Silva Fennica 1992, Vol. 26 N:o 2: 97–110

# Computations on the management of seedling stands of Scots pine under the influence of changing climate in southern Finland

Seppo Kellomäki & Marja Kolström

*TIIVISTELMÄ: ILMASTONMUUTOKSEN VAIKUTUS MÄNNYNTAIMIKOIDEN HOITOTARPEESEEN ETELÄ-SUOMESSA: SIMULOINTIIN PERUSTUVIA LASKELMIA*

Kellomäki, S. & Kolström, M. 1992. Computations on the management of seedling stands of Scots pine under the influence of changing climate in southern Finland. Tiivistelmä: Ilmastonmuutoksen vaikutus männyntaimikoiden hoitotarpeeseen Etelä-Suomessa: simulointiin perustuvia laskelmia. Silva Fennica 26(2): 97–110.

Model computations on the management of Scots pine (*Pinus sylvestris*) at the seedling stage showed that a rising temperature due to the suggested climate change could increase the competition capacity of birch species (*Betula pendula*) more than that of Scots pine, whose growth could even decline during the course of a rise in temperature. A temperature rise could, thus, bring the time of removal of birches forward when aiming at Scots pine timber in stands composed of these tree species. The increasing proportion of birches makes the removal of birches even more urgent and emphasizes the need for careful management of Scots pine stands under rising temperatures. The first thinning of Scots pine is generally brought forward; this is particularly the case when wide spacing is applied in planting. A further rise in temperature magnifies the above patterns by reducing further the competitive capacity of Scots pine in relation to birches.

---

Simulointiin perustuvat laskelmat osoittivat, että ilmaston lämpiäminen voi Etelä-Suomessa lisätä rauduskoivun kasvua enemmän kuin männyn kasvua. Männyn kasvattaminen muuttuvissa ilmasto-oloissa saattaakin osoittautua nykyistäkin vaativammaksi tehtäväksi. Samalla kun taimikon perkaaminen siirtyi aikaisemmaksi, tarvittiin useampia perkauksia vähentämään koivujen kilpailua. Myös männyntaimikoiden ensiharvennus aikaistui, erityisesti pieniä (< 2000 runkoa/ha) alkutiheyksiä käytettäessä. Ilmaston lämpiäminen edelleen näyttää voimistavan näitä kehityspiirteitä, sillä koivun kilpailukyky suhteessa mäntyyn kasvoi edelleen.

Keywords: seedling stands, management, Scots pine, *Pinus sylvestris*, models, simulation, climatic change.
FDC 232.4

Correspondence: *Seppo Kellomäki*, University of Joensuu, Faculty of Forestry, P.O.Box 111, SF-80101 Joensuu, Finland.

Accepted September 25, 1992

# 1 Introduction

The geographical distribution of forests relates closely to the global distribution pattern of temperature and precipitation (Aber and Melillo 1990, p. 16–18). Therefore the suggested change in the global climate could have a major effect on the survival and growth of trees and the consequent functioning and structure of the forest ecosystem. This could be particularly true in Scandinavia, where temperature does limit, to a great extent, the regeneration and growth of forest trees (Mikola 1962, Henttonen et al. 1986). Therefore, the suggested increase of 2–4 °C in the annual mean temperature could thoroughly change the competitive ability of the different tree species and the consequent growth and development of forest communities (Climate change... 1990).

In boreal conditions, the response of the forest community seems to be that of an increase of deciduous and decline of coniferous species, if forest managers do not respond by adopting appropriate actions to support the survival and growth of coniferous species (Kellomäki et al. 1988). In particular, the management of young growth (i.e. seedling stands) is crucial if the purpose is to produce coniferous timber on sites habitable by coniferous and deciduous species. Mielikäinen (1980, 1985), for example, has demonstrated that the amount and quality of coniferous timber from mixed stands composed of birch species and Scots pine is closely related to the tree species composition in seedling stands and in later phases of stand development.

Stand density, and thus clearings and even precommercial thinnings at the seedling phase, has a substantial effect on the later development of tree stands and the subsequent management regime needed to produce coniferous timber. The timing of the first thinning, for example, is closely related to the spacing and the growth rate of the trees. Therefore, one can expect that under a rising temperature the point in time of the first thinning could be earlier than under the current temperature conditions. The first thinning, for example, is needed later in northern than in southern Finland; this allows one to relate the thinning patterns to the temperature gradient between southern and northern Finland in other respects, too.

This study aims at recognizing how the climatic change in terms of rising temperature could effect on the management of Scots pine (*Pinus sylvestris*) stands at the seedling stage. In particular, the need for and the timing of removal of birches (*Betula pendula*) from mixed stands composed of Scots pine and birches and the timing of the first thinning with the aim of maintaining Scots pine in the tree stand are studied. The study is based on a computer model capable of simulating the competition process in a stand of varying tree species composition.

# 2 Computations

## 2.1 Outlines of the model

The response of tree species to the prevailing conditions in the stand (temperature and precipitation, supply of light and nitrogen) is quantified by applying the model developed by Kellomäki et al. (1992). The model development was based the model by Pastor and Post (1985, 1986). This model is of the gap-type one with light, temperature and nitrogen and soil water as factors controlling the successional dynamics of forest ecosystem. The model simulates growth and succession in the forest community by applying the time scales of the life cycle of individual trees, and of community maturation as determined by the regeneration, growth and death of trees in close connection with the cycling of carbon and nitrogen. The model simulates the growth of single trees on an area of 100 m². For further details of the gap-type models, see Shugart (1984).

The *growth* of stem wood and the other compartments of the tree structure (foliage, branches, roots) in the present model are based on the diameter growth, which is converted into the growth of the biomass components of a tree with the help of the allometric relations between the stem diameter (1.3 m above the soil level) and the mass of stem, foliage, branches and roots. Diameter growth is coupled to the properties of the environment with the help of the equation $Y = Y_O \cdot Y_I \cdot Y_T \cdot Y_W \cdot Y_N$, where Y is the diameter growth [cm], $Y_O$ is the potential diameter growth [cm], $Y_I$ is the multiplier for the light, $Y_T$ is the multiplier for the temperature, $Y_W$ the multiplier for the water supply and $Y_N$ is the multiplier for the supply of nitrogen. All the multipliers are scaled within the range from zero to one [0...1] (Tables 1 and 2).

