

Regional Predictions Concerning the Effects of Climate Change on Forests in Southern Finland

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A gap-model was used with forest inventory data in taking ground-true site, soil and tree characteristics into account in predicting the effects of climate change on forests. A total of 910 permanent sample plots established in the course of national forest inventory (NFI) in Finland and located on mineral soil sites in southern Finland were selected as the input data. The climatological input used in the simulations consisted of interpolated means of and deviations from long-term local temperature and precipitation records. The policy oriented climate scenarios of SILMU (Finnish Research Programme on Climate Change) were used to describe the climate change. The temperature changes in the climate scenarios were increases of ca. +1.1 °C (low), +4.4 °C (medium) and +6.6 °C (high) compared to the current climate in 110 years. The simulation period was 110 years covering the time years 1990–2100.

Southern Finland, divided into fifteen forestry board districts, was used as the study region. Regional development of stand volume, cutting yield, and total wood production of forests under different climate scenarios were examined. The annual average growth in simulations under current climate was close to that observed in NFI. Forests benefited from a modest temperature increase (Scenario 2), but under Scenario 1 the growing stock remained at a lower level than under the current climate in all parts of the study region. In wood production and cutting yield there were regional differences. In the southern part of the study region wood production under Scenario 1 was ca. 10 % lower than under the current climate, but in the eastern and western parts wood production was 5–15 % higher under Scenario 1 than under the current climate. The relative values of total wood production and cutting yield indicated that the response of forests to climate change varied by geographical location and the magnitude of climate change. This may be a consequence of not just varying climatic (e.g. temperature and precipitation) and site conditions, but of varying responses by different kinds of forests (e.g. forests differing in tree species composition and age).

Keywords Gap-model, simulation, climate change, regional predictions

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1 Introduction

Changes in the mean climatic conditions and in the range of variability about the mean are likely. In the coming decades, these changes may be greater and more rapid than hitherto. It is predicted that the most drastic changes will take place in northern latitudes, which are mostly covered by boreal forests. The predicted global climate change is among the major factors affecting future forest development in the boreal zone. The majority of Finland's land area is located within the boreal zone. Thus, climate change may have great influence on forests and forestry in Finland. The most direct impacts are expected to occur on a local scale, but their effects will rapidly spread to regional, national and global levels (Robinson 1989). The future climate must be viewed in local light, because impact assessment must start with local direct impacts (Robinson 1989).

Research addressing the response of forest ecosystems to climate change has relied on historic changes in climate and computer simulations (Dale and Franklin 1989). Computer simulations provide possibilities to specify climate scenarios and to compute the response of forests over long time periods and at various locations (Dale and Franklin 1989). Recent simulation studies concerning the effect of climate change on forests in Finland (Kellomäki and Kolström 1993, Kellomäki and Kolström 1994, Kellomäki 1995) have relied on theoretical forests, e.g. even-aged seedlings and saplings of Scots pine have been used as the initial objects of study. When theoretical forests are used to provide the input in simulations, the resultant predictions are general by nature and cannot be used to produce local or regional predictions about the effect of climate change on forests. In order to produce realistic quantitative predictions of the effect of climate change on forests, predictions should be made at the local level and they should be based on ground-true forest data with known geographical locations and environmental conditions.

The aim of this study was to produce local predictions of the effects of climate change on forests in southern Finland using an existing climate sensitive forest growth model and by generalising the predictions to the regional level.

This study examines regional development of stand volume, total wood production, and cutting yield of forests in southern Finland under different climate scenarios.

2 Material

The forest data used in this study consisted of data collected from 910 permanent sample plots in the course of the national forest inventory (NFI) carried out in 1990–1991 by the Finnish Forest Research Institute. The sample plots were located on mineral soil sites on forest land within boundaries of the fifteen forestry board districts in southern Finland (Fig. 1). No sample plots located on scrub land or waste land were included in these simulations. In accordance with the Finnish system of classification applied in forestry, scrub land is forestry land where the productivity of stem wood is less than $1 \text{ m}^3 \text{ ha}^{-1} \text{ a}^{-1}$ and on waste land it is less than

15



Fig. 1. The study area and the forestry board districts in southern Finland.

