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Model computations on the impacts of the climatic change on the productivity and silvicultural management of the forest ecosystem

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TIIVISTELMÄ: EKOLOGISEEN MALLIIN PERUSTUVIA LASKELMIA ILMASTON MUUTOKSEN VAIKUTUKSESTA METSÄN UUDISTAMISEEN JA KASVATUKSEEN

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The model computations indicate that the climatic change in the form of higher temperatures and more precipitation could increase the productivity of the forest ecosystem and lead to higher rates of regeneration and growth. More frequent and intensive thinnings are needed to avoid the mortality of trees induced by accelerated maturation and attacks of fungi and insects. The climatic change could support the dominance of deciduous tree species and necessitate an intensification of the tending of seedling stands of conifers. The rise of air temperature during autumn and winter could change also the annual growth rhythm of trees and result in dehardening and subsequent frost damages and attacks of insects and fungi. The pest management could be the greatest challenge to the future silviculture, which could be modified most in northern Finland.

Ekologisilla malleilla tehdyt laskelmat viittaavat siihen mahdollisuuteen, että odotettavissa oleva ilmaston muutos lämpötilan kohoamisen ja lisääntyvän sadannan muodossa voi nopeuttaa metsien uudistumista ja lisätä metsäekosysteemin tuottavuutta. Tämän vuoksi ilmaston muutos voi merkitä tarvetta huolehtia taimikonhoidosta ja harvennushakkuista nykyistä tarkemmin, sillä odotettavissa oleva ilmaston muutos suosii erityisesti lehtipuiden kasvua. Myös puuston nopeutunut kasvu ja kehitys voi helposti lisätä puiden kuolemista kasvutilan loppumisen sekä hyönteis- ja sienituhojen muodossa. Myös puiden vuotuisen kasvurytmin mahdollinen muuttuminen voi lisätä hyönteis- ja sienituhojen riskiä. Odotettavissa oleva ilmaston muutos korostaa metsänsuojelun merkitystä, sillä ilmaston muutos suosii monia jo nykyään tuhoja aiheuttavia hyönteisiä ja sieniä.

Keywords: climatic change, simulation, future silviculture, changing environment
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1. Introduction

In the foreseeable future, the air impurities and climatic change could modify the silvicultural practices in the Scandinavian countries. The impact of the air impurities is studied intensively throughout Europe, the studies demonstrating the detrimental effects of the air impurities on the functioning and structure of the forest ecosystem and the future timber yield. This could be the case also with the climatic change but the effects of the climatic change are much less known than those of the air impurities.

It is expected that the climatic change is, in particular, inevitable in the high latitudes of the northern hemisphere, which include the most productive forest sites in the Scandinavian countries (Kettunen et al. 1987). The climatic change at the high latitudes can result in higher temperatures with longer growing seasons, more rainfall and snow accumulation. These changes seem to increase cereal crops. For example, in southern Finland (between the 61st and 62nd latitudes) barley, spring wheat and oats crops are expected to increase up to 20 % with increasing certainty. Similar increases could occur also in northern Finland (between the 64th and 65th latitudes), but with lower certainty than in southern Finland (Kettunen et al. 1987).

The effects of the climatic change on the timber yield are more obscure than those on agriculture. For example, on the basis of the positive effect of higher summer temperatures on the growth and regeneration of Scots pine at the Scandinavian timber line one could also expect that timber yield could increase in the future (Hustich 1948, Mikola 1950, Henttonen 1984, Henttonen et al. 1986). The uncertainty of these expectations is, however, greater than in agriculture due to the delayed response of the forest ecosystem to climatic change. Therefore the direct projections of the effects of the higher summer temperatures and increased precipitation on growth and regeneration can only indicate possible outlines concerning the way in which the climatic change could affect future timber yield (cf. Henttonen 1984, Henttonen et al. 1986).

The future timber yield will be dependent on the structure and functioning of the forest ecosystem and the consequent patterns of silvicultural management. Therefore the interaction between the ecological processes and silvicultural practices is the basis for the analysis of the silvicultural implications of the climatic change. Consequently, the future timber yield is not predictable unless the silvicultural management of the forest ecosystem is outlined at the same time as the effect of climatic change on the structure and functioning of the forest ecosystem.

This paper outlines the functioning and structure of the boreal forest ecosystem and its silvicultural implications under climatic conditions representing higher temperatures and more precipitation than is now the case. Our example outlines the future trends in Finnish conditions.