Table 1. Functions and explanations for the growth multiplier.

Multiplier for light ($Y_I$)

$Y_I = A1 \cdot (1 - \exp(A2 \cdot (AL - A3)))$,

where AL = exp(–SL/SLEAFA), AL is the relative light [0...1], SL is the amount of foliage passed by light [kg/ha], SLEAFA is a parameter [ha/kg] and A1, A2 and A3 are parameters [dimensionless].

Multiplier for temperature ($Y_T$)

$Y_T = 4 \cdot (Dmax - X) \cdot (X - Dmin)/(Dmax - Dmin)^2$,

Dmin is the minimum value of the temperature sum [d.d., threshold 5 °C], Dmax the maximum value of the temperature sum [d.d.] making it possible for a particular tree species to survive and X is the temperature sum [d.d.].

Multiplier for soil water ($Y_W$)

$Y_W = ((D3 \cdot TGS - Fj)/(D3 \cdot TGS)^{0.5}$

TGS is the total length of the growing season in days, $D_3$ the maximum proportion of the growing season from the total length of the growing season for a species to be able to tolerate soil moisture below the wilting point (DRY), Fj percentage of number of dry days from the total number days of the growing season.

Multiplier for soil nitrogen ($Y_N$)

$Y_N = (N4 + N5 \cdot CONN)/1.7$,

where $CONN = N1 \cdot (1 - 10^{N2 \cdot (-170 + 4000 \cdot (AVAILN) + N3)})$, N4 [%] and N5 [dimensionless] are parameters and CONN is the nitrogen concentration of leaves and needles [% of dry weight] given as a function of the available nitrogen (ammonium and nitrate, kg/ha). In addition, N1 [dimensionless], N2 [ha/kg] and N3 [kg/ha] are parameters and AVAILN the amount of nitrogen available for growth [kg/ha].

Table 2. Values of some of the main parameters used in calculating growth and its coupling with selected environmental factors for the different tree species. For the explanation of the parameters, see Table 1 and text.

| Parameter | | Pine | Birch |
|---|---|---|---|
| $D_{min}$ | d.d. | 500 | 700 |
| $D_{max}$ | d.d. | 2500 | 4330 |
| $D_3$ | x) | 0.4 | 0.25 |
| AGMX | a | 400 | 130 |
| A1 | x) | 0.99 | 0.99 |
| A2 | x) | –5.1 | –3.80 |
| A3 | x) | 0.0286 | 0.036 |
| SLEAFA | ha/kg | 15500 | 11700 |
| G | $a^{-1}$ | 0.3674 | 0.8215 |
| DGRO | $cm^{-1}$ | –0.1261 | –0.1782 |
| CM1 | % | 2.94 | 2.99 |
| CM2 | ha/kg | 217.52 | 227.43 |
| CM3 | kg/ha | 0.0204 | 0.00199 |
| CM4 | x) | –0.984 | –1.0 |
| CM5 | $\%^{-1}$ | 1.14 | 1.18 |

x) Dimensionless

The survival of established trees (height > 1.3 m) is expressed as the probability of *death*, which is a function of diameter growth during the two previous years and the maximum age of the tree species. If diameter growth exceeds 0.01 cm/a (the specified minimum growth for each tree species), the probability of death C = 4.605/AGMX, where AGMX is the maximum age of a tree species [a]. This age-dependent mortality depends on whether the random number for each tree > 4.605/AGMX. This gives a tree the probability of 1 % of reaching maximum age. If diameter growth is less than 0.01 cm/a, the probability of death is 0.37. If the age of a tree is equal to the maximum age, then such a tree will die. In addition, if the January minimum temperature drops below the minimum temperature specified for a particular tree species, the survival of a tree of that species will be determined as in the case of below-minimum growth.

The model is of the Monte Carlo-type, i.e. certain events, such as birth and death of trees are stochastic events. Consequently, each time when such an event is possible, the algorithm selects whether or not the event will be realized by comparing a random number with the probability of the occurrence of an event. Each run of a Monte Carlo code is one realization of all possible time courses of the forest ecosystem. Therefore, the simulation of the succession of the forest ecosystem must be repeated several times to determine the central tendency or variation of the behaviour of the forest ecosystem. For further details of the model, see Kellomäki et al. (1992).

## 2.2 Temperature conditions

The scenarios of the climate are based on the assumption that the global mean temperature will be 2–4 °C higher if the concentration of atmospheric carbon dioxide ($2\times CO_2$) will double (Kettunen et al. 1987). This is expected to occur by the year 2040–2050 if the increase in the carbon dioxide concentration of the atmosphere continues at the current rate. These expectations are still uncertain with variability in the suggested rate of the rise in temperature. Therefore, different rates of temperature rise were applied in calculations; i.e. annual mean temperature 4.4 °C higher in 50, 75 or 100 years, mean temperature rise rate of 0.08 (Temp50), 0.06 (Temp75) and 0.04 (Temp100) °C/a. The outputs of these scenarios were compared to the output for the current climate, which represents the period 1960–1980 at Tampere Airport (61°28′ N, 24°44′ E, 92 m above sea level). The monthly precipitation values applied in the calculation were these representing the mean values for the above period with a mean annual precipitation of 600 mm/a.

Table 3. The current temperature for different months at Tampere Airport and the assumed increase of mean temperature assumed to take place during the simulations at different sites.

| Month | Current temperature, °C | Temperature increase, °C |
|---|---|---|
| January | –7.8 | 6.2 |
| February | –8.1 | 5.7 |
| March | –4.0 | 5.1 |
| April | 2.0 | 4.4 |
| May | 9.2 | 3.3 |
| June | 14.7 | 2.1 |
| July | 16.1 | 1.6 |
| August | 14.6 | 2.1 |
| September | 9.5 | 3.2 |
| October | 4.5 | 4.3 |
| November | –0.4 | 5.2 |
| December | –5.3 | 5.9 |

The patterns of annual temperature and precipitation are entered into the model in terms of monthly means and standard deviation on the site assuming that the above increase in the annual mean temperature will occur in a linear manner during the simulation period and be allocated to each month as given in Table 3. The *temperature* pattern for the each month is a random temperature (RT(k)) normally distributed around the mean temperature (T(k)) of the month k, i.e. $RT(k) = T(k) + VT(k) \cdot Z$, where VT is the standard deviation and Z a normally distributed random number [–1, 1]. The standard deviation of the monthly mean temperatures is assumed to be the same as for the current climate. The computation of precipitation followed the above pattern, but future precipitation was assumed to be the same as the current one.

