Changes in Wood Production of *Picea abies* and *Pinus sylvestris* under a Warmer Climate: Comparison of Field Measurements and Results of a Mathematical Model

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To project the changes in wood production of Norway spruce *Picea abies* (L.) Karst. and Scots pine *Pinus sylvestris* L. in Finland as a result of climate change, two separate studies were made. The first study, at the Faculty of Forestry, University of Joensuu, based its projections on mathematical models; the second one, at the Finnish Forest Research Institute, based projections on measurements of wood production in two series of aged provenance experiments. The results of the two studies were similar for both species: after a 4°C increase of the annual mean temperature a drastic increase in wood production in northern Finland, but little effect, or even some decrease in the southern part of the country.

However, the assumptions used in the two studies differed. One important difference was that in the models the temperature is assumed to be increasing gradually over the years; whereas in the provenance experiments, climate changed immediately when the seedlings were transferred to the planting sites. Another problem with the provenance experiments is that when material is moved in a north-south direction in Finland, not only temperature but also photoperiod changes markedly. To compare these two studies, site factors (e.g. soil type, temperature, precipitation) and silvicultural factors (e.g. plant spacing, survival, time of thinning, thinning intensity) from the provenance experiments were included as variables in the mathematical models.

Keywords Scots pine, Norway spruce, provenance trials, simulation model, global warming
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1 Introduction

To predict the growth of forests in the future, it is necessary to know how trees respond to climate warming. Different methods can be used to study this, for example, mathematical modelling or field trials. With modelling it is possible to separate various growth factors and to study the effects of rising temperature on each factor. It is also possible to predict long-term effects. It is, however, difficult to validate the results. Field trials give real values for the reactions of trees to elevated temperature. However, it is impossible to separate the different growth factors. In addition the trials are expensive to establish and they take time, especially when long-term reactions are to be studied. In provenance trials, which have been established in Finland since the early 1930's, trees have been grown for many decades in environments different from those to which they were adapted. These trials provide an unique opportunity to obtain data on the long-term effects of climate change on tree growth. Both types of studies can be used paralell to elaborate the outlines on how climate change could effect forest growth.

The aim of this study is to verify correspondence between results of simulations and of provenance trials by running the simulations using parameters from the trials. In this context two completely separate studies were utilized, both part of the Finnish Research Programme on Climate Change, SILMU (1990–1995). Both studies indicated the changes in wood production of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) as a result of climate change in Finland.

2 Material and Methods

2.1 Description of the two Studies

In the first study, which was carried out at the University of Joensuu by Kellomäki and Kolström (1994), projections of changes in wood production were based on model computations, using a gap type model (Kellomäki et al. 1992). This model, which was developed from the gap model of Pastor and Post (1985, 1986), has been adjusted to Finnish conditions and used to study how changing climate affects the yield of trees, species composition (Kellomäki and Kolström 1992b), soil factors (Kellomäki 1995), silviculture (Kellomäki, Hänninen and Kolström 1988, Kellomäki and Kolström 1992a, 1993) and frost damage to Scots pine (Kellomäki, Hänninen and Kolström 1995). It has also been used to study carbon sequestration in the forest ecosystem under changing climatic conditions (Karjalainen 1996a, b). The model has been further refined by Talkkari and Hypén (1996), among others, for different site and soil types. The growth factors included in the model are temperature, soil water, light and nitrogen. Growth and yield for different tree species were predicted for pure, even-aged stands over a rotation of the length commonly applied in forestry.

In the simulations only temperature was allowed to increase (Kellomäki and Kolström 1994). Precipitation was assumed to be the same as the current precipitation, because at that time estimations of future changes were still unreliable. The recalculated results of the simulations indicated that with rising temperature (0.04°C annually) the total yield of Scots pine in southern Finland could increase by a few per cent but in northern Finland by about 140%. The total yield of Norway spruce in southern Finland would remain unchanged but in northern Finland it may increase by about 200% (Table 1). These calculations are based on mean total production as calculated from 100 separate iterations over 160 years. An annual increase of 0.04°C corresponds with

Table 1. Comparison of the projections for the changes in wood production by the two studies.

		Simulations [1]	Provenance trials [2]
Scots pine	north	140 %	45 %
	south	5 %	–10 %
Norway spruce	north	200 %	300 %
	south	0 %	considerable decrease

[1] Calculated with a temperature increase of 0.04°C annually. The calculations are based on mean total production as calculated from 100 separate iterations over 160 years.
[2] Calculated with a 600 dd increase in annual mean temperature sum for a 27 years old stand for Scots pine and a 60 years old stand for Norway spruce.

an increase of the annual mean temperature with 4°C during 100 years, which is approximately the change which is projected for the next century (Kettunen et al. 1987, Carter et al. 1995).