2. Changes in climatic pattern

Kettunen et al. (1987) compare present temperature and precipitation patterns with those expected at a double CO_2 level simulated by the Goddard Institute for Space Studies (GISS) atmospheric general circulation model (Hansen et al. 1984) (Fig. 1). At Helsinki the *mean annual temperature* rises about two degrees and at Oulu the temperature rise is even higher, i.e. the mean annual temperature is expected to rise two to three degrees. The temperature rise is greatest during winter. The *effective temperature* sum (threshold 5 °C) at Helsinki is expected to rise from the prevailing 1300 d.d. to 1700 d.d. and at Oulu from 1000 d.d. to 1500 d.d. In terms of the thermal growing season (number of days with a mean daily temperature > 5 °C) the growing season will be lengthened considerably both at Helsinki and Oulu.

The increase in the *annual precipitation* at Oulu is not as dramatic as at Helsinki, but a nearly doubled amount in the annual precipitation could be expected in southern and central Finland. The increase in precipitation is relatively higher during wintertime than summer. Therefore snow accumulation could be enhanced in central and northern Finland. In southern Finland the winter climate could be too mild to allow any excess snow accumulation. The general weather pattern is expected to be more humid and warmer (more maritime) than today, implying longer growing season compared with the present situation (Kettunen et al. 1987).

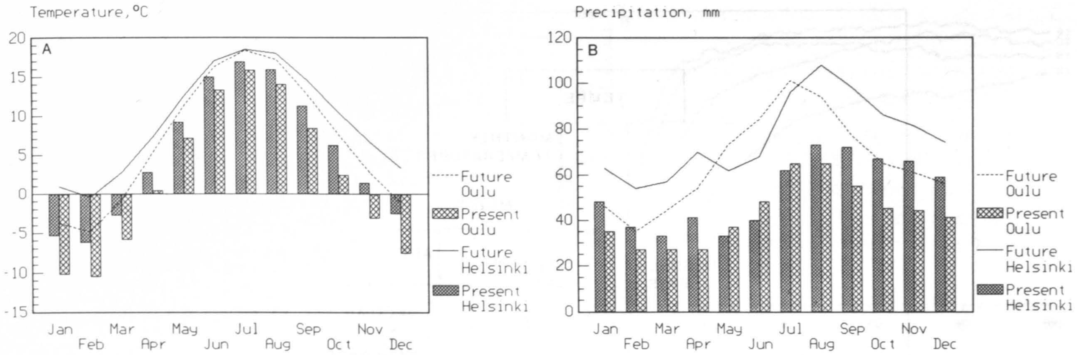

Fig. 1. A: Mean monthly temperature (°C) and B: mean monthly precipitation (mm) observed (1951–1980) and predicted for 2×CO_2 at Helsinki (latitudes 61°–62°) and Oulu (latitudes 64°–65°) (Kettunen et al. 1987).

3. Ecological implications of the changing climate

3.1. Ecological mechanisms

Dynamics of the forest ecosystem

The present functioning and structure of the forest ecosystem are product of the *interaction* between the prevailing environment and the biological populations occupying forest sites (Fig. 2). The climatic change is incorporated into the dynamics of the forest ecosystem through the *regeneration*, *growth* and *death* processes of tree species, as controlled by light, temperature and water and nutrient supply. The modifications of regeneration, growth and mortality as a response to the changing climatic and edaphic processes of the *site* could thoroughly change the *competition* patterns within and between the populations of the tree species and other organisms.

The survival and growth of the local tree species is also challenged by the possible *invasion* of new tree species which could be more capable of adapting to the changing conditions. These processes could also be enhanced by the changes in the populations of the *pathogenetic* insects and fungi to which the local tree species are not adapted. These processes determine the competition within and between biological populations and their adaptation to the changing climatic conditions as implied by the modifications of the underlying processes of the forest ecosystem.

Computational example

The ecological consequences of the climatic change can be evaluated with the aid of any