## 2.3 Site conditions and experimental design

The computations were divided into two cases; i.e. that concerning management (necessity for and timing of the removal of birches from a Scots pine stand) of mixed stands composed of Scots pine and birches and that concerning the timing of the first thinning of pure Scots pine stands. In both cases, the computations were directed at a forest site of the *Myrtillus* type. The soil texture was assumed to store water in the top 30 cm layer at 5.5 cm at the wilting point and at 12.4 cm when at field capacity. In the beginning of the simulation, the amount of litter and humus mass on and in the soil was 62 t/ha. Nitrogen deposition was assumed to be 10 kg/ha/a on the site throughout of the simulation.

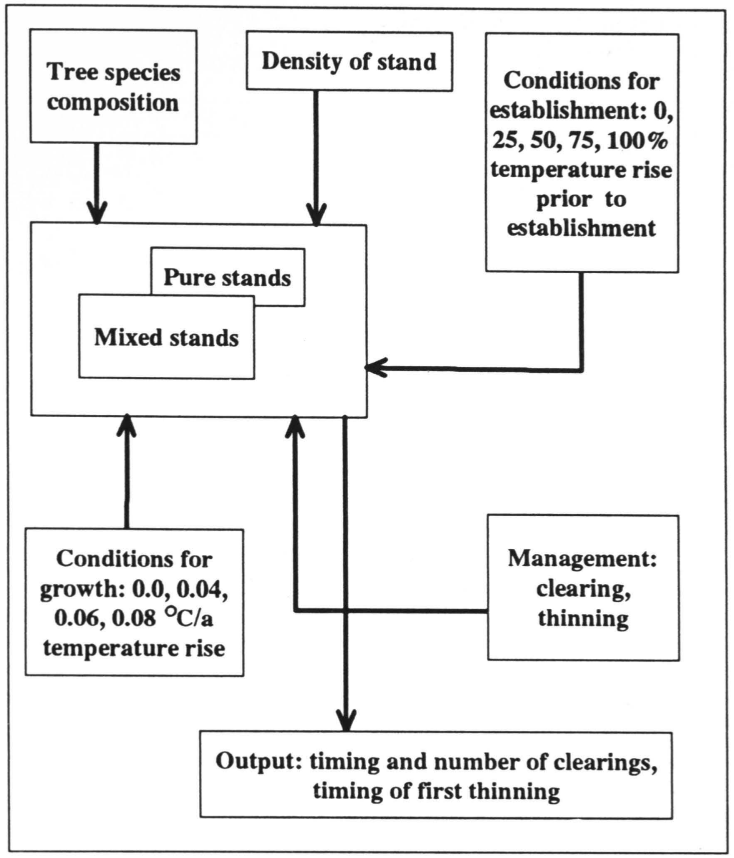


Fig. 1. Experimental design.

The computations represent in both cases two different conditions for management (Fig. 1). Firstly, the seedling stand is assumed to be established in climatic conditions with no temperature rise, the temperature rise starting just after the establishment at the rates indicated above. Secondly, the seedling stand is assumed to be established in climatic conditions with a partial or complete rise in temperature as regards the temperature for $2\times CO_2$ prior to stand establishment (timing of planting). The temperature conditions at the time of establishment represent 25 % (Heat25), 50 % (Heat50), 75 % (Heat75) and 100 % (Heat100) of rise from the total temperature rise for $CO_2$. Thereafter, the temperature is assumed to elevate further at the rate indicated above.

In the case of mixed stands composed of Scots pine and birches the total density of the seedling stand at the onset of each scenario was 4000 stems/ha, which was allocated to Scots pine and birches in such a way, that the percentage of the birches was 25, 50 or 75 from the total stand density. The initial diameter for Scots pine and birches was one centimeter at 1.3 m above the ground level in each scenario, trees being assumed to be distributed randomly in the stand. In addition, birches was allowed to regenerate naturally in order to study need of further removal of birches. In the case of the first thinning the initial stand was a pure Scots pine stand with the density 1500, 2500 and 4000 stems/ha. The output of each scenario represents the mean values of *ten* separate model runs.

## 2.4 Output of the computations

In the computation dealing with management, birches were removed from the stand whenever the accumulation of the biomass of Scots pine was smaller than that of birches with the subsequent suppression of Scots pines by birches. This procedure gave the timing for the removal of birches and indicated the need to tend the stand in relation to rising temperature, timing of planting and initial tree species composition. In the thinning computation, Scots pine stands were allowed to grow until natural mortality of trees was triggered due to decreasing availability of resources. This procedure gave the timing for the first thinning in relation to rising temperature, initial density and timing of planting.

# 3 Results

## 3.1 Growth and development of unmanaged seedling stands

The tree species composition had a substantial effect on the growth and development of mixed stands composed of Scots pine and Pendula birch already under the current temperature conditions. The role of birches was most pronounced in the initial stand with a higher proportion of birches (i.e. 1000 pines and 3000 birches per hectare), but Scots pine survived throughout the simulation period (up to 20 years) even then. In the initial stand with a lower proportion of birches, the role of birch was not pronounced in the early stage of succession, but it was able to coexist with Scots pine in the same stand. Under the current temperature, the total growing stock at the end of the simulation period was not much affected by the tree species composition; i.e. the decrease in the growing stock of one species was compensated by an increase in the growing stock of another species and vice versa. However, in the tree species composition of 1000 pines and 3000 birches per hectare the stocking was about 60 t/ha, which is about 10 to 20 t/ha less than in the other combinations of pines and birches (Fig. 2).