The second study was carried out by Beuker (1994) at the Finnish Forest Research Institute. In this study a series of provenance experiments was used to assess the effects of a warming climate on the wood production of Norway spruce and Scots pine. In provenance experiments, plant material was moved to an environment different from that to which it was originally adapted. When the same geographical origins are represented at different sites in different climates, such experiments offer an opportunity to study the influence of climate on the performance of trees of various origins. For the purpose of these studies, trees of different origins transferred from north to south, into a warmer climate, are most interesting.

The Norway spruce series consisted of 7 sites throughout Finland, including a total of 29 origins from Fenno-Scandinavia and Central Europe. This series was established in 1931 by the late Prof. Olli Heikinheimo. The Scots pine series, established by Prof. Max Hagman in 1966, consists of 11 sites throughout Finland, including 32 Finnish origins. Both series were measured in 1991, and the total wood production per hectare was calculated for each origin at each site. With these data, models were developed which project the change in wood production as a function of the annual mean temperature sum at the location of the origin in question and the change in annual mean temperature sum as a result of the geographical transfer (Beuker 1994).

The results of the latter study show that wood production of Norway spruce could decrease in southern Finland, but increase by about 300 % in northern Finland after an increase of 600 degree days in annual mean temperature sum, which corresponds with an increase in annual mean temperasture of approximately 4°C. For Scots pine the projections are a minor decrease in southern Finland and a 40 % increase in northern Finland (Table 1). For southern Finland it is not possible to give accurate figures, because these results are obtained by extrapollation.

2.2 Comparison of the two Studies

To combine the model and the provenance trials, four sites from each of the two series used by Beuker (1994) were included, two sites in northern Finland and two in southern Finland. As much data as could be retrieved from the experiment archives of the Finnish Forest Research Institute were included in the model (Table 2).

Table 2. Location of the sites and the parameters used in the simulations.

Parameter	Pine				Spruce			
	Pieksämäki	Kuorevesi	Rovaniemi	Muhos	Vilppula	Punkaharju	Muhos	Kivalo
Latitude	62°22'	62°02'	66°27'	64°53'	62°03'	61°48'	64°52'	66°28'
Longitude	26°51'	24°50'	26°45'	26°06'	24°23'	29°18'	26°04'	26°39'
Altitude, m above sea level	140	140	180	70	140	100	70	210
Annual mean temp. sum, dd	1124	1158	863	1029	1161	1208	1033	852
Beginning growing season, julian day	120	119	130	123	118	116	123	130
End growing season, julian day	278	280	267	274	282	286	274	267
Forest type, Cajander	VT	VT	VT	VT	MT	OMT	MT	HMT
Soil type	Till	Till	Till	Till	Stony till	Stony till	Till	Stony till
Field capasity, mm	105	105	105	105	60	60	105	60
Wilting point, mm	45	45	45	45	9	9	45	9
Humus mass, t/ha	42	42	42	42	51	32.6	51	51
Nitrogen mass, t/ha	6.3	6.3	6.3	6.3	10.2	8.8	10.2	10.2
Planting spacing, m	2×2	2×2	2×2	2×2	1.5×1.5	1.3×1.5	1.5×1.5	2×2
Number of thinnings	0	0	0	0	5	6	1	1

For each location, temperature and precipitation data were calculated according to data of the Finnish Meteorological Institute. The beginning and end of the growing season were calculated according to Talkkari and Hypén (1996).

Soil type and forest type were obtained from the archives of the Finnish Forest Research Institute (Beuker 1994). For the site in Vilppula the soil data obtained were corrected from sand to stony till. The field capacity and wilting point for each soil type were taken from Talkkari and Hypén (1996, their Table 2). Data on thickness of the humus at the time of planting were calculated for each forest type by using the figures given by Tamminen (1991, his Table 16) and transforming them into figures for treeless sites, as done by Talkkari and Hypén (1996, their Table 3). Nitrogen concentrations were then calculated according to Talkkari and Hypén (1996, their Table 4).

Data on plant spacing, time of thinning and thinning intensity (for volume as well as number of stems) were also available from the archives. It was, however, not always clear what kind of thinnings had been carried out; usually the smallest individuals and suppressed trees were removed. In the simulations the trees were first devided into four height classes, whereafter the same percentage of trees was removed from each height class. The thinning percentage was equal to that used in the provenance trials. The height model of Näslund has different parameter values for northern and southern Finland (Talkkari and Hypén 1996), which affects the total production. Therefore different parameter values were used for the northern and southern sites in the simulations. The simulations were run until the ages at which the last measurements in the trials were made. For spruce this was at the age of 60 years; for pine it was at the age of 25 years (Beuker 1994).

The model was run for each site to project total wood production under present climatic conditions, thus without change in temperature. These projections were compared with the performance of the local origin at each site or the origin closest to the site in the field experiments. The development of the number of stems at each site was simulated and compared with the number of stems of local origin at each inventory made in the experiments.

