption of several commodities. The equilibrium is found by maximizing the sum of producer and consumer surplus subject to material balance, capacity constraints, and possible trade barriers, in each region, and in each projection period.

The dynamic changes from year to year are modeled by recursive programming, that is, the multiyear spatial equilibrium problem is broken up into a sequence of problems, one for each year or period. The theory combines market optimization in the short run and imperfect foresight of decision-makers (Gilless and Buongiorno 1987). From one period to the next, the demand changes in each region due to assumed changes in GDP.

The wood supply potential changes according to a chosen scenario. Technology can also change, such as the amount of recycled fiber used in making paper and paperboard (Zhang et al. 1996). Production capacity increases or decreases according to new investments that depend on past production and the profitability of production in different regions, as given by the shadow price of capacity in the previous year. Then, a new equilibrium is computed subject to the new demand and supply conditions, new technology, new capacity, and inertia constraints that limit the change in exports and imports from year to year.

Main assumptions

The differences between the model applied in this study and the GFPM-model described in FAO (1997) and Buongiorno et al. (1997) are mainly the disaggregation of industrial roundwood into sawlogs, pulpwood and particles, and the division of the world into 8 geographical regions instead of individual countries (Table 1).

Sixteen different products were recognized explicitly, with sufficient detail to represent the interaction between the paper and solid wood sub sectors. The products were defined according to the nomenclature given by FAO (1996b) and are listed in Table 2. The year 1994 served as the base year and the projections were up to the year 2010.

The final demand for a commodity in a region was described by an equation that gave quantity demanded as a function of economic activity (GDP) and real prices. Each demand equations for the base year (1994) was defined by base year consumption, base year price and price elasticity. Base year consumption was either computed from production, import and export data (FAO 1996a), or in the case of the former USSR, estimated as in FAO (1997). Base year prices were the weighted averages of unit values of import and exports, in 1994 US dollars per unit (Table 2). Transportation costs were not specified explicitly in this model, but the base-year import prices included transport costs. Price elasticities by product and income group were those reported in FAO (1997), with the income groups shown in Table 1. GDPs were shifters of demand, and were strictly exogenous. Scenarios regarding GDP growth are in Table 3 and follow

Table 1. Regions and income groups.

Region	Abbreviation	Includes	GDP group
Africa	Africa		Low
South & Central America	S&C Am.	America except Canada and the USA	World
USA	USA		High
Canada	Canada		High
Asia	Asia	Oceania	World
Rest of Europe	Europe	Europe except Scandinavia and former USSR	High
Scandinavia	Scand.	Finland, Norway and Sweden	High
Former USSR	USSR		World

Table 2. Products, definition of demand and supply activities, and base year prices.

Product	Includes	Demand [1)]	Suply [1)]	Base year price (US$)[2)]
Sawlogs	Coniferous and non-coniferous logs	I	E	129 [3)]
Pulpwood	Coniferous and non-coniferous pulpwood	I	E	55 [3)]
Particles	Wood residues from sawnwood and veneer/ plywood production	I	I	50 [4)]
Other industrial roundw.	Coniferous and non-coniferous roundwood	E	E	98
Sawnwood	Sawnwood and sleepers, coniferous and non-coniferous	E	I	232
Veneer & plywood	Veneer sheets and plywood, coniferous and non-coniferous	E	I	490
Particle board	Sheet materials manufactured from small pieces of wood.	E	I	230
Fiber board	Compressed and non-compressed fiberboard	E	I	322
Mechanical wood pulp	Mechanical, chemi-mechanical and thermo-mechanical pulp	I	I	348
Chemical pulp	Chemical and semi-chemical wood pulp for paper	I	I	471
Dissolving pulp	Dissolving grades	F	I	663
Other fiber pulp	Pulp of fibrous vegetable materials other than wood	E	E	300
Waste paper	Recycled paper	I	E	118
Newsprint	Uncoated paper, used mainly for the printing of newspapers	E	I	486
Printing & writing paper	Paper except newsprint, suitable for printing	E	I	834
Other paper & paperboard	Construction paper and paperboard, house-hold and sanitary paper, wrapping and packing paper and paperbord, etc.	E	I	708

1) E: Activity represented by an equation, I: Activity represented with input-output coefficients, F: Activity fixed at 1994 level.
2) Prices are weighted average of global import and export 1994 prices.
3) For sawlogs and pulpwood import and export values after 1989 are not reported separately. The 1994 prices are calculated based on 1994 figures for industrial roundwood, sawlogs, pulpwood and other industrial roundwood prices for 1984-1989, assuming the same price relationships in 1994 as the average of 1984-1989.
4) As the product *Chips and particles* reported by FAO includes both wood residues and chipped pulpwood, the 0particles price is set slightly lower than the pulpwood price.

those used by FAO (1997). It was assumed that the GDP growth rates would tend to converge, but countries with higher current economic growth would continue to grow faster until 2010. Demand for primary and intermediate products derived from the demand for final products through input-output coefficients for each activity that described the technology in each region, such as in Takayama and Judge (1964). To each activity corresponded a manufacturing cost and a limited capacity. The supply of wood in each region was represented by the reservation prices given in Table 4 up to the wood supply potential. The price elasticity of wood supply was hence infinite up to the

Table 3. Assumed growth rates of real GDP 1995-2010.% per year, based on FAO (1997).

Region			Base scenario	
	1995	1996	1997	2000
Africa	3.2	3.4	3.4	3.0
S&C Am.	1.1	3.5	3.4	3.1
USA	2.0	1.8	1.9	2.2
Canada	2.2	1.9	2.1	2.7
Asia	8.4	4.5	4.3	4.1
Europe	2.8	2.1	2.2	2.6
Scandin.	3.7	3.0	2.8	2.2
USSR	-4.3	-2.0	1.2	1.4

potential. The maximum potential roundwood supply up to 2010 for the base scenario, expressed as a growth rate, is shown in Table 4. Those rates set the maximum growth of wood supply. The actual supply could be less if conditions were such that it was worth producing only part of the maximum potential. The maximum recovery rate of waste paper was set at 0.60 for all paper products and regions. One improvement of this model relative to the GFPM was recognition of the possible use of residuals from sawnwood and veneer and plywood production as input in the production of wood pulp, particle board and fiber board.

The manufacturing coefficients were based on Kallio et al. (1987) and on FAO (1997). By comparing consumption of raw materials and intermediate products with production of intermediate and final products in the base year, the input coefficients were also adjusted to ensure consistency between input and output quantities. Because different products are produced with the same type of inputs, the consistency of input and output could only be checked on an aggregate level (e.g. sawlogs consumption in relation to sawnwood and veneer and plywood production, and waste paper consumption in relation to paper and paperboard production). The technology was held constant at the 1994 level, except for paper and paperboard. There, as in FAO (1997), it was assumed that the use of recycled paper and other fiber pulp would increase mainly as a substitute for chemical pulp.

Manufacturing costs by product and region, that is variable costs except cost of raw materials recognized explicitly in the model, were calculated as the difference between base year price (the same in all regions, see Table 2) and cost of raw materials at base year prices and input-output coefficients. Given the assumption of competitive markets, pure profits were nil, and the manufacturing costs included a normal return to capital.

Capacity changes were governed in this model by past production and by relative profitability. Capacity data were available for pulp and paper products only. For the base year the projected production capacities published in the FAO capacity survey (FAO 1995) were used for pulp and paper products. For particle board and fiberboard, the base year capacities were set equal to the base year production, whereas for sawnwood and veneer and plywood, base year capacities were set equal to 1.2 times the base year production, as in FAO (1997). The distributed-lag function that linked global capacity changes to changes in past production was:

$$\Delta K_k = b_{1\,k}\,\Delta Y_{k,-1} + b_{2\,k}\,\Delta Y_{k,-2} + b_{3\,k}\,\Delta Y_{k,-3}$$

where k = commodity, Y is quantity manufactured and the value of the parameters are

$b_{1\,k,}$=0.55, $b_{2\,k}$= 0.35 and $b_{3\,k,}$= 0.20, as in FAO (1997).

Imports and exports of sawlogs and pulpwood are no longer reported separately by FAO, since 1990. For lack of data, it was assumed that the percentage distribution of net trade (exports minus imports) of industrial roundwood between sawlogs, pulpwood and other industrial roundwood was the same in 1994 as in 1989. The adjustment of trade flows between countries or regions is bound to take time. Thus, trade inertia constraints were introduced to limit trade in a given year to be within a specified fraction of the previous year's trade. In this model trade inertia constrained net trade from each region to the world market in a given year to be within 20% of that in the previous year. The drawback of the simplification made by using net trade was that net exporters or importers of a given product were constrained to remain so, throughout the projection period.