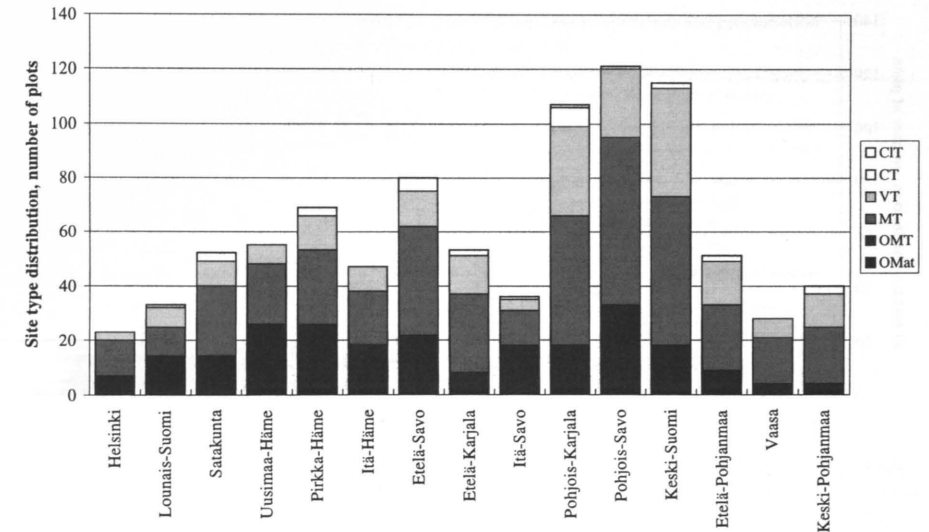


Fig. 2. Site type distribution in the simulation data.

$1 \text{ m}^3 \text{ ha}^{-1} \text{ a}^{-1}$. The number of sample plots varied greatly by forestry board district (between 23 and 121).

In this study, the term “southern part” refers to the nine southernmost forestry board districts, “eastern part” refers to the forestry board districts of Pohjois-Karjala, Pohjois-Savo and Keski-Suomi, and “western part” refers to the forestry board districts of Etelä-Pohjanmaa, Vaasa and Keski-Pohjanmaa (Fig. 1).

Site types included in the data were, from richer to poorer, as follows: Oxalis-Maianthemum Type (OMaT, grove), Oxalis-Myrtillus Type (OMT), Myrtillus Type (MT), Vaccinium Type (VT), Calluna Type (CT), and Cladonia Type (CIT) (Cajander 1949) (Fig. 2).

The soil textures included in the data were coarse moraine, fine moraine, gravel, sand, fine sand, silt, and clay (Fig. 3). Unsorted soil textures, rough and fine moraine, covered most of the sample plots in the simulation data. Sand and fine sand were the most common sorted soil textures in the data (Fig. 3).

The tree species in the sample plot data represented Finland's six main current tree species.

Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) were the commonest tree species in forests on mineral soil sites in Finland in 1990. The other four tree species included in the data were pendula birch (*Betula pendula*), pubescent birch (*Betula pubescens*), aspen (*Populus tremula*), and grey alder (*Alnus incana*).

The climatological input of the simulation model was based on recordings made at twenty-eight weather stations located at airports throughout Finland. The long-term monthly mean values were based on the daily means of temperature ($^{\circ}\text{C}$) and precipitation (mm) recorded during the period 1961–1990 by the Finnish Meteorological Institute. Monthly mean temperature and precipitation and their deviations were needed in simulations. Weather data were interpolated to a grid of $10 \text{ km} \times 10 \text{ km}$ throughout Finland by the Finnish Meteorological Institute.

