1999

Climate variations and tree growth between 1961 and 1995 in Austria

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Recommended Citation

Hasenauer, H., Nemani R. R., Schadauer K., and Running S. W. Climate variations and tree growth between 1961 and 1995 in Austria. EFI Proceedings No. 27: Causes and Consequences of Accelerating Tree Growth in Europe, Timo Karjalainen, Heinrich Spiecker and Olivier Laroussinie (eds.). Proceedings of the International Seminar held in Nancy, France 14-16 May 1998.

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.

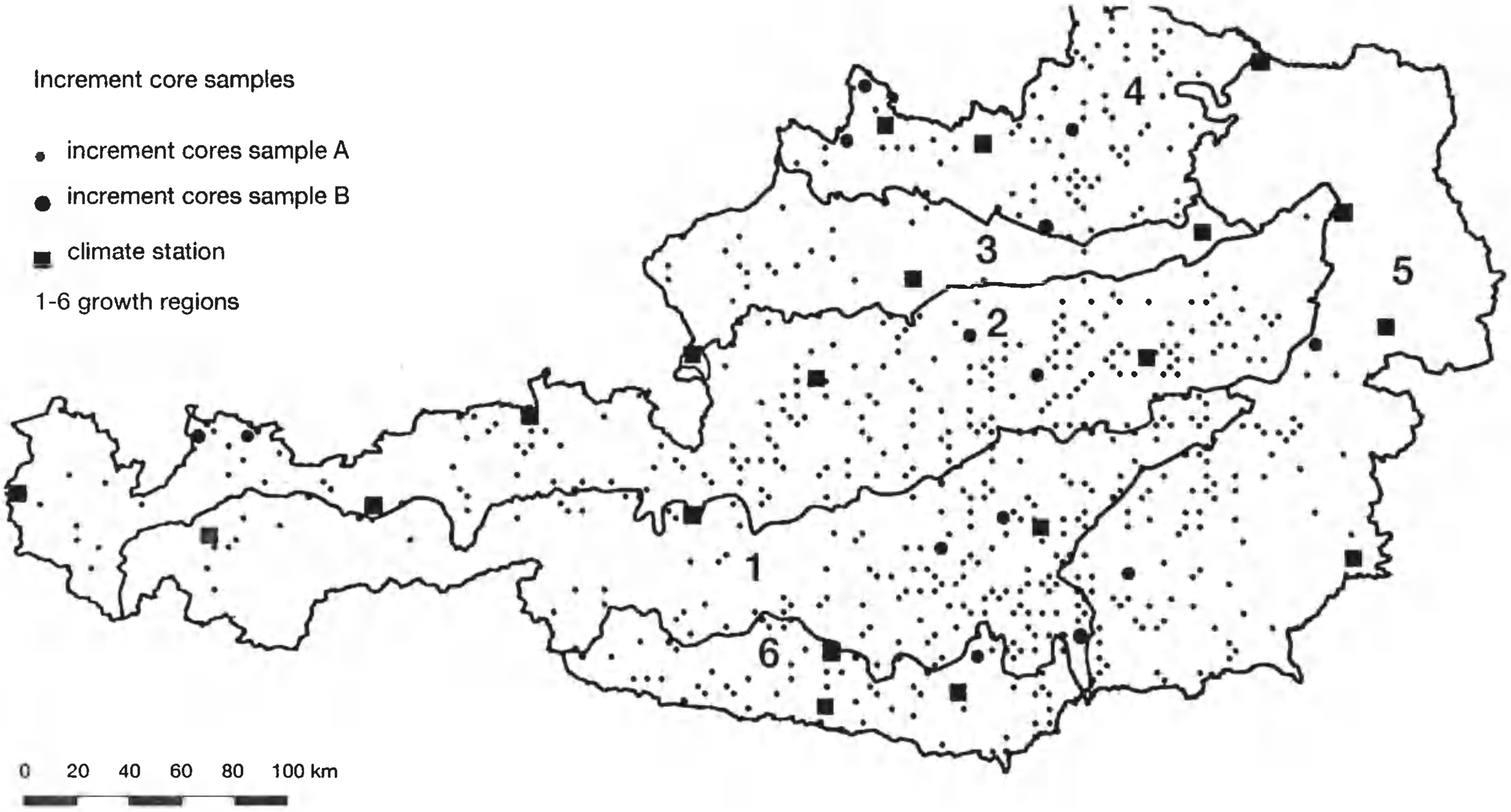


Figure 1. The growth regions of our study including the 20 weather stations with daily climate records between 1961 to 1995 and the 1179 increment cores for Norway spruce. The 6 growth regions represent a simplification of the 9 growth districts of Kilian et al. (1994) and characterize the major forest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