When a rising temperature was assumed, the role of the higher proportion of birches (3000 birches and 1000 pines per hectare) became more pronounced with a clear reduction in the growth of Scots pine. Furthermore, the total stocking of the stand at the age of 20 years increased along with the increasing temperature rise rate; i.e. about 75, 80 and 85 t/ha for temperature rise rates of 0.04, 0.06 and 0.08 °C/a. This was not the case in the lower proportion of birch (3000 pines and 1000 birches per hectare), where the stocking (85–90 t/ha) was not related to the temperature rise rate; i.e. Scots pine was fairly capable of competing with birch whenever the proportion of Scots pine was substantially larger than that of birch from the very beginning of succession. Under a rising temperature, the total stocking of the stand remained nearly the same as that under the current temperature whenever pine was the dominant species in the initial stand. In the higher proportion of birches, the rise in temperature was not utilized as efficiently as under the current climate with the decreasing stocking of the stand. This was particularly the case with a temperature rise rate of 0.04 °C/a when stocking at the end of the simulation period was about 15 t/ha more than the 60 t/ha achieved under the current temperature for the same tree species composition (Fig. 3).

## 3.2 Removal of birches from stands established under current temperature

Under the *current* climate, birch was not able to suppress Scots pine if the proportion of birch was 25 %. Consequently, the *first* removal of birch from the stand was not necessary whereas it was necessary in the cases where the proportion of birches was 50 % and 75 %. In the former case, birches would need to be removed 32 years after the onset of the simulation, otherwise birch would suppress Scots pine to an excess. In the latter case, birches would have to be removed three years after the onset of the simulation. The removal of birch was to be repeated if the proportion of birch was 75 %; i.e. about six years after the first removal. As expected, the increasing proportion of birch in a Scots pine stand seems, thus, to make the removal of birch necessary earlier in the succession as one can expect (Fig. 4).

Even under *rising* temperatures and birch proportion of 25 %, it was not necessary to remove the birches in order to avoid suppression of Scots pine. With birch proportions of 50 % and 75 %, however, suppression of Scots pine was quite evident. The timing of the removal was affected by the rate of temperature rise.

- A 50 % proportion of birch required removal to take place 17 years after since the onset of simulation at temperature rise rate of 0.04 °C/a, and 13 years after the onset of simulation at temperature rise rate of 0.08 °C/a.
- A 75 % proportion of birch required removal to take place three years after the onset of simulation at all rates of temperature rise.

A repeated removal of birches was also necessary under a rising temperature; i.e. the *second* removal five years after the establishment of the stand with a 75 % birch proportion at any temperature rise rate (Fig. 5).

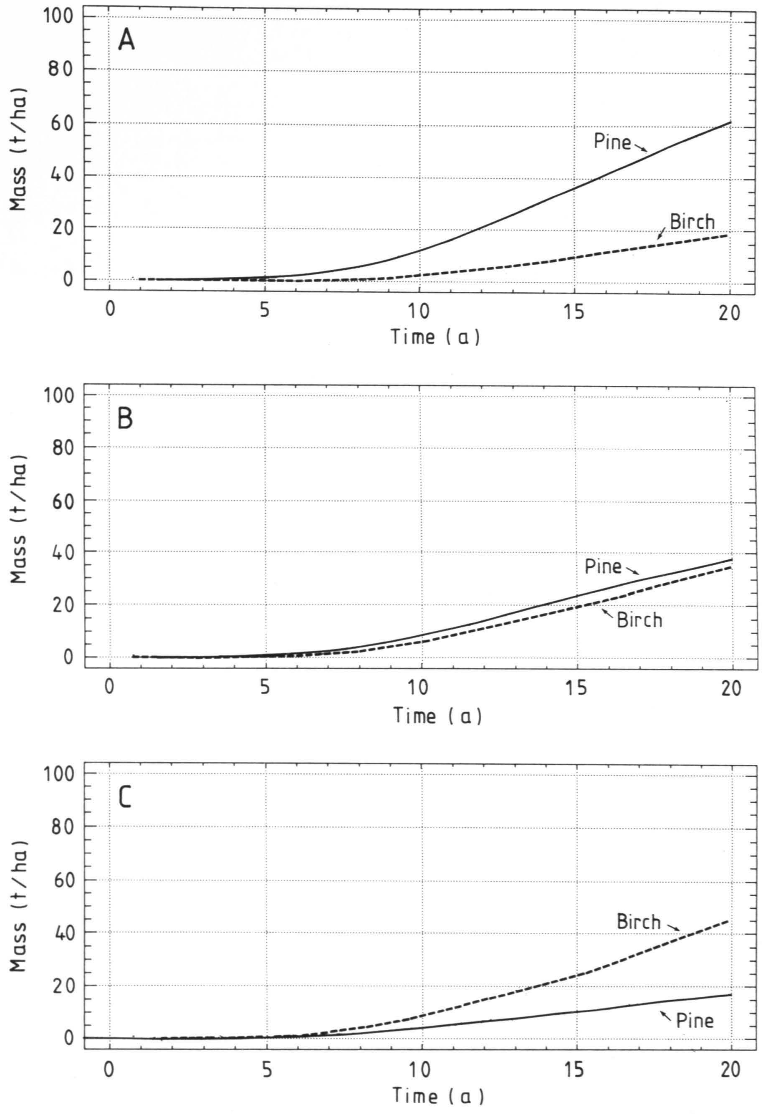


Fig. 2. Growth and development of seedling stands assuming varying initial tree species composition under current temperature conditions.