To analyze the consequences of increased forest growth in Central Europe, the growth rate of the timber supply potential in Europe was increased from a "most likely" scenario called the base scenario. In the base scenario, the annual growth in timber potential for sawlogs, pulpwood and other industrial roundwood was assumed to be 1.4%. In the "medium growth scenario", the annual increase in timber potential in Europe (except Scandinavia and Russia, which remained as in the base scenario) was increased to 2.0%. In the "high growth scenario", the annual growth was set at to 2.7%, similar to Scenario 2 in FAO (1997). The timber supply potential in the other regions was not changed.

3. RESULTS

The effects on Europe of the increased timber supply potential in this region are shown in Table 5. The effects on global production are shown in Table 6. Global pulpwood supply in the year 2010 was 511 million cubic meters in the high growth scenario, giving an average annual growth rate from 1994 to 2010 of 1.2%, compared to 502 million cubic meters and 1.1% in the medium growth scenario, and 493 million cubic meters and 1.0% in the base scenario. The increase in pulpwood supply from Europe, did not reduce the supply from the other regions. The effects on regional trade of pulpwood for the year 2010 is shown in Figure 1. Pulpwood and particles consumption in Europe increased by 0.7% and 0.3% in Europe in the medium growth scenario and by 1.3% and 0.6% in the high growth scenario. The increased supply from Europe flattened out the price of pulpwood and particles (Figure 2 and Figure 3).

Global sawlogs supply increased from 1,089 million cubic meters in the base scenario, by the year 2010 to 1101 million cubic meters in the medium growth scenario and 1111 million cubic meters in the high growth scenario. The changes in sawlogs supply in Europe are shown in Figure 4. The increased availability of sawlogs from

Table 4. Industrial roundwood supply 1994 and potential supply up to year 2010[1)]

Region	Product	Production 1994[2)]	Potential 2010[3)]	Annual growth
Africa	Sawlogs	24127	30095	
	Pulpwood	12796	15961	
	Other industrial roundwood	28482	35527	
	Total, industrial roundwood	65405	81584	1.4 %
S&C Am.	Sawlogs	72365	89230	
	Pulpwood	47552	58634	
	Other industrial roundwood	8923	11003	
	Total, industrial roundwood	128840	158867	1.3 %
USA	Sawlogs	233486	247195	
	Pulpwood	151474	160367	
	Other industrial roundwood	14765	15632	
	Total, industrial roundwood	399725	423194	0.4 %
Canada	Sawlogs	142028	167618	
	Pulpwood	35700	42132	
	Other industrial roundwood	3326	3925	
	Total, industrial roundwood	181054	213676	1.0 %
Asia	Sawlogs	197951	241551	
	Pulpwood	33674	41091	
	Other industrial roundwood	68865	84033	
	Total, industrial roundwood	300490	366675	1.3 %
Europe	Sawlogs	102738	127525	
	Pulpwood	59414	73749	
	Other industrial roundwood	12830	15925	
	Total, industrial roundwood	174982	217200	1.4 %
Scand.	Sawlogs	55674	63298	
	Pulpwood	48092	54678	
	Other industrial roundwood	1035	1177	
	Total, industrial roundwood	104801	119153	0.8 %
USSR	Sawlogs	93234	122208	
	Pulpwood	35423	46431	
	Other industrial roundwood	32666	42817	
	Total, industrial roundwood	161323	211456	1.7 %
World	Sawlogs	921603	1088721	
	Pulpwood	424125	493044	
	Other industrial roundwood	170892	210040	
	Total, industrial roundwood	1516620	1791805	1.1 %

1) In 1000 cubic meters.
2) Based on FAO (1996) and for former USSR on FAO (1997).
3) Based on FAO (1997).

Europe did not decrease the sawlogs production in other regions. The timber potential for sawlogs was fully utilized in all years in the base and medium growth scenario. Sawlogs supply in Europe was less than the potential from year 2004 onward in the high growth scenario and was 95% of the potential in 2010. The increase in sawlogs

Table 5. Effects of changes in timber potential in Europe. (Excluding Scandinavia and countries in former USSR).

Product			Base scenario			High-growth scenario			Medium-growth scenario		
		1994	2000	2010	1994-2010	2000	2010	1994-2010	2000	2010	1994-2010
P	Pulpwood	59419	64430	73749	1.4 %	69794	91279	2.7%	67067	82076	2.0 %
R	Sawlogs	102783	111412	127526	1.4 %	120687	149153	2.4 %	115972	139844	1.9 %
O	Other industrial roundwood	12830	13913	14107	0.6 %	13551	13205	0.2 %	13551	13205	0.2 %
D	Particles	25216	28570	32020	1.5 %	29478	35155	2.1 %	29273	33666	1.8 %
U	Waste paper	27831	31665	36758	1.8 %	31601	37426	1.9 %	31814	38826	2.1 %
C	Wood pulp for paper	13392	14786	16896	1.5 %	16320	21996	3.2 %	15489	19398	2.3 %
T	Other fiber pulp	212	648	1391	12.5 %	655	1422	12.6 %	655	1432	12.7 %
I	Paper and paperboard	53836	61313	72282	1.9 %	60825	70866	1.7 %	61261	73666	2.0 %
O	Sawnwood and veneer & plywood	60001	68634	75822	1.5 %	70763	82958	2.1 %	70386	79796	1.8 %
N	Particle and fiberboard	30599	32901	36627	1.1%	32611	38321	1.4%	33025	36782	1.2 %
N	Pulpwood	-715	-2028	-2654	8.5 %	-2028	-2120	7.0 %	-2028	-2634	8.5 %
E	Sawlogs	-5000	-11216	-9168	3.9 %	-5804	-729	-11.3 %	-9718	-3927	-1.5 %
T	Other industrial roundwood	-1685	-447	-48	-19.9 %	-442	-47	-20.0 %	-442	-47	-20.0 %
	Particles	-899	-384	-1058	1.0 %	-248	-1021	0.8 %	-248	-681	-1.7 %
T	Waste paper	-85	-254	-1572	20.0 %	-84	-154	3.8 %	-113	-310	8.4 %
R	Wood pulp for paper	-10265	-11486	-13413	1.7 %	-9570	-7342	-2.1%	-10632	-11401	0.7 %
A	Other fiber pulp	-19	-11	-12	-2.8 %	-16	-25	1.7 %	-15	-7	-6.1 %
D	Paper and paperboard	-12466	-8834	-2957	-8.6 %	-10213	-6561	-3.9 %	-9511	-3428	-7.8 %
E	Sawnwood and veneer & plywood	-25288	-19107	-16986	-2.5 %	-17396	-11051	-5.0 %	-17216	-15858	-2.9 %
	Particle and fiberboard	1365	2854	1512	0.6 %	2125	1913	2.13 %	2718	1707	1.4 %
C	Pulpwood	60134	66458	76403	1.5 %	71823	93399	2.8 %	69096	84710	2.2 %
O	Sawlogs	107783	122627	136694	1.5 %	126492	149882	2.1%	125690	143771	1.8 %
N	Other industrial roundw	14515	14360	14155	-0.2 %	13993	13253	-0.6%	13993	13253	-0.6 %
S	Particles	26115	28954	33078	1.5%	29726	36177	2.1 %	29521	34347	1.7 %
U	Waste paper	27916	31919	38329	2.0 %	31685	37580	1.9%	31926	39136	2.1 %
M	Wood pulp for paper	23657	26272	30309	1.6 %	25889	29339	1.4 %	26121	30799	1.7 %
P	Other fiber pulp	231	659	1403	11.9 %	670,6	1447	12.2 %	669,7	1439	12.1 %
	Paper and paperboard	66302	70147	75238	0.8 %	71038	77427	1.0 %	70772	77094	1.0 %
	Sawnwood and ven & plyw	85289	87741	92808	0.5 %	88159	94009	0.6 %	87601	95653	0.7 %
	Particle and fiberboard	29234	30047	35115	1.2 %	30486	36408	1.4 %	30307	35075	1.2 %

Table 6. Impacts of changes in timber potential in Europe on global production. %= annual growth rate, percent.