Climate change in the simulations was described as changes in monthly mean values of temperature and precipitation. The climate scenarios used in this study were SILMU- policy scenarios based on a GCM (General Circulation Model) composite (Carter et al. 1995). The ex-

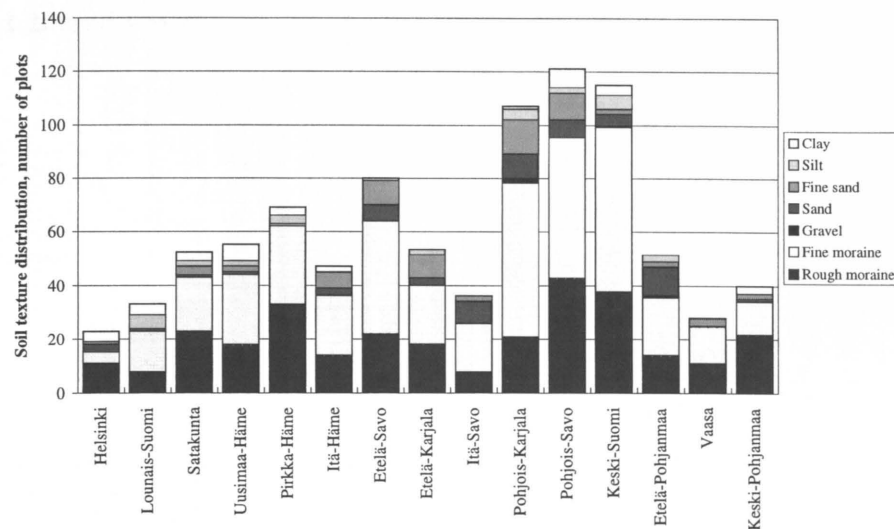


Fig. 3. Soil texture distribution in the simulation data.

ception was Scenario 0, which was based on the current climate with no temperature and precipitation changes. Scenario 1 (Medium) assumed emissions according to IS92a and a climate sensitivity of 2.5 °C, Scenario 2 (Low) assumed IS92c emissions and a climate sensitivity of 1.5 °C, and Scenario 3 (High) assumed emissions IS92f and climate sensitivity of 4.5 °C (Houghton et al. 1992). Climate sensitivity indicates how strongly the climate responds to increasing emissions of greenhouse gases. The rates of change in monthly mean temperature and precipitation were assumed to be uniform all over Finland and linear with respect to time (1990–2100) (Table 1). In practice, the scenarios presented above represent temperature changes of 4 °C (Scenario 1), 1 °C (Scenario 2) and 6 °C (Scenario 3) within a period of one hundred years.

3 Methods

The simulation model used in this study was a gap-type forest ecosystem model presented by

Kellomäki et al. (1992), and further developed to utilise spatial ground-true data as input and assessed by Talkkari and Hypén (1996). Forest regeneration, thinnings and clear felling were included in this study's simulations. The growth of trees in the simulation model is based on diameter growth, which is controlled by light conditions, temperature, soil water, and the supply of nitrogen (Kellomäki and Kolström 1994).

Simulations were carried out using the site and tree data of each NFI plot as the input for the model. The site data consisted of site type and thickness of humus layer, which were used to determine the initial nitrogen content of the site, and soil texture on which the water holding capacity of the soil was based (see Talkkari and Hypén 1996). The data on trees (i.e. tree species and diameter at breast height) within a radius of 5.63 m (i.e. within an area of 100 m²) from the centre of sample plot were included in simulations, because the current model used the plot size of 100 m². The height of trees in the model was calculated using the equation presented by Näslund (1937) with parameters presented by Talkkari and Hypén (1996) and the tree volume

Table 1. The SILMU policy oriented scenarios of seasonal temperature and precipitation changes over Finland, 1990–2100 (Carter et al. 1995).