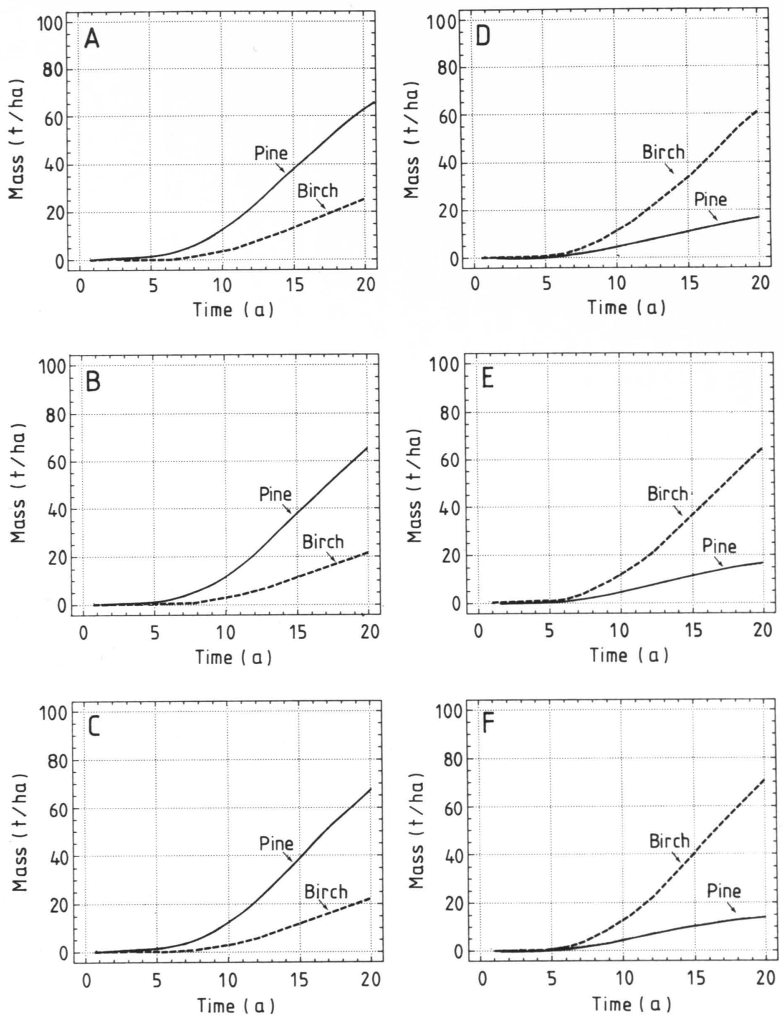
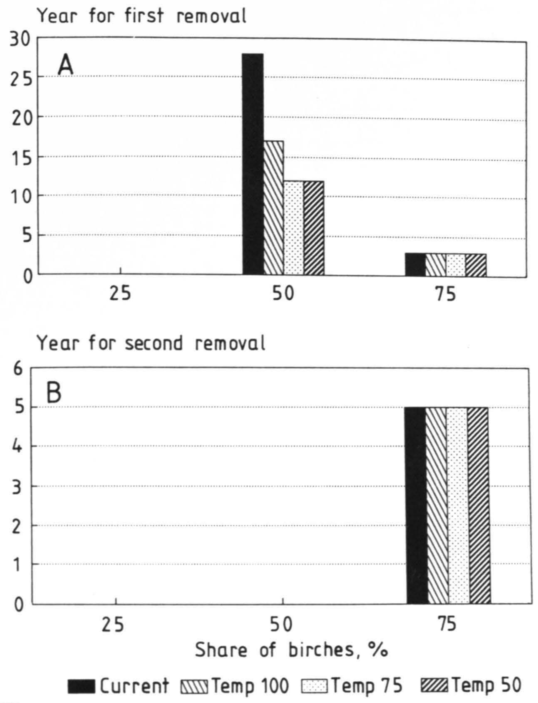


Fig. 3. Growth and development of seedling stands assuming varying tree species composition (3000 pines and 1000 birches per hectare, 1000 pines and 3000 birches per hectare) under rising temperatures (rise rates of 0.04 °C/a (Temp100), 0.06 °C/a (Temp75), 0.08 °C/a (Temp50)).

### 3.3 Removal of birches from stands established under risen temperature conditions

The above conclusions are also supported by simulations that were started assuming the temperature rise to be partially or fully completed before planting. The findings of these computations are indicated by the cases where the temperature after the establishment rises at the rates of 0.04 and 0.08 °C/a. Furthermore, the results are compared to the results representing no prior temperature rise. In principle, the latter results are similar to those above, but they deviate from them due to the Monte Carlo-type simulation applied in the calculations. In the case of *temperature rise at the rate of 0.04 °C/a after planting* the following results were obtained (Fig. 6).

- *No temperature rise prior to planting:* removal of birch was not required in the case of birch proportion of 25 % but it took place in year 17 in the case of birch proportion of 50 % and in year 3 for birch proportion of 75 %.



rig. 4. Timing of the removal of birches as a function of the rate of temperature rise and the proportion of birches. A: first removal, B: second removal. Legend: Current = No temperature rise, Temp100 = Temperature rise takes place in 100 years (rise rate of 0.04 °C/a). Temp75 = Temperature rise takes place in 75 years (rise rate of 0.06 °C/a). Temp50 = Temperature rise takes place in 50 years (rise rate of 0.08 °C/a).

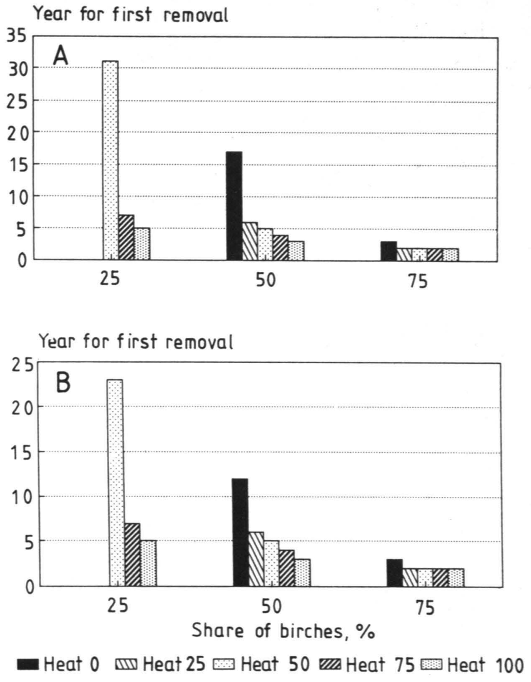


Fig. 5. Timing of the first removal of birches as a function of the share of birches and temperature condition at the establishment of the stand. A: the temperature rise rate 0.04 °C/a after planting. B: the temperature rise rate 0.08 °C/a after planting. Legend: Heat0 = no prior temperature to rise, Heat25 = 25 % prior temperature rise, Temp50 = 50 % prior temperature rise, Temp75 = 75 % prior temperature rise and Temp100 = 100 % prior temperature rise prior to planting.