		Base scenario			High-growth scenario			Medium-growth scenario		
Product	1994	2000	2010	1994-2010	2000	2010	1994-2010	2000	2010	1994-2010
Pulpwood	424130	448511	493186	1.0 %	453875	510715	1.2 %	451148	501513	1.1 %
Sawlogs	921648	980533	1088890	1.1 %	989808	1110517	1.2 %	985093	1101209	1.1 %
Other industrial roundwood	170892	181161	206488	1.2 %	180799	205515	1.2 %	180799	205515	1,2 %
Particles	222476	237945	263114	1.1%	239002	266275	1.2 %	238584	265021	1.1 %
Waste paper	99182	119673	144886	2.4 %	120683	148407	2.6%	120196	149290	2.6 %
Wood pulp for paper	152824	162388	176559	0.9 %	163851	182124	1.1 %	163207	179433	1.0 %
Other fiber pulp	20686	28211	36413	3.6 %	28830	38174	3.9 %	28420	37912	3.9 %
Paper and paperboard	271101	308046	355780	1.7 %	310932	365690	1.9 %	309468	363458	1.9 %
Sawnwood and veneer & plywood	477455	506337	562262	1.0 %	512371	574028	1.2 %	509323	569486	1.1 %
Particle and fiberboard	73795	76770	91945	1.38 %	78230	94525	1.6 %	77455	91944	1.4 %

production decreased imports of sawlogs to Europe significantly. The low income elasticity for sawnwood and excess sawlogs supply caused the real sawlog price to be relatively stable and not significantly affected by the increased supply from Europe.

The production of wood pulp for paper in Europe increased annually by 2.3% in the medium growth scenario, and by 3.2% in the high growth scenario, compared to 1.5% in the base scenario. Global production of wood pulp for paper increased to 179 million tons in the medium growth scenario in the year 2010 and to 182 million tons in the high growth scenario, compared to 177 million tons in the base scenario. In all scenarios, the real price of wood pulp stayed close to its level in 1994 (Figure 5).

Global production of paper and paperboard increased from 356 million tons in year 2010 in the base scenario, to 363 in the medium growth scenario and 366 in the high growth scenario. The production and price of other paper and paperboard were more sensitive to changes in the timber potential than the price of other paper grades. The production of paper and paperboard in Europe did not increase significantly when the timber potential increased. It actually decreased in the high growth scenario as the production was constrained by the capacity and other regions increased their production in response to the lower prices of pulpwood and pulp. The increased pulpwood supply caused higher wood pulp production in Europe and less wood pulp imports, whereas the paper and board production remained approximately constant. As the mix of wood pulp and waste paper in paper production was independent of their prices in this model, a change in production of paper and paperboard changed the demand for waste paper proportionally. Still, the price of waste paper did not differ much according to the alternative timber supplies in Europe.

The European production of sawnwood and veneer and plywood increased less than the sawlogs supply, as net import of sawlogs decreased. Net import of sawnwood and veneer and plywood decreased as well and the timber supply potential was not fully utilized in the high growth scenario. As a result of these effects, the consumption of sawnwood and veneer and plywood increased only slightly in Europe when the timber potential increased. Global production of sawnwood and veneer and plywood increased at an average annual rate of 1.1% from 1994 to 2010 in the medium growth scenario, and by 1.2% in the high growth scenario, compared to 1.0 in the base scenario. The increase in timber potential in Europe did not affect the prices of sawnwood and veneer and plywood significantly.

The production of particle board and of fiberboard in Europe increased only significantly in the high growth scenario where the annual growth was 1.4% compared to 1.1% in the base scenario, similar to the change in global production rates. The increased pulpwood and particles supply resulted in a price decrease for particle board and fiberboard.

4. DISCUSSION

FAO (1997) found that the real price of industrial roundwood (sawlogs and pulpwood) would change little until the year 2010 under the medium scenario (similar to the base scenario in this study). The more detailed analysis done in this study showed that, the

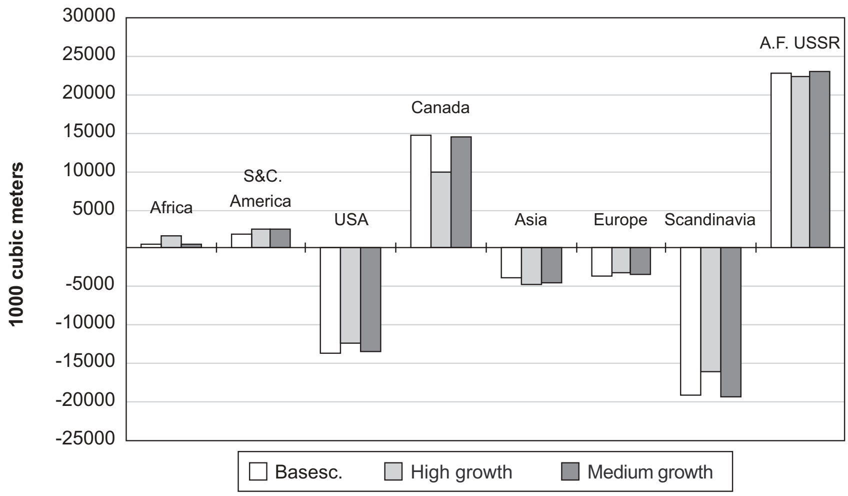

Figure 1. Regional net trade of pulpwood and particles by year 2010.

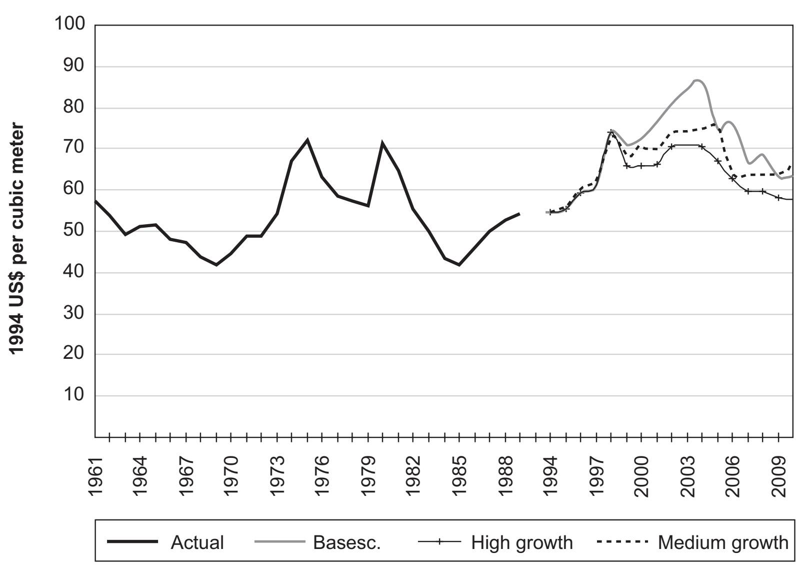

Figure 2. Pulpwood price, by timber potential scenario.

development of real prices of pulpwood and sawlogs were significantly different. Whereas the real price of sawlogs remained approximately constant, the price of pulpwood (and particles) increased significantly from about 55 dollars in the year 1994 to 86 dollars in 2004 before it decreased and reached 65 dollars in year 2010.

Because the timber supply potential was binding for both pulpwood and sawlogs in all regions in the base scenario, assumptions about this potential are crucial for the