	Temperature change (deg C/decade)			Precipitation change (percent/decade)		
	Scen1	Scen2	Scen3	Scen1	Scen2	Scen3
Spring (MAM)	0.400	0.100	0.600	0.500	0.125	0.750
Summer (JJA)	0.300	0.075	0.450	1.000	0.250	1.500
Autumn (SON)	0.400	0.100	0.600	1.000	0.250	1.500
Winter (DJF)	0.600	0.125	0.750	2.000	0.420	2.500

was calculated using the equations of Laasasenaho (1982). The data collected from the nearest point on the interpolated grid to the sample plot were used as temperature and precipitation data.

Felling rules were adapted from the management instructions for private, non-industrial forestry prepared by Forestry Centre Tapio (Luonnonläheinen... 1994). Thinning instructions vary by stand location (i.e. southern or northern Finland), site type, dominant species, and the limits are defined based on stand dominant height and basal area (Luonnonläheinen... 1994). Clear-felling limits are based on the mean stand diameter and they vary by stand location (i.e. southern or northern Finland), site type, and dominant tree species (Luonnonläheinen... 1994). No limitations to felling, e.g. reduced felling or conservation areas, were included in this study.

The simulation time covered the period 1990–2100. Since the model includes stochastic processes such as the birth and death of trees, each stand simulation was repeated fifty times in order to determine the prevailing tendency in stand development. Thus, the results for each sample plot are the means of fifty simulations.

The plotwise results of the model computations were stored in a database in order to generalise the predictions to apply each of the forestry board districts. The regional predictions were presented as the mean values of the simulation results for the sample plots located within each forestry board district. The regional results of this study were presented as sums of the results for the main tree species in Finland i.e. Scots pine, Norway spruce, pendula birch and pubescent birch.

4 Results

4.1 Initial Conditions

The regional stand volumes based on the simulation data at the onset of the simulation in 1990 varied from 75 m³ ha⁻¹ in the forestry board district of Keski-Pohjanmaa to 183 m³ ha⁻¹ in Lounais-Suomi (Table 2).

When compared to the inventory data, the regional stand volume based on the simulation data were systematically greater than stand volume based on the national forest inventory (NFI) re-

Table 2. Stand volumes by forestry board district at the onset of the simulations based on the simulation data and national forest inventory results (Kuusela and Salminen 1983, Salminen 1993).

Forestry board	Number of plots	Stand volume (simulation data) m ³ ha ⁻¹	Stand volume (NFI) m ³ ha ⁻¹
Helsinki	23	136	139
Lounais-Suomi	33	183	128
Satakunta	52	139	114
Uusimaa-Häme	55	155	150
Pirkka-Häme	69	125	127
Itä-Häme	47	172	140
Etelä-Savo	80	144	132
Etelä-Karjala	53	155	121
Itä-Savo	36	153	134
Pohjois-Karjala	107	102	85
Pohjois-Savo	121	125	96
Keski-Suomi	115	112	99
Etelä-Pohjanmaa	51	114	81
Vaasa	28	123	94
Keski-Pohjanmaa	40	75	65

sults. The simulation data consisted of data collected from sample plots located on mineral soil sites representing forest land, whereas inventory results are based on data collected from a great number of sample plots located on both mineral soil sites and on peatland, and this can lead to systematic differences. In two regions (Helsinki and Pirkka-Häme) the stand volume based on simulation data at the onset of the simulations was smaller than that based on inventory results, but the difference was only 2–3 m³ ha⁻¹.

4.2 Regional Results

Regional predictions are presented using the mean values of the simulation results for sample plots located within each forestry board district. The regional mean values for stand volume, wood production and growth, and cutting yield under climate change scenarios at the end of the simulations were compared to those under the current climate.