- *Temperature rise of 25 % prior to planting*: removal of birch was not required in the case of birch proportion of 25 % but it took place in year 7 in the case of birch proportion of 50 % and in year 2 for birch proportion of 75 %.
- *Temperature rise of 50 % prior to planting*: removal of birch was required in year 32 in the case of birch proportion of 25 %, in year 5 for birch proportion of 50 % and in year 2 for birch proportion of 75 %.
- *Temperature rise of 75 % prior to planting*: removal of birch was required in year 7 in the case of birch proportion of 25 %, in year 4 for birch proportion of 50 % and in year 2 for birch proportion of 75 %.
- *Temperature rise of 100 % prior to planting*: removal of birches was required in year 5 in the case of birch proportion of 25 %, in year 3 for birch proportion of 50 % and in year 2 for birch proportion of 75 %.

In general, the above results hold also for the *temperature rise rate of 0.08 °C/a after planting*, but the time for the removal is brought forward regardless of the birch proportion in the stand. This is particularly true for the stand with a birch proportion of 25 %, in which case the birches will be removed nearly 10 years earlier than in the case of the temperature rise rate of

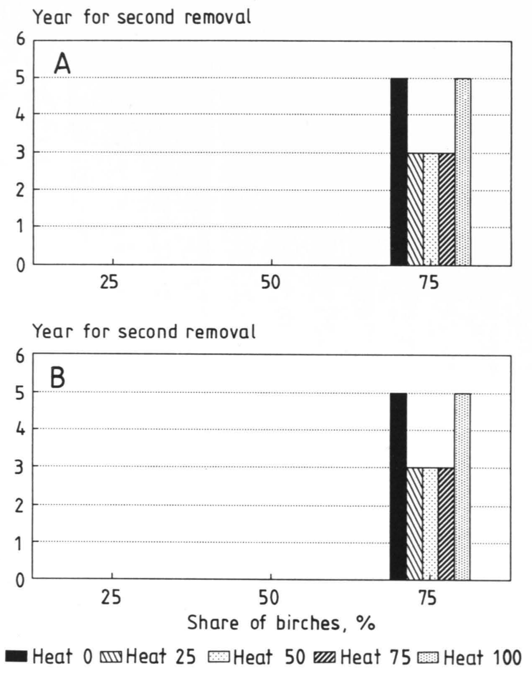


Fig. 6. Timing of the second removal of birches as a function of the proportion of birches and temperature conditions at the establishment of the stand. A: Temperature rise rate of 0.04 °C/a. B: Temperature rise rate of 0.08 °C/a. Legend: Heat0 = No prior temperature rise, Heat25 = 25 % prior temperature rise, Heat50 = 50 % prior temperature rise, Heat75 = 75 % prior temperature rise and Heat100 = 100 % prior temperature rise prior to planting.

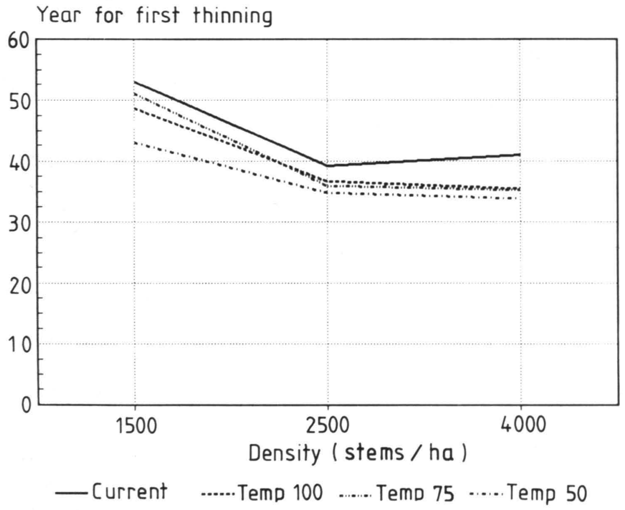


Fig. 7. Timing of the first thinning of Scots pine stand as a function of stand density and temperature rise rate. Legend: Current = No temperature rise, Temp100 = Temperature rise takes place in 100 years (rise rate of 0.04 °C/a). Temp75 = Temperature rise takes place in 75 years (rise rate of 0.06 °C/a). Temp50 = Temperature rise takes place in 50 years (rise rate of 0.08 °C/a).

0.08 °C/a. In conclusion, the tree species composition, temperature rise rate and the prevailing temperature conditions affect the need for and timing of the removal of birches from Scots pine stands, if the latter species is to form the final crop.

## 3.4 Timing of first thinning in stand established under current temperature

Under the *current* temperature conditions, the first thinning takes place about 52, 40 and 40 years after planting for stand densities of 1500, 2500 and 4000 stems/ha. A *rising* temperature brings the time of thinning slightly forward; i.e. at temperature rise rates of 0.04, 0.06 and 0.08 °C/a, thinning was required at the ages of 48, 50 and 42 for a density of 1500 stems/ha. The corresponding values for a density of 2500 stems/ha were the ages of about 38, 37 and 36 years, and for a density of 4000 stems/ha the ages were 37, 36 and 35 years after the onset of the simulation, the first thinning being slightly earlier. In conclusion, the temperature rise could bring the first thinning forward, especially when applying wide spacing in planting. This applied also to the stands with higher initial density. In the case of closely-spaced stands, the change was smaller than in the case of wide spacing (Fig. 7).

## 3.5 Timing of first thinning in stand established under risen temperature

The above conclusions are also supported by the simulations where the temperature rise was assumed to have occurred prior to planting. These computations represent temperature rise rates of 0.04 and 0.08 °C/a after planting as in the case of the pure seedling stands. Furthermore, the results are compared to the results representing no prior temperature rise. Again, the latter results are, in principle, similar to those above, but they deviate from them due to the Monte Carlo-type simulation applied in the calculations. In the case of *temperature rise at the rate of 0.04 °C/a after planting* the following results were obtained (Fig. 8).