3 Results

For Scots pine at age 25 the total production of wood projected by the simulations was considerably higher than the total production of the local origin at each site (Fig. 1). For Norway spruce at age 60 there was also a difference between the projections and the trial values, but the differences were less consistent. In two cases the trials had the highest total production of wood; in one case the simulation and the field results were almost the same (Fig. 2).

When the numbers of stems in the pine trials were compared (Fig. 3), it was found that at the sites in Rovaniemi and Pieksämäki the number of stems projected by the simulations was much higher than that in the trials; but at Muhos and Kuorevesi the number of stems in the trials was higher. For spruce (Fig. 4) the number of stems at the southern sites, Vilppula and Punkaharju, was close to that projected by the simulations. On the northern sites, the projections of the simulations were much lower than the trial values, although the number of stems at the site in Muhos has decreased drastically between the age of 35 and 57.

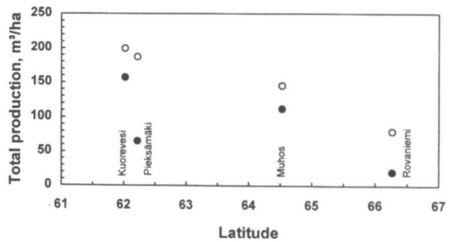

Fig. 1. The total wood production of the local origin at each of the four Scots pine sites (●), and the corresponding values obtained from the simulations (○).

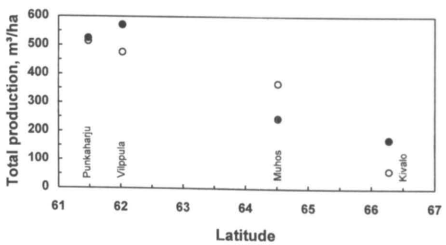

Fig. 2. The total wood production of the local origin at each of the four Norway spruce sites (●), and the corresponding values obtained from the simulations (○).

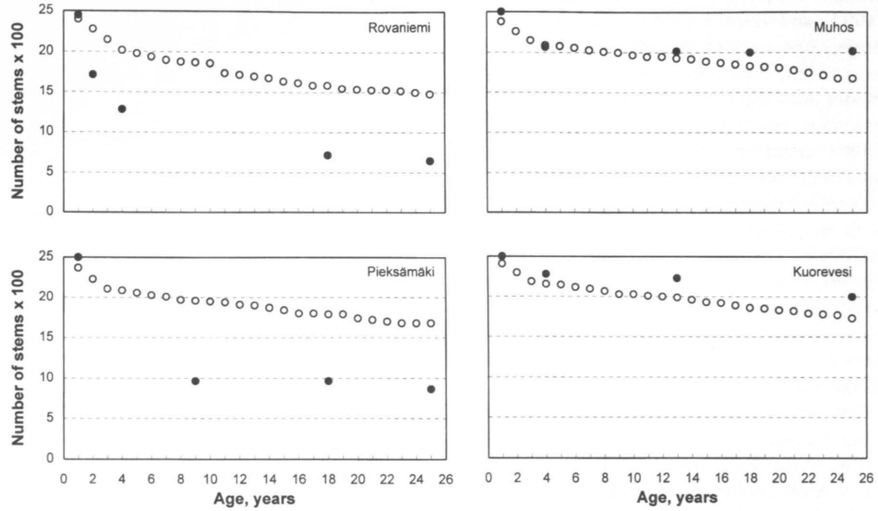

Fig. 3. The number of stems per ha, calculated for the local origin at each of the four Scots pine sites during the regular inventuries (●), and the projected number of stems for each year from the simulations (○).

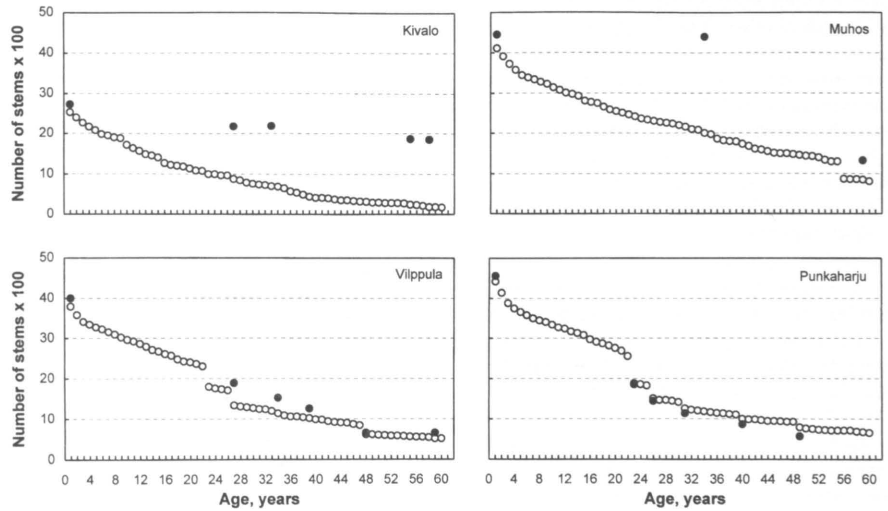

Fig. 4. The number of stems per ha, calculated for the local origin at each of the four Norway spruce sites during the regular inventuries (●), and the projected number of stems for each year from the simulations (○).