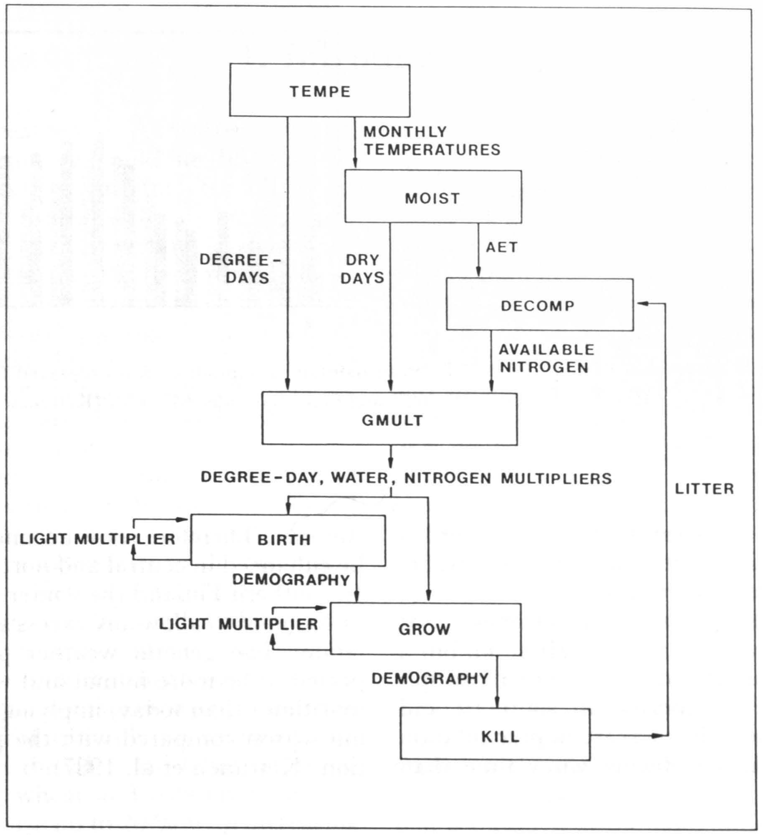

Fig. 2. Structural and functional relationships in the forest ecosystem and the effects of climatic factors on the functioning of the forest ecosystem according to Pastor and Post (1985).

ecological *model* capable of utilising temperature and precipitation as control factors of the ecological processes. In the following we have applied the model developed by Pastor and Post (1985) (Fig. 2). The model is tailored to Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula pendula* and *B. pubescens*) growing in boreal conditions, the parameters of the tree species being valid within the Finnish territory.

The computations represent pure Scots pine stands growing on sandy or moraine soils of a *Vaccinium* type, i.e. sites of medium fertility in the Finnish classification of forest sites. The present and future functioning and structure of the forest ecosystem are given for Helsinki and Oulu following the climatic patterns presented in Fig. 1. The initial stands were of pure Scots pine but seedings by other tree species were permitted.

The climatic change enhances the *growth rate*, particularly in northern Finland where the growth rate could be nearly the same as in southern Finland today (Fig. 3). The growth rate will also be increased in southern Finland, but not to the same extent as in northern Finland. The growth rate will also culminate earlier in the future and will be decreased at a greater rate than is presently the case.

The increased productivity is also recognisable in the values of the *standing crop* which will grow in northern Finland, in particular, assuming no genetic constraints limiting the productivity of the local tree populations (Fig. 3). The growth of the *carrying capacity* of the sites could, however, be temporary, because the climatic change seems to decrease