- *No temperature rise prior to planting*: first thinning occurred in year 48 with a density of 1500 stems/ha, in year 37 with a density of 2500 stems/ha and in year 36 with a density of 4000 stems/ha.
- *Temperature rise of 25 % prior to planting*: first thinning occurred in year 43 with a density of 1500 stems/ha, in year 34 with a density of 2500 stems/ha and in year 33 with a density of 4000 stems/ha.
- *Temperature rise of 50 % prior to planting*: first thinning occurred in year 46 with a density of 1500 stems/ha, in year 33 with a density of 2500 stems/ha and in year 32 with a density of 4000 stems/ha.
- *Temperature rise of 75 % prior to planting*: first thinning occurred in year 45 with a density of 1500 stems/ha, in year 35 with a density of 2500 stems/ha and in year 34 with a density of 4000 stems/ha.
- *Temperature rise of 100 % prior to planting*: first thinning occurred in year 51 with a density of 1500 stems/ha, in year 39 with a density of 2500 stems/ha and in year 35 with a density 4000 stems/ha.

In general, the above results hold also for the *temperature rise rate of 0.08 °C/a after planting*, but the first thinning will be delayed in the case of the 75 % rise in temperature prior the planting. This is particularly true for the stand density of 1500 stems/ha. This delay indicates that the temperature conditions in this case, too, are becoming suboptimal for Scots pine as they were with the rise rate of 0.04 °C/a when assuming a rise of 100 % prior to the establishment of the stand. In conclusion, the stand density, temperature rise rate and the prevailing temperature conditions affect the timing of the first thinning. In particular, the widely-spaced stands appeared to be particularly sensitive to the effects of rising temperatures.

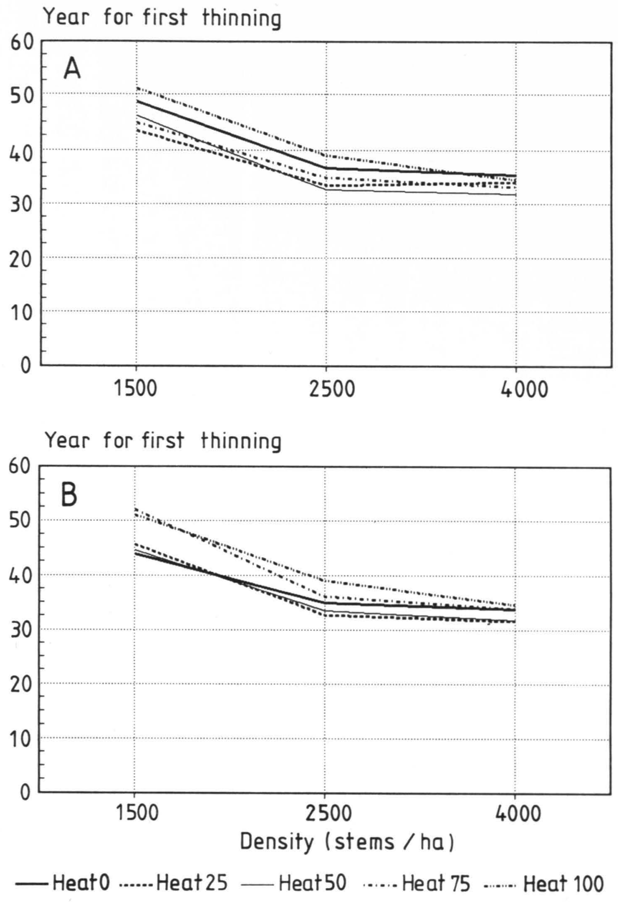


Fig. 8. Timing of the first thinning of Scots pine stand as function of stand density and the temperature conditions at the planting. A: the temperature rise rate 0.04 °C/a after planting. B: the temperature rise rate 0.08 °C/a after planting. Legend: Heat0 = No prior temperature rise, Heat25 = 25 % prior temperature rise, Heat50 = 50 % prior temperature rise, Heat75 = 75 % prior temperature rise and Heat100 = 100 % prior temperature rise prior to planting.

## 4 Discussion and conclusions

The present calculations concern the growth of young Scots pines and birches occupying the same site, and the subsequent need to remove birches when aiming at Scots pine as the final crop in the management of the stand. The calculations exclude the effects of any external factors (other than temperature rise) on the course of stand development, but they include the effects of the tree species composition on the competition between the tree species and the consequent growth and structure of the seedling stand. Therefore, the output of these calculations will indicate the changes taking place in the dynamics of the tree community as derived from the interaction between the biological properties of tree species and the changing climate and the subsequent management needs. The model applied in the calculation is thoroughly discussed elsewhere (Kellomäki et al. 1992), and it is not treated here.

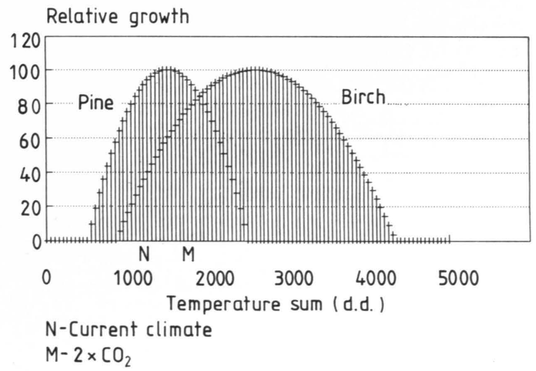


Fig. 9. Relative diameter growth of Scots pine and Pendula birch as a function of temperature sum.

The computations show that a rising temperature could favour birch more than Scots pine (see also Kellomäki et al. 1988). A change in the competitive capacity of birch and Scots pine as a response to a rising temperature is expected on the basis of the response of these tree species to the temperature conditions, since the optimal conditions for Scots pine presuppose 1500 d.d. and for birch 2600 d.d. (Fig. 9). This indicates that a rising temperature will favour the tree species in the order Scots pine and birch. Similarly, the maximal temperature sum applied in the case of Scots pine is 2500 d.d. for birch 4330 d.d. with a subsequent loss of competitiveness by Scots pine when the prevailing temperature sum exceeded the value of 2500 d.d. The distributional limits of Scots pine and Pendula birch in terms of temperature sum are estimated from the current literature (Kienast 1987, Kellomäki and Väisänen 1991, Prentice and Helmisaari 1991, Nikolov and Helmisaari 1992).