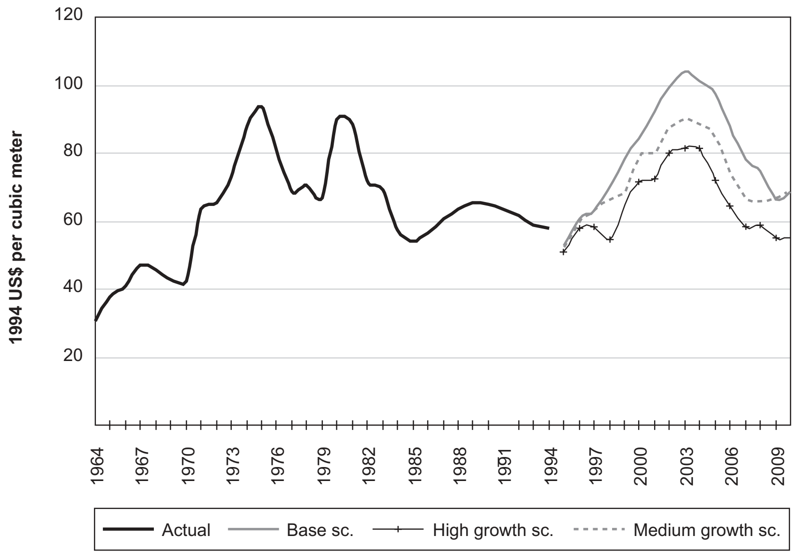

Figure 3. Particles price, by timber potential scenario

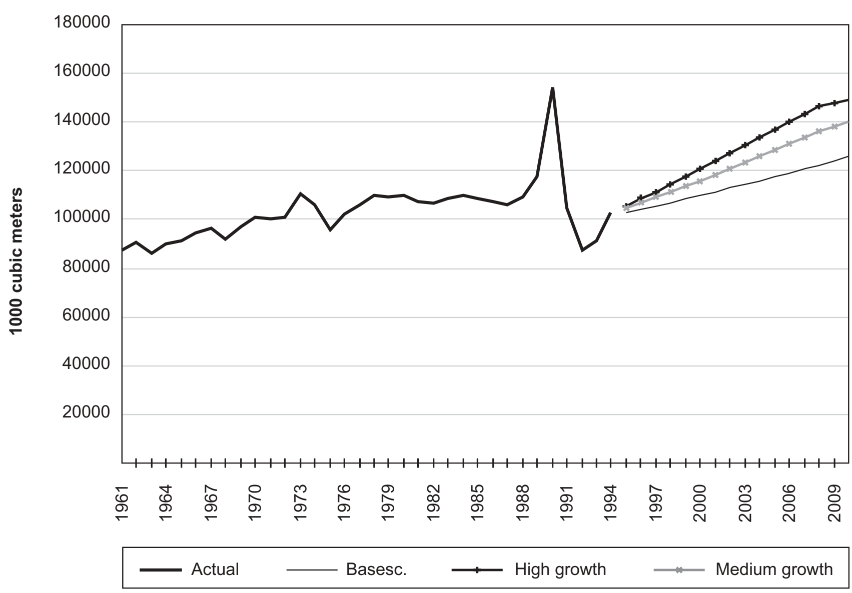

Figure 4. European sawlogs supply by timber potential scenario.

global price projections especially for pulpwood. The scenarios featuring increased timber potential in Europe lowered considerably the price of pulpwood. The price of particles showed a similar response to changes in timber potential. The sawlogs price responded less than the pulpwood and particles prices.

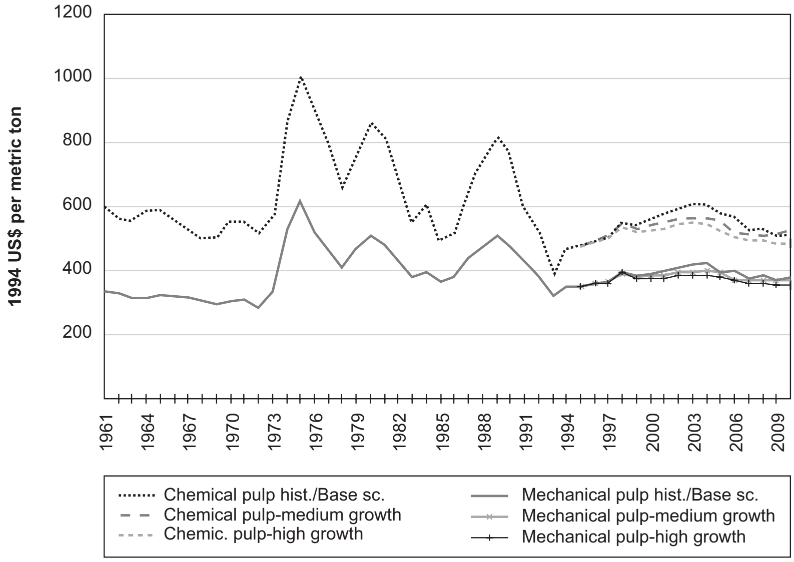

Figure 5. Real prices of chemical and mechanical pulp, by timber potential scenario.

A basic shortcoming of the methodology is that there was one single technology in each region, unaffected by the relative prices of input. Even though the substitution possibilities are limited in the forest industries, it is likely that a price increase for industrial roundwood as found in the low timber potential scenario would induce a technical change to reduce the input of wood. Hence the price of industrial roundwood would increase less, and the production of intermediate and final products would decrease less than predicted here.

Apart from the attempt to distinguish between sawlogs and pulpwood, the products in the model were still broad aggregates. The projected trends of demand and supply might hide different trends for specific products within a commodity group. Yet, this is how most data are available at the international level. Especially problematic is the fact that current international trade statistics do not distinguish any more between logs and pulpwood. In general, there are never enough data to model accurately forest industries. This is even more true at the international level. However, the material balance between raw materials, intermediate and final products imposed by the PELPS system and its related input-output coefficients help ascertain the plausibility of the data.

Demand and supply analyses in Europe are summarized in Solberg and Moiseyev (1997). There are quite a few studies, especially for Finland, Sweden and Norway, but the findings differ widely from study to study. Even within Scandinavia and Northern America, there is much uncertainty about the magnitude of price elasticities, and to what extent they are relevant in modeling timber supply. Change in inventory is an important shift variable in the theory of timber supply. As a result, some models attempt to model inventory explicitly (see e.g. the GTM model in Kallio et al. 1987). But inventory data are very scarce, the magnitude of the inventory elasticities are uncertain, and the timber potential is guided at least as much by political as by economic forces. Therefore, modeling timber supply as an exogenous constraint, as was done here, may well be a suitable alternative. A possible immediate improvement would be the addition of an elasticity to represent the short-term supply response to price.

The production of intermediate and final products was described by activity variables and input-output coefficients that describe the technology in each region. Each activity corresponds with a manufacturing cost and a limited capacity. A behavior as in perfect competition is assumed, hence each supplier produces up to the level where marginal cost equals the price, possibly constrained by the capacity limit. In fact imperfect competition may prevail, due for example to increasing returns to scale (Krugman 1979). Studies of the US pulp and paper sector are not conclusive regarding the importance of returns to scale (see e.g. Gilless and Buongiorno 1980, Stier 1985, and Orr and Lee 1990). At the international level, the assumption of competitive markets for pulp and paper products, which implies the law of one price, seems tenable (Uusivuori and Buongiorno 1992). In the current set up, the demand for raw materials (waste paper, wood and wood pulp) responds to the price of final product, but not the technology. If alternative technologies, with different mixes of raw materials were incorporated for each given product and region, substitution would occur more readily and could also have a dampening effect on prices (Zhang et al. 1996).

The parameters of the distributed lag-function that decide the global capacity expansion are the same for all products in this study. Better estimates should be obtained by econometrics, for each product. Due to the importance of capacity expansion, the implications of other investment models such as Tobin's q-model (described by Zhang and Buongiorno 1993, and usable in PELPSIII) should be investigated.

In the present model, regional net trade is the result of different manufacturing costs in each region, and of the trade inertia constraints. As a result, the prices of a given product are the same in all regions (equal to the "world price") in the base year, though they may differ somewhat in later time periods as a result of the trade inertia constraints. That is the trade flow between a region and the world market cannot change by more than 20% from year to year. The use of trade inertia was criticized by Cardellichio and Adams (1990) because the bounds are arbitrary and that they generate "noneconomic" behavior. However, trade flows are not solely decided by prices, and adjustments are bound to take time because of factors such as long-term contracts, information flows and regulations. So, the use of trade inertia parameters may be justified, but their magnitude must be refined by empirical study. Another possibility is to develop a more flexible model of trade inertia than the lower and upper bounds used here.

5. CONCLUSIONS

In the base scenario the real price of sawlogs, sawnwood and veneer and plywood were found to remain rather constant, whereas the prices of pulpwood and particles increased significantly at the beginning of the projection period, though they declined after year

2000. The real prices of intermediate and final products in the pulp and paper sector increased less than those of raw materials. As the capacity constrained the production of printing and writing paper and other paper and paper board towards 2010, their real prices began to rise.

It is likely that the faster increase in pulpwood price relative to sawlogs is due to the higher income elasticities of demand for paper products than for solid wood products. If a higher fraction of the industrial roundwood supply will come as pulpwood in the future, due to increase output of young plantations, the actual price increase of pulpwood might be lower than projected here.

As the timber supply potential was binding in the base scenario, the assumptions of alternative scenarios regarding the timber supply potential in Europe affected regional and global demand and supply significantly. The real price of pulpwood were reduced by 13% in the medium growth scenario and by 18% in the high growth scenario in year 2004, although global production increased by 1% and 2% only.