The mean stand volume under the current climate (Scenario 0) varied between 125 m³ ha⁻¹

and 140 m³ ha⁻¹ in all the fifteen forestry board districts (Fig. 4). The stand volume under Scenario 2 at the end of the simulations was very close to that under the current climate, but under Scenarios 1 and 3 the growing stock remained at a clearly lower level than under the current climate. On comparing Scenarios 1 and 3, it was revealed that in the southern part of the study region the growing stock under Scenario 3 remained at a higher level than under Scenario 1, but in the eastern and western parts of the study region the situation was the opposite.

Annual average simulated growth under the current climate varied between 4.9 and 6.0 m³ ha⁻¹ and it was compared with annual growth given by the NFI results (Salminen 1993, Tapion Taskukirja 1991) (Table 3). The difference in annual growth between the simulations and the NFI results varied within the range of 0.2–2.1 m³ ha⁻¹ (Table 3). In the nine southernmost forestry board districts (from Helsinki to Itä-Savo) the relative difference in growth varied between 3.6 % and 14.0 %. In eastern and western parts the relative difference in growth varied between 17.7 % and 68.5 % (Table 3). The large differ-

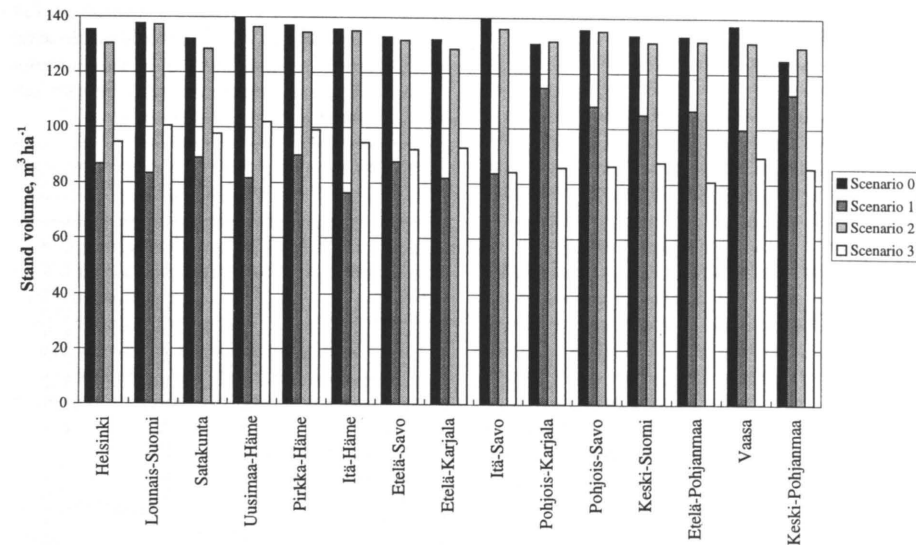


Fig. 4. Stand volume at the end of the simulations in year 2100.

Table 3. Annual average simulated growth under the current climate as compared to national forest inventory results (Salminen 1993, Tapion Taskukirja 1991).

Forestry board	Simulation m ³ ha ⁻¹	Inventories (NFI) m ³ ha ⁻¹	Difference m ³ ha ⁻¹	Difference %
Helsinki	5.8	6.1	-0.3	-5.3
Lounais-Suomi	6.0	5.7	0.3	5.5
Satakunta	5.8	5.1	0.7	14.0
Uusimaa-Häme	5.9	6.7	-0.8	-12.1
Pirkka-Häme	5.8	5.5	0.3	5.5
Itä-Häme	5.9	6.3	-0.4	-6.7
Etelä-Savo	5.7	6.2	-0.5	-7.5
Etelä-Karjala	6.0	6.2	-0.2	-3.6
Itä-Savo	5.3	5.8	-0.5	-8.6
Pohjois-Karjala	4.9	4.2	0.7	17.7
Pohjois-Savo	5.2	4.4	0.8	19.3
Keski-Suomi	5.4	4.4	1.0	23.2
Etelä-Pohjanmaa	4.9	3.4	1.5	45.5
Vaasa	5.5	3.6	1.9	52.3
Keski-Pohjanmaa	5.1	3.0	2.1	68.5