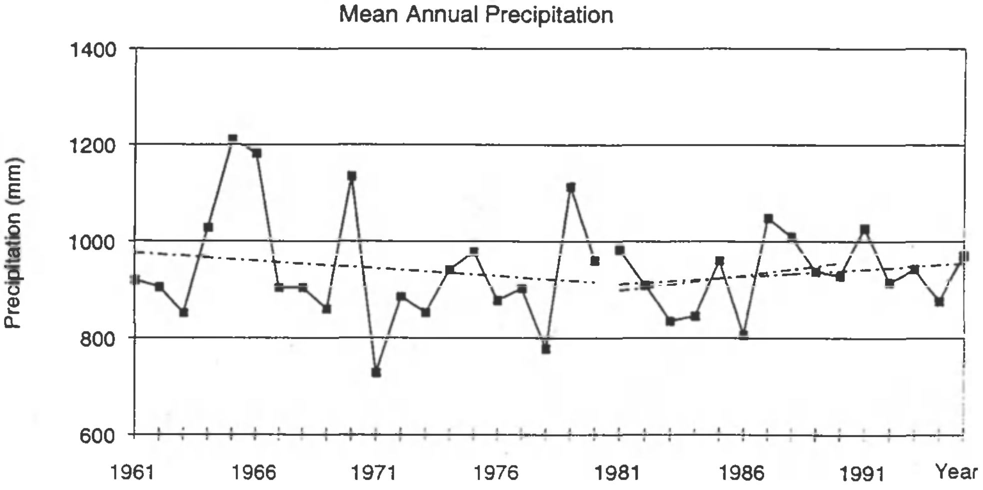
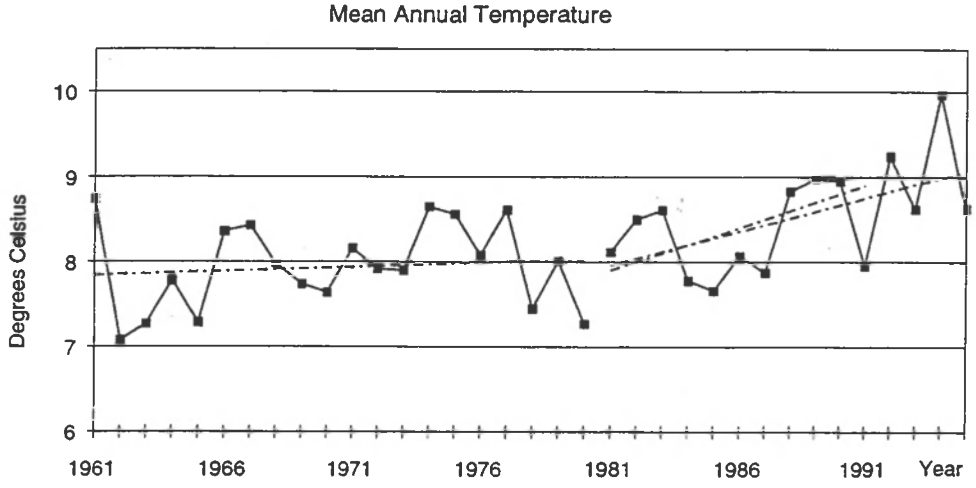


Figure 2. Mean annual precipitation including the corresponding regression lines for the time spans 1961-1980, 1981-1990, and 1981-1995 in Austria. The numbers represent the means from 20 weather stations.