The model used in this study predicted that higher timber potential in Europe would increase the supply of industrial roundwood and especially the supply of pulpwood. This might lead to higher production of wood pulp, but not necessarily of paper and board, as the import of wood pulp decreased. The increased supply of sawlogs led to higher production and less imports, but the consumption of sawnwood in Europe stayed relatively stable. A growth rate of 2.7% in the timber potential in Europe gave excess timber potential for sawlogs in this region when the economic growth was assumed to slow down after the year 2000.

The results of the timber potential scenarios showed that they are critical assumptions in predicting the future development of demand, supply and prices in the forest sector. This suggests that a useful improvement of the model would be to make the potential supply constraints for timber price responsive.

The analysis presented here is burdened with considerable uncertainties and should be regarded as a first attempt to estimate the order of magnitudes of the potential impacts of increased forest growth in Europe. Nevertheless, the model developed for this specific purpose, and the PELPS system on which it is based are useful tools in bringing together in a consistent way a wide variety of variables and relationships that bear on the European timber market. The availability of data is a major problem for approaches like this and the results illustrate the importance of high quality data for timber potentials, timber supply elasticities and other technical coefficients.

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SHORT AND LONG TERM EVOLUTION OF *PINUS HALEPENSIS* (MILL.) HEIGHT GROWTH IN PROVENCE (FRANCE) AND ITS CONSEQUENCES FOR TIMBER PRODUCTION

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ABSTRACT

A study of *Pinus halepensis* (Mill.) in Southeast of France showed a continuous acceleration of height growth, starting more than 80 years ago. Two different models, based on (i) stem analysis and (ii) a site fertility index, converged in the same estimation of a 4.5 cm/year average increase of the height index. This acceleration showed variations that could be linked to short term climate variations (period < 10 years). Identified and suggested causes include changes in land use and forestry practices, soil recovery, CO_2 rate increase and long term climate changes. Consequences of this trend are assessed for timber production.

Keywords: Southeast France, Provence, Pinus halepensis, height growth, model, climate change, height index.

1 INTRODUCTION

In the French Mediterranean area, the ecology of most of the main forest tree species has been extensively studied in the last 20 years by Cemagref, including height growth models. Booklets were edited for foresters, with synthetic decision trees to evaluate each species potential growth, according to local environment conditions.

During these studies, and when using decision trees for forest management and afforestation projects, some differences between stands growth were reported in homogeneous places, that cannot be explained by usual variables. Age of the stands appeared to be one of the possible explanations, being well correlated with observed deviations. However, the studies were not tailored out to tackle the problem, and field observations by foresters were not precise enough.

Corroborating results of numerous scientific studies on tree growth acceleration in Europe, led us to think that it was necessary to go deeper in this field. Among the

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studied species, *Pinus halepensis* appeared to be much concerned. It was also chosen because available databases allowed us in a first stage to tackle the problem with few extra data collection.

The main goal was not to explain in detail the acceleration, but while calculating this acceleration, to know whether it was necessary to update forest management tools. Subsequently, we tried to identify possible causes and consequences, using environment and historical variables of the databases.

Following these first results, we are now starting extensive research specifically dedicated to *Pinus halepensis* response to local and global environment changes, with various partners.

2 MATERIAL AND METHOD

2.1 Study area

The study area is located in Provence, Southeast of France. It covers 500 000 ha among which 100 000 ha of *Pinus halepensis* pure or mixed stands. The climate is mediterranean, with two sub-types (Ripert and Nouals 1988):

- the Basse Provence sub-type characterised by a long dry summer period (average 2 to 4 months, up to 7 months in exceptional years), mean annual rainfall ranking from 400 to 700 mm with summer rains < 100 mm (June-August), a mean annual temperature > 12 °C and 0 to 2 cold months (CNRS 1975), and
- the Arriere Pays sub-type with a shorter dry summer period (1 to 2 months, rarely up to 4 months), a lower mean annual temperature (<12°C), higher mean annual rainfall (650 to 1000 mm) with however few summer rains (90 to 130 mm) and 2 to 4 cold months in winter.

The dominant rock is limestone, with smaller areas dominated by marl, dolomite, sandstone, argilites and similar rocks, and all intermediate forms between all of these rocks. More than 95 % of these parent rocks are carbonated, and acid soils are very rare.

2.2 Reference stands and data

Only sites with an old, undisturbed forest, and free from fire for at least 30 years were targeted, in order to factor out as much as possible unpredictable effects of land use and forestry practices. Uneven-aged stands were accepted, as representative of the majority of *Pinus halepensis* stands in Provence, and because they allow, for phytosociological analyses, a better development of undergrowth and herbaceous layers than dense even-aged stands.

Old forest means that stands are being considered as more or less dense forest for at least 50 years, even if older trees could have grow in opened stands or isolated, considering the importance of grazing in the past.

Because all the valleys and most of the lower slopes were cultivated at a time, some plots were laid out on former terraces, which represent very large areas. The favourable effect of these terraces was evaluated and afterwards taken into account in our models.

Data used for this paper derive from a forest site assessment study of Provence, and a Pinus halepensis autecology study carried out between 1996 and 1998. A total 320 plots were sampled throughout the study area. The sampling design allowed a complete crossing of all classes of four main variables (elevation, climate sub-type, parent rock, and exposure/slope Becker index), and a balanced distribution of other important variables of local extension, describing topography and soil parameters (Vennetier et al. 1997). More than 800 age/height pairs are available, for trees between 15 and 180 years. Among these trees, 109 were felled and logged into 0.5 to 2 m long sections, to reconstruct their height growth curve by stem analyses (Brochiero 1997).

2.3 Height growth modelling

2.3.1 Method

In order to build site index curves, the classical approach used in evenaged stands is to establish for each sampled plot a mean dominant height growth curve which is obtained by averaging the observed individual height growth curves of some dominant trees sampled in the stand. A height growth model is then fitted to the set of mean plot curves, allowing the direct computation of a site index for each stand (Duplat and Tran-Ha, 1997).

In the present situation, given the large within-stand differences in the ages of trees, a tree by tree approach was preferred: the individual tree height growth curves were not averaged by plot, but directly fitted by an individual height growth model. The model allows the computation for each tree of a “tree index” (defined as the estimated tree height at a reference age). Then, tree indexes can be averaged over a plot to define a site index.

To take into account effects of inter-tree competition, we selected very severely among the dominant trees to eliminate those who could have been shaded in the past. The younger trees were always selected in gaps. The main criterion is living branches as close to the base as possible. As *Pinus halepensis* is light demander and the branches prune naturally very quickly when shaded, trees with large branches down to the base are unlikely to have been shaded even for a short period.

2.3.2 Height growth model

A height growth model was thus fitted to the individual height growth curves obtained by stem analysis. 86 such curves were available in 1997, coming from 31 plots. A preliminary visual inspection of the set of curves revealed that they do not cross each other too much. A height growth model of the following form seemed therefore possible:

$$H_i(\text{age}) = F(\text{age}, \alpha_i, \beta) + \varepsilon,$$

where H_i(age) is the height of the tree i at age and F is a sigmoidal function of age, depending on the parameters α_i (a single tree specific parameter which allows the definition and the computation of the tree index) and β (a vector value parameter common to all trees).

Different sigmoidal functions F and different choices for the tree specific parameter α_i were fitted to the data by minimization of the sum of squared errors between observed and predicted heights. This led to retain the Richards function with the asymptote (Hmax = maximum height) as the tree specific parameter. The resulting tree height growth model was (with age in years):

$$H_i(\text{age}) = \text{Hmax}_i \{1\text{-exp}(-0.021 \text{ age})\}^{1.5385} + \varepsilon, \quad (1)$$

with a residual standard deviation of 0.86 meter. Figure 1 presents four examples of individual fits.

The model produces a set of growth curves proportional to each other. Figure 2 gives an idea of the overall variation of height over age and of its description by the model.