ences in growth between simulations and the NFI results in Etelä-Pohjanmaa, Vaasa and Keski-Pohjanmaa are probably due to the large proportion of poorly growing peatland forests in those parts of the study region. According to Kuusela and Salminen (1983), the proportions of peatlands in Etelä-Pohjanmaa, Vaasa and Keski-Pohjanmaa are 39.6 %, 29.9 % and 40.9 %, respectively. Furthermore, both forest land and scrub land stands are included in the NFI-based growth in the eastern and western parts of the study regions (i.e. from Pohjois-Karjala to Keski-Pohjanmaa). Therefore, the simulation model appears to overestimate forest growth in those three forestry board districts, but elsewhere simulated growth appeared to be realistic. The average annual growth in the southern part of the study region in the simulations was 5.8 m³ ha⁻¹ and in NFI results it was 6.0 m³ ha⁻¹. Thus, the quantitative estimate of average annual growth in the nine southernmost forestry board districts, where the proportions of peatlands and scrub lands are low, is very close to national forest inventory results (Salminen 1993).

Total wood production under the current climate (Scenario 0) in the nine southernmost for-

estry board districts varied between 583 m³ ha⁻¹ and 662 m³ ha⁻¹ (Fig. 5). In the eastern and western parts of the study region, total wood production remained 50–100 m³ ha⁻¹ lower than in the southern part, varying between 544 m³ ha⁻¹ and 603 m³ ha⁻¹ (Fig. 5). According to Koivisto (1959), wood production in managed pure stands in southern Finland amounts to 582 m³ ha⁻¹ in Scots pine stands with a rotation of 90 years, 688 m³ ha⁻¹ in Norway spruce stands with a rotation of 110 years, and 491 m³ ha⁻¹ in pendula birch stands with a rotation of 80 years. Total wood production in the southern part of the study region under Scenario 1 remained at a lower level than under the current climate, but the results under Scenario 2 were similar to those achieved under the current climate in southern parts of the study region (Fig. 5). In eastern and western parts of the study region total wood production reached higher levels than under the current climate in all the scenarios.

In the southern part of the study region the cutting yield varied between 356 m³ ha⁻¹ and 463 m³ ha⁻¹, and in eastern and western parts it varied between 281 m³ ha⁻¹ and 348 m³ ha⁻¹ under the current climate (Fig. 6). According to

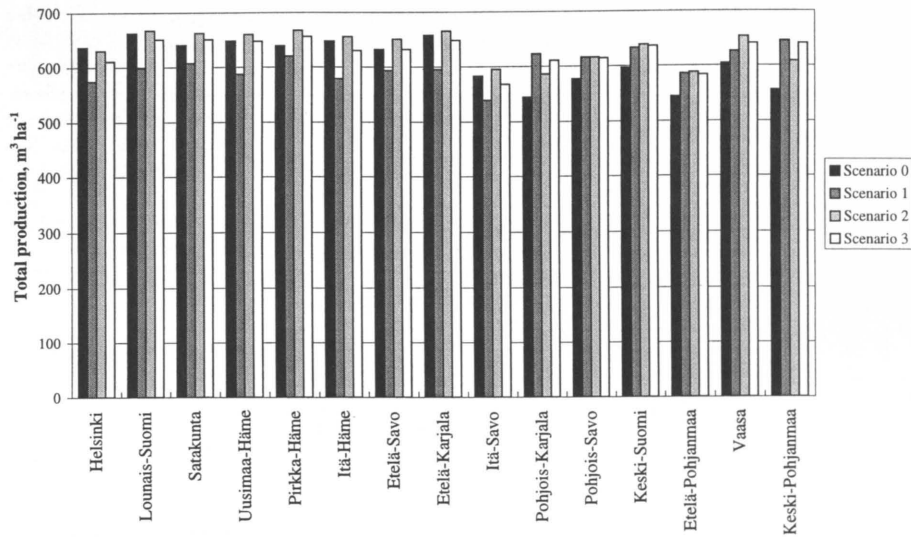


Fig. 5. Total wood production during the simulation period 1990–2100.