4 Discussion and Conclusions

The studies on changes in wood production of Scots pine and Norway spruce as a result of climate warming by Kellomäki and Kolström (1994) and Beuker (1994) resulted in similar projections, despite differences in methods and, as a result, differences in assumptions. In the model simulations the temperature was increased gradually over the years (0.00, 0.04, 0.06 or 0.08°C annually), whereas in the provenance trials climate changed at once when the material was transferred to the test site. Another problem with the provenance trials is the change in light conditions as a result of the geographical changes. When material is moved over long north-south distances at high latitudes such as in Finland, there are considerable changes in photoperiod and total radiation during the growing season (Meteorological Yearbook, 1993).

The most accurate comparison that could be made between these two studies was inclusion of the characteristics of the sites of the provenance trials into the simulations, which were run with a zero increase in temperature, and comparison of the results with the performance of the local origin at each site. The simulations were made for total wood production and for decrease in of stem number. The annual mean temperature sums for the sites used by Beuker (1994) were estimated using the program of Ojansuu and Henttonen (1983); whereas in the simulations, the estimations were made on the basis of climatic data. It was found that the estimations made by the simulations were higher than those of Ojansuu and Henttonen (Fig. 5), which might explain part of the differences between the simulations and the trial values.

The large difference in total wood production between the simulations and the Scots pine trial in Pieksämäki can, at least partly, be explained by the fact that this site has suffered from *Scleroderris* canker of pine (*Ascocalyx abietina* (Lagerb.) Schläpfer), which has caused considerable dieback in the trial. The difference at the Rovaniemi site, on the other hand, might be due to insufficient accuracy of the model. This model was developed mainly for southern Finnish conditions and may therefore give too high values for the northern part of the country. All the northern sites in this series (Beuker 1994) have very low production. The main reason for this seems to be a decrease in the number of stems to about 50 % during the first 4 years. Furthermore, survival in Scots pine provenance trials has been studied intensively in Northern Sweden (Eiche and Andersson 1974, Eriksson 1975, Eriksson et al. 1980, Persson and Ståhl 1990, 1993, Persson 1994). According to the results of these studies, there is much variation in the survival of trees of local origin at the different sites, and at those sites with the harshest climate, high mortality occurred during the early years of the trials (Persson and Ståhl 1990, 1993). The site in Rovaniemi is certainly harsher than that in Muhos. Muhos is not only situated 1.5° farther south, but is also close to the Gulf of Bothnia, which has a warming effect. In the trials on the sites in Kuorevesi and Muhos the wood production was lowest, despite the larger number of stems on these sites.

For Norway spruce the results were just the opposite. For this species the number of stems at the northern sites was greater in the trials than was projected by the simulations. These discrepancies resulted from differences in natural mortality in the early stage of stand development. Ruotsalainen (1987) found large variation in survival of the local origin in Norway spruce provenance trials in northern Finland. At one site, where two local seed sources were used, he found a survival of about 55 % for one source and about 75 % for the other. At the Muhos site, survival of the local origin was very high, at

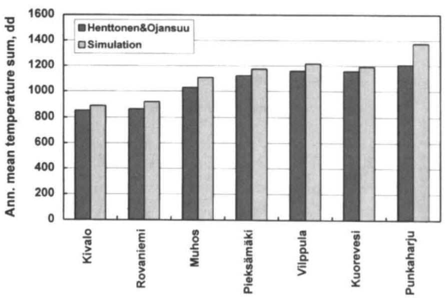

Fig. 5. Annual mean temperature sum in degree days (5°C thresshold) for each site, as they were calculated according to Ojansuu and Henttonen (1983) and by the simulations.

least until the stand reached 35 years of age. After that, there was a strong decrease in stem number, which cannot be explained only by the one thinning at age 55.

From these studies we conclude that a temperature elevation could increase the forest growth, especially in northern Finland. This conclusion is based on the combination of field experiments and model calculations. This involves, however, many problems as far as the assumptions and the methodology are concerned. In particular the genetic structure of the tree populations are poorly described in ecological models. In this respect the large number of provenance experiments provide unique opportunities to improve the interaction between ecologists and genetisists to improve our understaning on how climate change effects growth and development of forests.

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