2.3.3 Definition of the tree index and choice of a reference age

The tree specific parameter Hmax could be used directly as tree index, but it is more convenient for practical use, and without any theoretical consequence for the analysis, to use the estimated height at a reference age ao. The tree index TIao is then defined, for a tree i, as:

$$\text{TIao}_i = \text{estimated height at age ao} = \text{Hmax}_i \{1\text{-exp}(-0.021 \text{ ao})\}^{1.5385} \quad (2)$$

For a tree, given its actual height H_i and age ($\text{age}_{i)}$, the parameter Hmax_i is estimated by inverting equation (1), ignoring the random deviation ?. TIao_i is then estimated using equation (2) above, leading to:

$$\text{(estimated) TIao}_i = H_i \{(1\text{-exp}(-0.021 \text{ ao}))/((1\text{-exp}(-0.021 \text{ age}_i))\}^{1.5385} \quad (3)$$

Notice that the estimation error comes from neglecting the random deviation ε in (1) and equals to:

$$\text{TIao}_i - \text{estimated TIao}_i = \varepsilon \{(1\text{-exp}(-0.021 \text{ ao}))/((1\text{-exp}(-0.021 \text{ age}_i))\}^{1,5385} .$$

It can be seen that this error decreases (and tends toward zero) when age_i increases. Inversely, it can be very high if age_i is too small. For this reason, trees younger than 35 years old were excluded from the following analysis.

In practice, the reference age ao = 70 years has been chosen, because it is close to the usual logging age. It is also approximately equal to the mean age of measured trees. Applying equation (3) with ao = 70, we obtain:

$$\text{(estimated) } TI70_i = 0.669\ H_i / \{1\text{-}\exp(-0.021\ age_i)\}^{1.5385} \quad (4)$$

Any other choice for the reference age would have resulted in the same formula, except that a different multiplying constant (0.669 above) would have been used. This makes clear that the choice of the reference age has no consequences on the analysis.

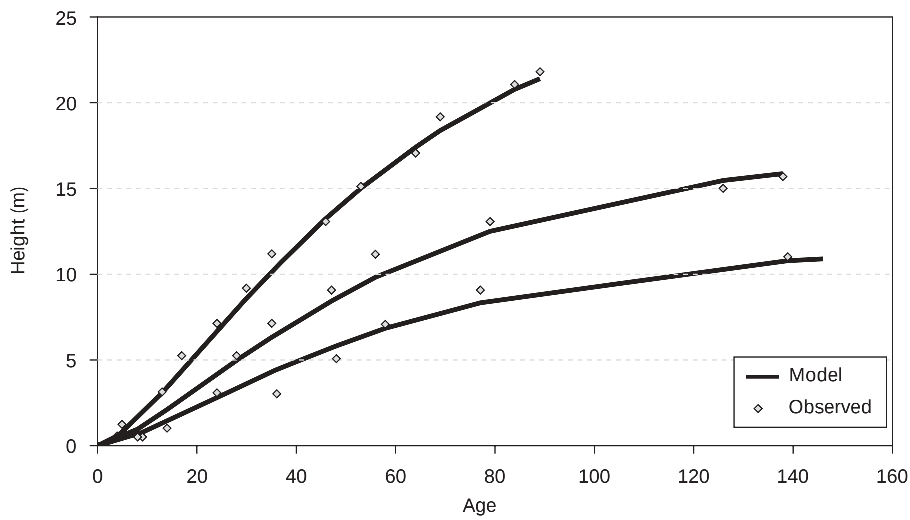

Figure 1. Examples of observed (broken lines) and fitted (bold lines) height growth curves.

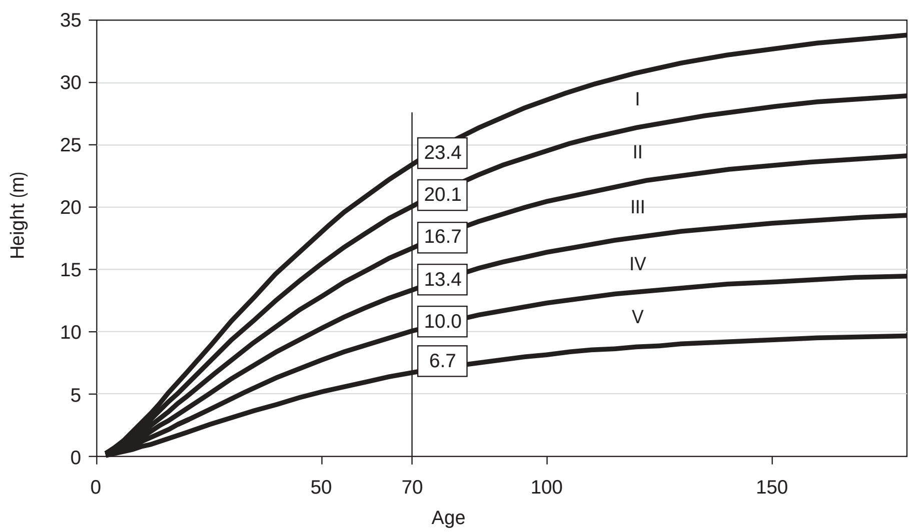

Figure 2. 6 model curves, which delimit 5 fertility classes.

3 LONG TERM VARIATIONS

3.1 Generation effect on the tree index

The tree index TI70 was computed for the 521 sampled trees with age over 35 years available in 1997. While the tree index, being the estimated height of a tree at age 70, should be free of developmental age effect, there was a linear relationship between the tree index and the actual age of the trees

$$TI70 = 19.642 - 0.079 * age; \ R^2 = 0.288 \qquad (p < 10^{-4})$$

This is a generation effect: the older trees tend to have smaller indexes than the younger ones.

This relationship may be the result, at least in part, of the unbalanced distribution of age in fertility classes, the older trees being on less fertile sites. Trees on good sites are bigger, higher and often straighter, and are therefore more liable to be logged, and if so, earlier than on poor sites. It was difficult to find undisturbed forest with old trees on good sites. To remove this age/fertility bias, we made use of the differences in tree ages within a plot to study the relationship between TI70 and age inside plots, i.e., we observed the difference $TI70_i$ - mean plot TI70 versus the difference age_i - mean plot age (Figure 3). As long as age effect is concerned, it is equivalent to an analysis of covariance of TI70 with additive age and plot effects.

As expected, the within-plot relationship is not so strong but still clear: within the same site, the older trees tend to have smaller height indexes than the younger ones. The effect amounts to -4,64 cm/year on TI70 (Figure 3). An interaction between age and plot

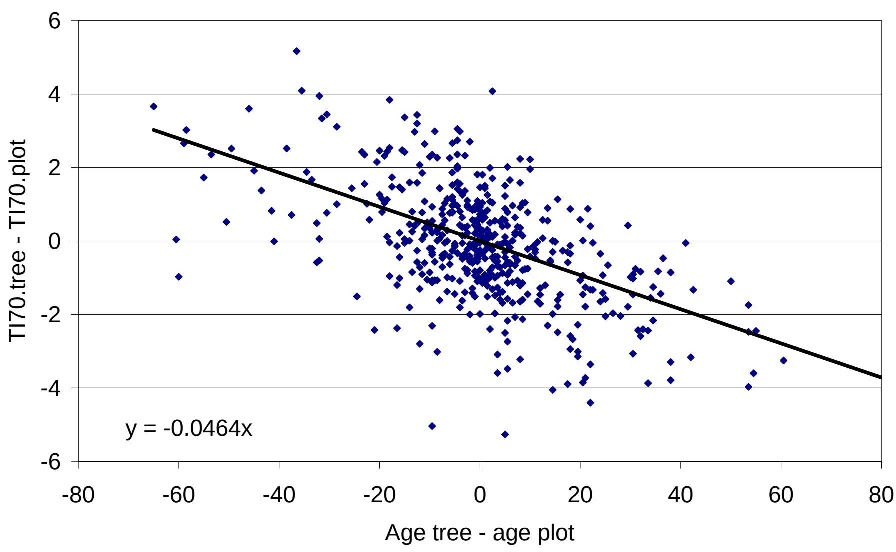

Figure 3. Within-plot fertility index variation.

effects has been further tested in the analysis of covariance of TI70, but appeared to be non-significant. This indicates that the within-site generation effect on tree height is the same for all sites.

3.2 Site assessment index

A model was developed to allow the prediction of *Pinus halepensis* height index according to abiotic variables. This model is based on the data set obtained through the 200 plots available in 1997 (Vennetier et al. 1997). It takes 9 individual or combined variables into account, most of them describing site topography and soil. *Pinus halepensis* does not respond significantly to climatic variables in the study area for geographical reasons: a strong negative correlation exists in Provence between rainfall variables and temperature, both of them strongly linked but in an opposite way to elevation. A favourable increase of rainfall has consequently a systematic counterpart of detrimental temperature fall, as this species is heat demander and does not withstand deep frosts (Devaux et Le Bourhis 1978).