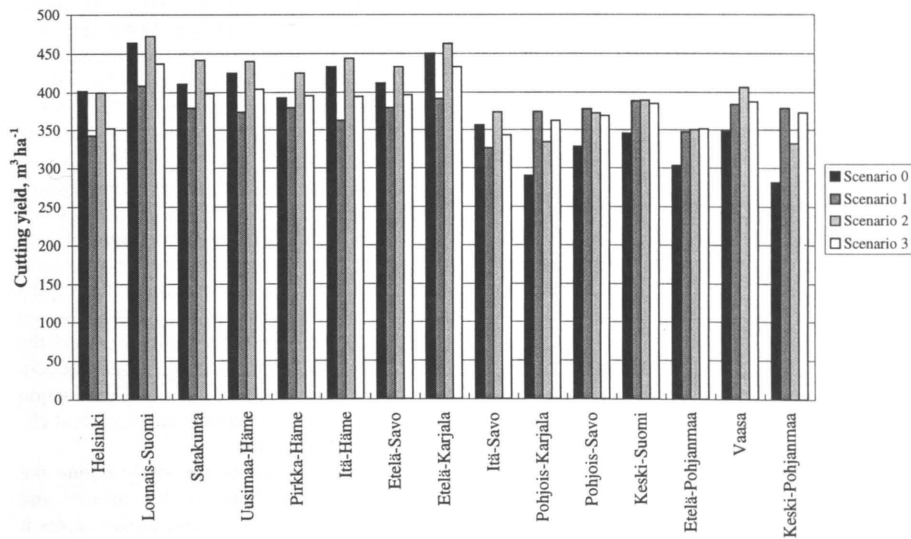


Fig. 6. Cumulative cutting yield during the simulation period 1990–2100.

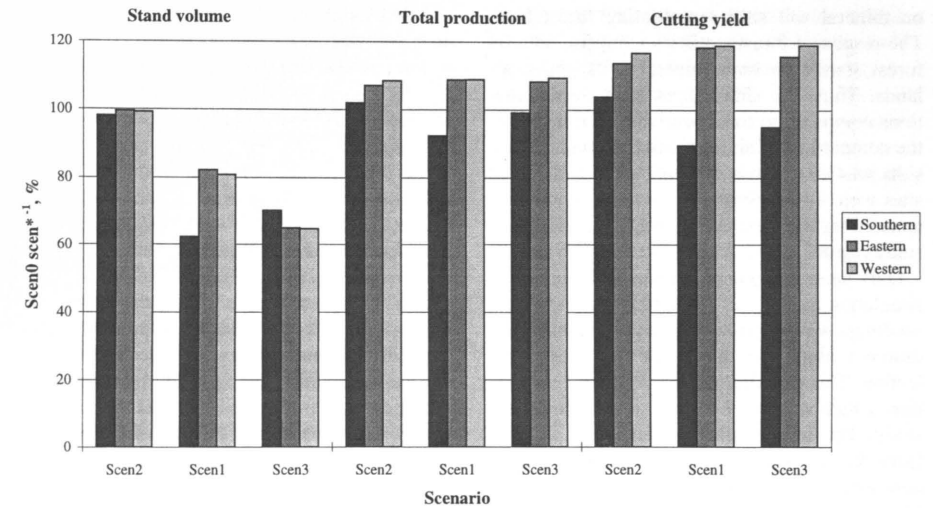


Fig. 7. Relative stand volume, total wood production, and cutting yield under climate change scenarios by southern, eastern and western parts of the study region.