The growth and development of Scots pine and birch in a mixed stand is also determined by the shade tolerance of these species. At the value of 1800 d.d., for example, Scots pine is still stronger as a competitor than birch even below the value of 50 % for the available light from that above canopy. At values greater than 1900 d.d., birch under full light will outcompete Scots pines also having access to full light. At values greater than 2000 d.d., the competitive capacity of birches with access to 50 % of the full light will be greater than that of Scots pines with access to full light. The response of Scots pine and birch to a rising temperature and availability to light are thus clearly differentiated with a consequent increase of the competition power of birch and decrease competitive of capacity of Scots pine if the suggested climatic change takes place.

The need to *remove* birch from a tree stand was obvious even under the current climate if the proportion of birch increased. However, the need to remove birches from Scots pine stands became more urgent if temperature was assumed to rise. This was particularly obvious if the temperature rise was assumed to take place in 50 years. Several removals were needed to grow Scots pine through the seedling phase of the stand development with higher proportions of birches in the initial stand. In other words, seedling stands established prior to the onset of temperature rise, but growing under a rising temperature, may need more tending if the production of a final crop of Scots pines is aimed at on sites habitable for both Scots pines and birches.

The overall response of the seedling stand is, however, much influenced by the tree species composition; i.e. the greater the share of a particular tree species was, the more capable the species was of maintaining its position in the tree stand. This was obvious even under a rapid rise in temperature allowing Scots pine to occupy a tree stand in the temperature conditions favouring the growth of birch. This was also recognizable in the computations where the temperatures at planting were higher than the current one.

Under a rising temperature, the timing of the first *thinning* in pure stands was earlier in the closely-spaced stands than in the widely-spaced stands; this was to be expected on the basis of the studies under the current temperature conditions. However, a rising temperature made the first thinning slightly earlier, especially in the case of wide initial spacing. This, too, was to be expected, since the availability of light and nitrogen do not limit growth in widely-spaced stands as much as they do in closely-spaced stand, the temperature rise thus being more effective in the former case than in the latter case. This was also recognizable in the computations when the temperatures at planting were higher than the current one. Thus, the timing of the first thinning is also affected by the prevailing temperature conditions and the rate of change in the temperature conditions as well as by the stand density.

The scenario of the future needs of tending of seedling stands and the timing of the first thinning yielded by the model computations is still a tentative one, since the future development of the temperature conditions is susceptible to substantial uncertainty. In addition, the results of the present computations cannot be compared to findings of any empirical results, since competition between different tree species in relation to the temperature and the subsequent management needs and timing of the first thinning were not studied. The model output is, however, well in the line with the general observation that the competitive capacity of birches diminishes towards the north; i.e. along with decreasing temperature and subsequent decrease in management needs in terms of timing and number of the removals of birches from Scots pine stands on sites habitable by both species. Similarly, the results on the timing of the first thinning are in line with the earlier findings, which indicate that increasing planting density and growth rate will bring the first thinning forward. This holds for both factors separately, and both tendencies will interact resulting in first thinning that comes earlier than expected on the basis of the single factors.

## References

Aber, J.D. & Melillo, J.M. 1991. Terrestrial ecosystem. Saunders College Publishing, Philadelphia. 429 p.

Climate change. The IPCC impact assessment. 1990. Intergovernmental Panel on Climate Change. Australian Government Publishing Service, Canberra.

Henttonen, H., Kanninen, M., Nygren, M. & Ojansuu, R. 1986. The maturation of Scots pine seeds in relation to temperature climate in northern Finland. Scandinavian Journal of Forest Research 1: 234–249.

Kellomäki, S. Hänninen, H. & Kolström, T. 1988. Model computations on the impacts of the climatic change on the productivity and silvicultural management of the forest ecosystem. Silva Fennica 22: 293–305.

— & Väisänen, H. 1991. Application of a gap model for the simulation of forest ground vegetation in boreal conditions. Forest Ecology and Management 42: 35–48.

— , Väisänen, H., Hänninen, H., Kolström, T., Lauhanen, R., Mattila, U. & Pajari, B. 1992. A simulation model for the succession of the boreal forest ecosystem. Silva Fennica 26: 1–18.

Kettunen, L., Mukula, J, Pohjonen, V. Rantanen, O. & Varjo, U. 1987. The effect of climatic variations on agriculture in Finland. In: Perry, M.L., Carter, T.R. & Konijn, N.t. (eds.). The impact of climatic variations on agriculture. Vol. 1. Assessment in cool temperate and cold regions. International Institute for Applied Systems Analysis. 90 p.

Kienast, F. 1987. Forece – A forest succession model for southern central Europe. Oak Ridge National Laboratory. Environmental Science Division. Publication 2989: 1–73.

Mielikäinen, K. 1980. Mänty-koivusekametsiköiden rakenne ja kehitys. Summary: Structure and development of mixed pine and birch stands. Communicationes Instituti Forestalis Fenniae 99(3). 82 p.

— 1985. Koivusekoituksen vaikutus kuusikon rakenteeseen ja kehitykseen. Summary: Effect of an admixture of birch on the structure and development of Norway spruce stand. Communicationes Instituti Forestalis Fenniae 133. 79 p.

Mikola, P. 1952. Havumetsien viimeaikaisesta kehityksestä Lapin metsärajaseudulla. Summary: On the recent development of coniferous forests in the timber line region of northern Finland. Communicationes Instituti Forestalis Fenniae 51(8). 49 p.

Nikolov, N. & Helmisaari, H. 1992. Silvics of circumpolar boreal forest tree species. In: Shugart, H.H., Leemans, R. & Bonan, G.B. (eds.). A systems analysis of the global boreal forests. Cambridge University Press, Cambridge. p. 13–84.

Pastor, J. & Post, W.M. 1985. Development of linked forest productivity-soil process model. Oak Ridge, Tennessee. ORNL/TM-9519: 1–168.

— & Post, W.M. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. Biogeochemistry 2: 3–27.

Prentice, C. & Helmisaari, H. 1991. Silvics of north European trees: compilation, comparison and implications for forest succession modelling. Forest Ecology and Management 42: 79–93.

Shugart, H.H. 1984. A theory of forest dynamics. The ecological implications of forest succession models. Springer-Verlag, New York. 278 p.

*Total of 16 references*