This model is based on a multivariate regression. Selection of basic variables has been done by analyses of variance and tree models analyses. Being intended to site assessment by foresters, it was designed to complete three conditions:

- to optimise the coefficient of multiple correlation: predicted vs. observed height index,
- to limit as much as possible the number of observations with a very important deviation of the prediction i.e. more than one fertility class (to avoid possible fatal errors in site assessment). This condition has priority on a slight improvement of the correlation coefficient.
- to avoid partial coefficient for each variables in the model to have the opposite sign of the individual correlation coefficient of these variables. Field technicians would not understand and accept that a model gives a negative effect to an increasing soil depth ! For this condition, after a first stage of free mathematical optimisation, constraints were set on the sign of the coefficient of the main variables.

Because of interaction between variables, some synthetic variables were created, combining classes of individual variables. After several optimisation phases with various variables combinations, the model fitted well to observed tree height index, as displayed in Figure 4.

The model predicted 89% of the trees height index in a span of one fertility class, among which 62% were predicted within one half of a fertility class. Looking for variables that could explain part of the residual errors, we found that most of the trees situated far over the prediction were young and most of the trees situated far under the prediction were old (Figure 4).

As expected, residual estimation errors were linked to tree age, with 4.4 cm/year trend, very close to the above assessment by the intra-plot index.

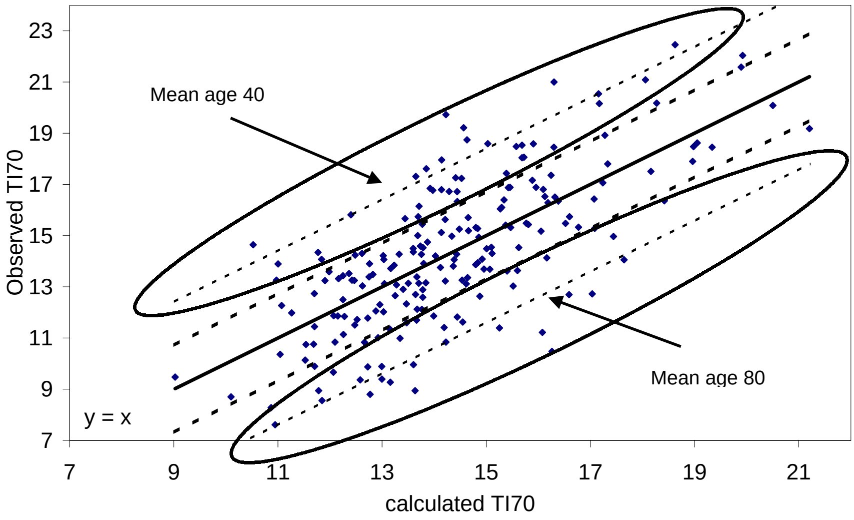

Figure 4. Model calculated vs. observed *Pinus halepensis* height.

In plots with two or more tree generations, with a span of more than 80 years between the youngest and the oldest, it was possible to verify that the height index has gained between three and four meters within the 20th century, what means about one fertility class.

4 SHORT TERM VARIATIONS

4.1 Periodic variations in the last 30 years

These results take the complete data set (1997/98) into account. In many of individual height growth curves, including that of oldest trees, three phases could be distinguished in the last three decades. (i) 1972/81: fast growth, (ii) 1982/90: reduced growth, (iii) 1991/97 acceleration. These trends are reflected in the average height growth as well as in maximum and minimum observed growth (Figure 5).

They can also be highlighted by a comparison with the model-predicted growth, which gives a general smoothed pattern of the growth curve during this period. It can be seen that height growth differs from model-predicted values for the three periods, mainly the first and third one.

Figure 5 and Table 1 show the growth of the same trees for the 3 periods, based on stem analyses. The normal shape of growth curves for trees of this age is assymptotic (Figure 2). Growth should have slowed down regularly. This explains that growth is

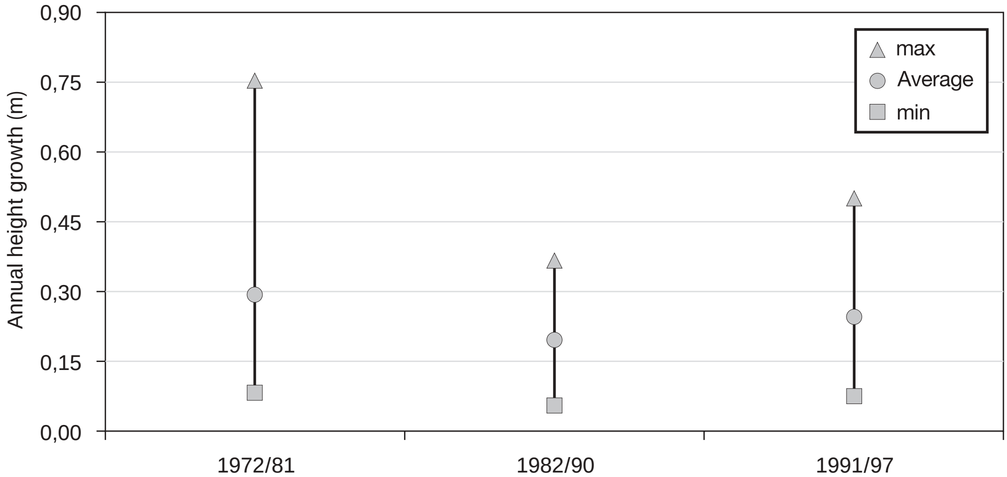

Figure 5. Short term variation of *Pinus halepensis* height growth

Table 1. Height growth variations of *Pinus halepensis* in the last three decades (m/year)

	Annual height growth (h.g.)			Observed h.g. – Model calculated h.g.			
	1972/81	1982/90	1991/97	1972/81	1982/90	1991/97	1972/97
Observed	0.29	0.20	0.25	0.055	-0.019	0.048	*0.012*
max	0.75	0.37	0.50	0.38	0.12	0.24	0.114
min	0.08	0.06	0.08	-0.22	-0.16	-0.13	-0.120
s	*0.12*	0.08	0.09	0.09	0.05	0.08	*0.044*
Model	0.235	0.219	0.202				

logically slower in the 1990s than in the 1970s, and underlines the low value of the 1980s compared with the 1990s.

4.2 Link with short term climate variations

Growing phases of *Pinus halepensis* in the previous 30 years can be related to short-term variations of local climate. Compared with the 1970s, the period 1982-90 was characterized by:

- lower annual rainfall, with 4 among the 5 driest years since 1970. The average annual rainfall experienced a 20% fall, up to 30 % on the east part of the study area (Ladier and Ripert 1996).
- a summer drought regularly extended to the entire month of September.

- exceptionally low temperatures, particularly 1985/86 winter, with 3 among the 4 coldest winters since 1970, and regularly late frost in spring.
- exceptionally high temperatures, with the two hottest summers since 1960.

Since 1991, the average climate is closer to that of the 1970s, with early springs, short summer dry periods, mild winters and a higher annual rainfall (+ 20 % compared with the 1980s).

The conjunction of exceptional climatic events seems to be at the origin of the lowest growth rate in the 1980s: added to exceptionally dry years, deep frost, late springs and the hottest summers deprive *Pinus halepensis* from a normal growth in the years with sufficient rainfall.

However, a more comprehensive study of various climate variables and of *Pinus halepensis* annual height growth is necessary to establish clearly their links (Serre 1973; 1976). This work is under way.

5 DISCUSSION

5.1 Causes

5.1.1 Land use practices

The acceleration of *Pinus halepensis* height growth was already noticeable 80 years ago. At least three environmental and land use conditions explained this early phenomenon.

Among former practices, resin tapping and regular burning to maintain grasslands were probably the most detrimental to tree growth. The dates of resin tapping and fire occurrence are generally easy to read even for the oldest trees, thanks to the scars they left in tree rings.

We have no precise reference for the consequences of resin tapping on height growth of Pinus halepensis, but it is probably similar to what has been observed for other pine species. Tapped trees have not been selected for stem analysis. However, most of the oldest trees showing tapping scars experienced an improved diameter growth after resin tapping abandonment.

By analogy with what we observed in young stands partially burnt in recent years, we suggest that each of these fire occurrences is able to slow down height and diameter growth for two to five years, and even more in case of partial to extensive crown destruction.

As these practices were gradually abandoned since the beginning of the 20th century (and even before for some areas), tree growth was partly released from overwhelming constraints.

5.1.2 Competition and shelter

Land abandonment and fire reduction also led gradually to natural regeneration of old and generally scattered trees. The young stands grew therefore with more competition. Higher stand density led to accelerated height growth.