Koivisto (1959), the cutting yield in managed pure stands in southern Finland is $320 \text{ m}^3 \text{ ha}^{-1}$ in Scots pine stands with a rotation of 90 years, $423 \text{ m}^3 \text{ ha}^{-1}$ in Norway spruce stands with a rotation of 110 years, and $316 \text{ m}^3 \text{ ha}^{-1}$ in pendula birch stands with a rotation of 80 years. The temperature increase in Scenarios 1 and 3 decreased the cutting yield in the southernmost part of the study region, but increased that in the eastern and western parts (Fig. 6). In most of the study region, the modest temperature increase of Scenario 2 had a positive effect on the cutting yield. In all parts of the study region the development of the cutting yield followed the development of total wood production. The diameter, basal area, and dominant height limits applied in the felling rules were reached earlier under those scenarios, where growth increased due to temperature increase.

The relative values of stand volume, total wood production, and cutting yield under the climate change scenarios as compared to the situation under the current climate by southern, eastern and western part are presented in Fig. 7. The relative values varied by part of the study region,

i.e. in the southern part the relative total wood production and cutting yield remained at a lower level than in the other parts. These relative values indicate that the response of the forest to climate change varied according to geographical location and the magnitude of climate change (Fig. 7).

5 Discussion

Ground-true forest inventory and climate data were used in simulations to produce regional predictions about the effect of climate change on forests. The results of these simulations under the current climate were compared to national forest inventory results (Salminen 1993, Kuusela and Salminen 1983) and to growth and yield tables (Koivisto 1959). The quantitative regional predictions of forest annual growth, total wood production, and cutting yield under the current climate were very similar to forestry statistics data. The greatest difference occurred in stand volume. The data in this study consisted of a subset of NFI's permanent sample plots located

on mineral soil sites representing forest land. The results of forest statistics comprise data on forest stands on both mineral soils and peatlands. Thus, the simulations gave overestimations compared to forest statistics. Furthermore, the comparison of simulations and inventory results was even more difficult when scrub land sites were also included in the inventory results concerning the eastern and western parts of the study region.

Only natural regeneration was included in the simulation model, i.e. the establishment of new seedlings was controlled by environmental conditions without any man-made tree species selection. This can alter the tree species composition, which was not, however, examined in this study. The felling rules applied were adopted from the management instructions for private, non-industrial forestry (Luonnonläheinen... 1994). There were no restrictions to felling; i.e. stands were thinned or clear-felled once the limits were reached. This can increase the cutting yield more than happens in practice.

However, the realistic predictions achieved under the current climate indicated the model's ability to work with forest inventory data and it provided a basis for comparing the climate scenarios. The predictions under Scenario 2 (Low) were similar to those under the current climate. In many forestry board districts forest growth was slightly higher under Scenario 2 than under the current climate. This indicated that forests derived a little benefit from the temperature increase of 1 °C in the space of one hundred years. Greater differences were observed between the current climate and Scenario 1 (Central). The growing stock remained at a lower level under Scenario 1 than under the current climate in all parts of the study region.

In wood production and cutting yield there were regional differences. In the southern part of the study region wood production under Scenario 1 was ca. 10 % lower than under the current climate, but in the eastern and western parts wood production was 5–15 % higher under Scenario 1 than under the current climate. This indicated that forests in the central part of Finland could increase their growth due to climate change. The results under Scenario 3 were similar to those achieved under Scenario 1; the exception

was that stand volume at the end of the simulations remained at a clearly lower level in the eastern and western parts of the study region and slightly higher level in the southern part. This may be due to increased growth of birch caused by temperature increase.

The relative values of total wood production and cutting yield indicated that the response of forests to climate change varied by geographical location and the magnitude of climate change. This may be a consequence of not just varying climatic (e.g. temperature and precipitation) and site conditions, but of varying responses by different kinds of forests (e.g. forests differing tree species composition and age). Thus, further computations concerning possible changes in tree species distribution and response of tree species to climate change could clarify the results presented above.

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