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



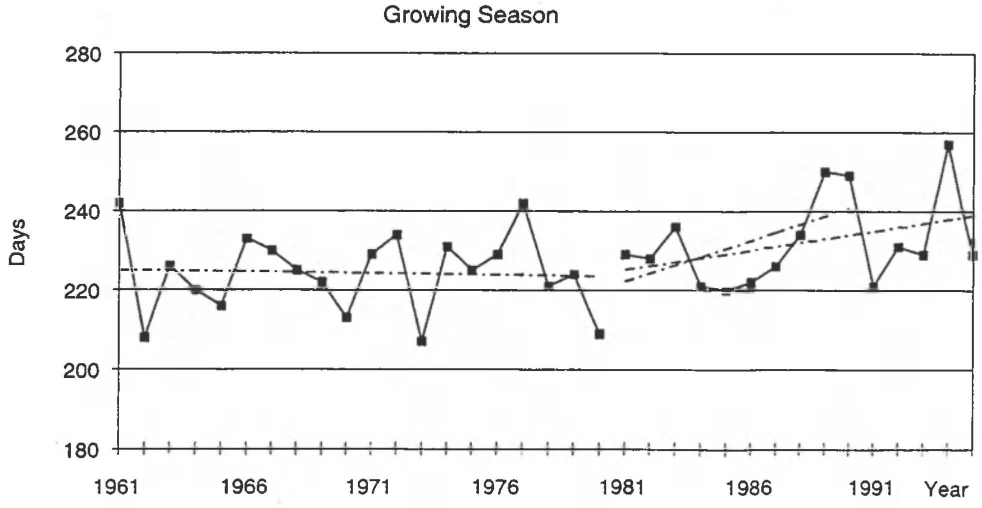
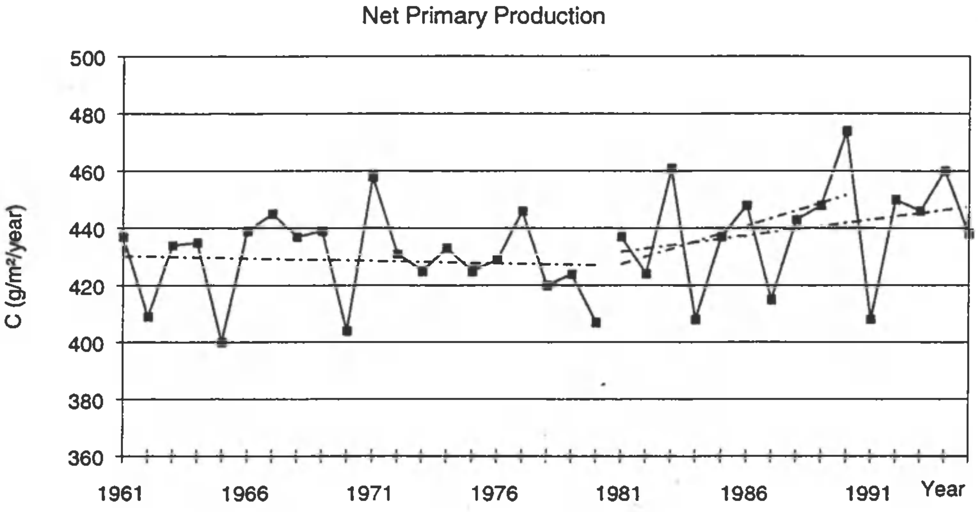


Figure 3. Average annual temperature and growing season length (defined as the sum of days with a daily temperature > 5°C) including the corresponding trend lines for the time spans 1961-1980, 1981-1990, and 1981-1995 in Austria. The numbers represent the means from 20 weather stations.



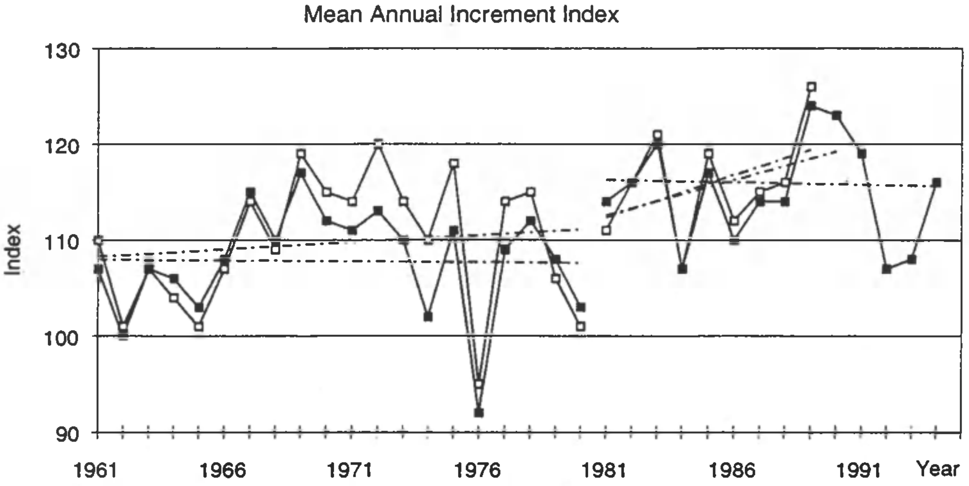


Figure 4. Mean annual net primary production (NPP) vs. the increment index development for Norway spruce plus the calculated regression lines for time spans 1961-1980, 1981-1990, and 1981-1995. The NPP is the average value simulated for 20 weather stations. Sample A gives the mean annual increment index 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.

Acknowledgments

This research was conducted when H. Hasenauer was Visiting Scientist at the School of Forestry, University of Missoula, in Missoula, Montana, where he worked on a Schrödinger research grant from the Austrian Science Foundation. We are grateful to M. Neumann of the Federal Forest Research Center, Vienna for the increment cores. Helpful comments were provided by the two referees, who wish to remain anonymous.

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O. Laroussinie
(eds.)

Causes and Consequences of Accelerating Tree Growth in Europe

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EFI Proceedings No.27, 1999

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Theme I: Biological Basis for Understanding the Causes and Consequences of Increased Forest Growth

Theme II: Possible Consequences of the Increased Forest Growth

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.

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[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.

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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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Olivier Laroussinie
Forest Ecosystem Coordination Unit

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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