Even without direct competition amongst neighbours, trees grew more and more in a forest environment providing lateral shelter and favourable microclimatic conditions, instead of an opened and more or less agricultural environment. In many pure *Pinus halepensis* stands, an undergrowth dominated by green and/or white oak *(Quercus ilex* and/or *Q. pubescens*) mixed with numerous shrubs is establishing with the pines becoming old (Tatoni et al. 1994). In mixed oak and *Pinus halepensis* stands, the coppicing period has become longer and longer, many of the stands being abandoned in the last 50 years.

Competition with oak species is detrimental to Pinus growth in the first years. Seedlings may not be able to grow straight for 10 to 25 years in a dense oak shrubby stand, even if not directly shaded, probably because of root competition. However, those that survive are able to carve out their place and finally to overgrow oak species, showing from this time a rapid growth.

5.1.3 Soil recovery

Fire and grazing reduction, as well as the abandonment of litter raking and lopping, combined with stands and undergrowth recovery, allow gradual soil improvement, and in turn tree nutrition enhancement (Vaudour 1991). In most of the soils of our plots, organic matter is significantly present in the upper horizons, whereas it is rare nearby in similar site conditions under young or degraded forests.

5.1.4 Combined causes

None of the above causes can explain alone the acceleration of tree growth. Improving environment enhances vegetation growth and diversity, which in turn improves soil and microclimatic conditions.

5.1.5. Other suggested causes

As stated in other papers of these proceedings, in many parts of European Union and other parts of the world, CO_2 rate increase, long term climate changes and nitrogen atmospheric deposition are surely involved in the process of accelerating growth of *Pinus halepensis*. As our primary studies were not directed towards one of these specific aspects, it is impossible to assess the relative importance of these variables versus the more local causes.

5.2 Consequences

Whatever the causes, the average *Pinus halepensis* height in Provence showed a gain of 4 meters in a 100 years time span. This increase amounts to more than one fertility class (in a scale of 5 classes), and the acceleration is going on for all sites in all fertility classes. Considering the 250 000 ha of French existing stands, a predictable further improvement of one half of a fertility class (0.75 m^3/ha/year) would mean a gain of 180 000 m^3/year.

It is impossible to predict the long-term trend of this acceleration. The observed trend could be theoretically down regulated by:

- The global fertility of sites (risks of shortage for some nutrients), but this is not likely to happen in most of the study area where parent rocks and derived soils are rather rich and chemically balanced.
- By physiological limits of the species, whether for growth or adaptability to changing environment variables, including climate (Keller et al 1997), but *Pinus halepensis* is far from its limits in this area.
- By biological unbalanced evolution of the environment: parasites epidemic development (Mirault et Regad 1992), replacement of favourable by less favourable mycorrhyzal species, …. There are much uncertainties about these possible evolutions.

As mediterranean forest environment, particularly the soil, is far from having finished its recovery process, considering the acceleration on today's most fertile sites, and the probable continuity of global causes of this trend, we suggest that *Pinus halepensis* height index will go on improving in the following years.

6 CONCLUSION

French Mediterranean low elevation coniferous forests have lost today most of their economic importance for wood-based industries, because of their real or supposed low productivity, and bad quality. This unfavourable picture is partly biased due to the image of former old forests, growing in the less fertile sites where agriculture was impossible, and submitted to intensive man use.

With the outstanding expansion of forest on fallows and abandoned agricultural land, *Pinus halepensis* is now more and more growing on potentially fertile sites. With accelerating growth, and higher density, beautiful and productive stands have developed on large areas. Similar results where observed on other important species of French mediterranean forests, including *Cedrus atlantica* (Ripert and Boisseau 1993) and *Pinus nigra corsicana* (Nouals and Boisseau 1992). We have accordingly to address quickly the valorisation of this increasing and improving, but widely under-exploited, natural resource.

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PROGRAMME

Causes and Consequences of Accelerating Tree Growth in Europe

17-19 May 1998
Champenoux INRA centre of Nancy
France

Sunday 17 May

Excursion

Monday 18 May

9.00 Official welcome and opening of the seminar
Dr. François Le Tacon, INRA Forest Research Centre of Nancy
Mr. Philippe Leroy, President of the French High Council of Forests and Forest Products
Dr. Ian Hunter, Director of the European Forest Institute

Theme: Biological basis for understanding causes and consequences of increased forest growth

Moderator: Dr. Ian Hunter, European Forest Institute

9.30 Growth trends in European forests – Do we have sufficient knowledge?
Prof. Dr. Heinrich Spiecker, University of Freiburg, Germany

10.00 Accelerated tree growth and nutrition – Nitrogen perspectives from the Nordic countries
Prof. Folke Andersson, Swedish University of Agricultural Sciences, Sweden

Timo Karjalainen, Heinrich Spiecker and Olivier Laroussinie (eds.)
Causes and Consequences of Accelerating Tree Growth in Europe
EFI Proceedings No. 27, 1999

11.00 The Recognition project – Investigation into relationships between recent changes of growth and nutrition of Norway spruce, Scots pine and beech forests in Europe
Dr. Jörg Prietzel, University of Munich, Germany

11.30 Relative importance of increasing atmospheric CO_2, N-deposition and temperature in promoting European forest growth
Prof. Melvin Cannell, Institute of Terrestrial Ecology, Edinburgh, UK

12.00 Modelling CO_2 and nitrogen fertilisation of forests in selected countries of Europe
Prof. Dr. Gundolf Kohlmaier, University of Frankfurt, Germany

12.30 Effect of CO_2 and nitrogen interaction on the productivity of boreal forest ecosystem
Prof. Seppo Kellomäki, University of Joensuu, Finland

Moderator: *Prof. Dr. Heinrich Spiecker, University of Freiburg, Germany*

14.00 Carbon – water relations in temperate trees in response to rising CO_2. Implications for growth and sensitivity to drought
Dr. Jean-Marc Guehl, INRA-Nancy, France

14.30 Changes in phenology of trees in Europe
Prof. Dr. Peter Fabian, University of Munich, Germany

15.00 Genetic improvement reduces loss and accelerates tree growth
Dr. Eric Teissier du Cros, INRA-Avignon, France

15.30 Spatial analysis of radial growth of Norway spruce in Norway
Prof. Dr. Geir-Harald Strand, Norwegian Institute of Land Inventory, Norway

16.30 Historic forest use in Central Europe and its implications to forest ecosystem status
Prof. Dr. Gerhard Glatzel, Institute of Forest Ecology, Vienna, Austria

17.00 Floristical changes in Central European forest ecosystems during the last decades as an expression of changing site conditions
Prof. Dr. Anton Fischer, University of Munich, Germany

Tuesday 19 May

Theme: Possible consequences of the increased forest growth

Moderator: *Prof. Melvin Cannell, Institute of Terrestrial Ecology, Edinburgh, UK*

9.00 Enhanced tree growth: possible effects on food chain dynamics in forest ecosystems
Prof. Dr. Erwin Führer, University of Agricultural Sciences, Vienna, Austria

9.30 Consequences of increased tree growth on silviculture and forest management planning
Mr. Konstantin von Teuffel, Federal Ministry of Food, Agriculture and Forestry, Bonn, Germany

10.00 Causes and consequences of long-term forest productivity changes: new perspectives from dendroecological research
Dr. Jean-Luc Dupouey, INRA-Nancy, France

10.25 Group photograph and coffee

11.10 Policy consequences
Mr. Ernst Wermann, Federal Ministry of Food, Agriculture and Forestry, Germany

11.40 Development of increment of forests in Europe – What can we find in the international statistics?
Dr. Risto Päivinen, European Forest Institute

12.10 Economic and trade implications of increased timber supply in Europe
Prof. Dr. Birger Solberg, Agricultural University of Norway, Norway

12.40 Possible effects on wood quality to be expected from accelerating tree growth in Europe: tentative questions and answers
Dr. Gerard Nepveu, INRA, France

Moderator: *Prof. Dr. Birger Solberg, Agricultural University of Norway, Norway*

14.30 Assessment of long-term changes in timber quality: combining national forest inventory data and growth and wood quality models
Dr. Jean-Michel Leban, INRA-Champenoux, France

15.00 Consequences of accelerated growth for the long-term wood supply of a central European country
Mr. Gert-Jan Nabuurs, IBN-DLO Institute for Forestry and Nature Research, Wageningen, the Netherlands

Moderator: *Prof. Dr. Karl-Eugen Rehfuess, University of Munich, Germany*

16.00 Final discussion and concluding remarks

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