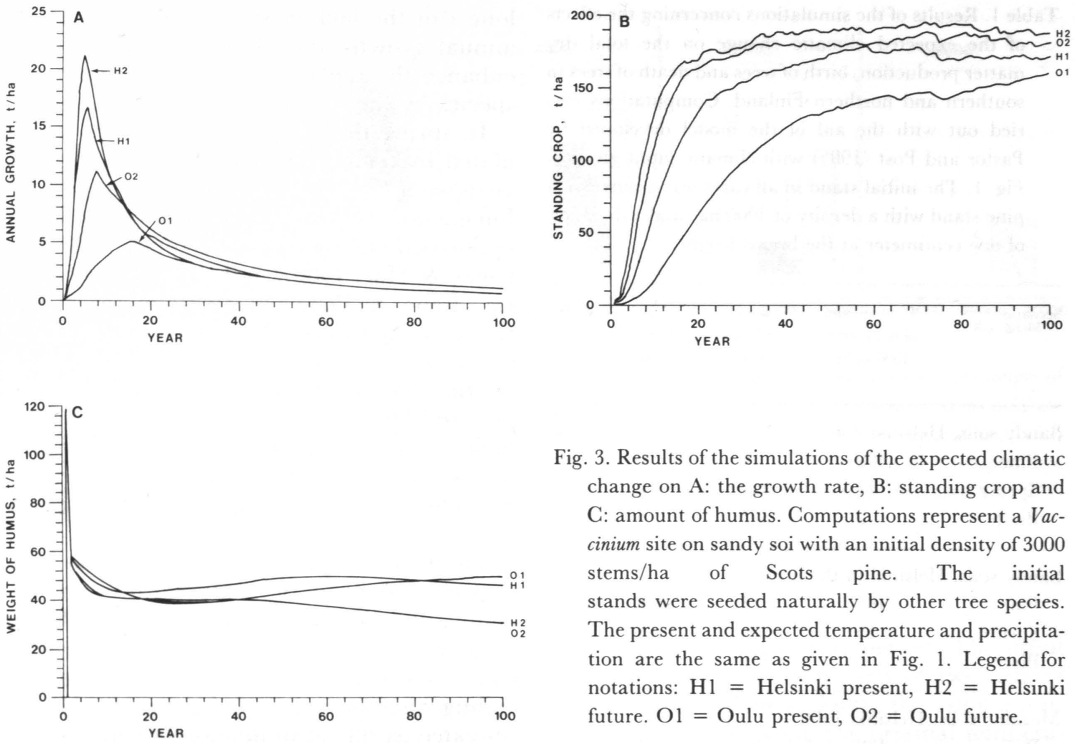

Fig. 3. Results of the simulations of the expected climatic change on A: the growth rate, B: standing crop and C: amount of humus. Computations represent a *Vaccinium* site on sandy soi with an initial density of 3000 stems/ha of Scots pine. The initial stands were seeded naturally by other tree species. The present and expected temperature and precipitation are the same as given in Fig. 1. Legend for notations: H1 = Helsinki present, H2 = Helsinki future. O1 = Oulu present, O2 = Oulu future.

the amount of *humus* in the soil as a consequence of the enhanced decomposition of litter and humus. Thus, in the long run the productivity and the standing crop of trees could be decreased, if the humus and nutrients are depleted to a greater extent.

On the basis of the growth rate one can expect that the *total account of the biomass* within the rotation will be increased due to the climatic change (Table 1). On sandy soils this is true, in particular, for pine, but on moraine soils the productivity of birch will also increase. Norway spruce seems to be fairly neutral as regards the climatic change. The increase of the dry matter production was mainly due to the increased growth of the trees in the initial stands; the increased standing crop prevented the establishment of numerous seedlings of spruce and birch which were born in the gaps in the canopy induced by the mortality of the initial trees.

The climatic change also seems to accelerate the *death rate* of trees, since the capacity of the site will be exceeded earlier than is now the case. Similarly, trees will exceed their maximum dimensions earlier than at present, i.e. they will *mature* within a shorter time under the changed climatic conditions. The simulations indicate that the climatic change could increase the death rate more than the growth rate of trees with a consequent acceleration in the turn-over of the biomass in the forest ecosystem. This seems, in particular, to be characteristic of northern Finland.

3.2. Adaptational mechanisms

Sychronization between annual growth and climatic patterns

The risk of tree death is also associated with the *annual growth rhythm* of trees which could be susceptible to change under the changing climatic pattern. Temperature and photoperiod are the main environmental factors that regulate the annual development of the trees (Weiser 1970, Sarvas, 1972, 1974, Landsberg 1977, Fuchimami et al. 1982). Thus, changes in the annual growth rhythm of the trees may be expected as a result of the changes in temperature conditions. In the

Table 1. Results of the simulations concerning the effects of the expected climatic change on the total dry matter production, birth of trees and death of trees in southern and northern Finland. Computations carried out with the aid of the model developed by Pastor and Post (1985) with climatic input given in Fig. 1. The initial stand in all cases was a pure Scots pine stand with a density of 3000 ha^{-1} and a diameter of one centimeter at the breast height.

Scenario	Total account of dry matter 1000 kg/ha a	Born seedlings 100/ha b	Total account of dead trees 1000 kg/ha c	Ratio c/a
Sandy soils, Helsinki 1980				
Pine	422	70	255	0.60
Spruce	13	352	12	0.92
Birch	2	375	5	0.40
Sandy soils, Helsinki in the future				
Pine	486	61	298	0.61
Spruce	15	296	15	1.00
Birch	5	359	5	1.00
Moraine soils, Helsinki 1980				
Pine	438	51	258	0.59
Spruce	11	293	11	1.00
Birch	1	218	1	1.00
Moraine soils, Helsinki in the future				
Pine	482	44	304	0.63
Spruce	11	302	11	1.00
Birch	4	279	4	1.00
Sandy soils, Oulu 1980				
Pine	341	73	181	0.53
Spruce	16	453	16	1.00
Birch	2	338	2	1.00
Sandy soils, Oulu in the future				
Pine	465	55	284	0.61
Spruce	14	368	14	1.00
Birch	1	315	1	1.00
Moraine soils, Oulu 1980				
Pine	361	59	213	0.59
Spruce	12	362	12	1.00
Birch	1	211	1	1.00
Moraine soils, Oulu in the future				
Pine	463	42	293	0.63
Spruce	12	366	11	0.92
Birch	3	276	3	1.00

long run the lack of sychronization between annual growth and climatic patterns could enhance the replacement of the present tree species by the invading ones.

In spring the development of trees is regulated by temperature. The *rate* of *ontogenetic development* (Sarvas 1972, 1974, Kobayashi & Fuchigami 1982a), the rate of increase in the photosynthetic capacity (Pelkonen 1980, Pelkonen & Hari 1980), and the *rate of dehardening* (Repo & Pelkonen 1986) increase with rising temperature. As a result of climatic warming, any given development stage will on the average be reached earlier than at present. This results in more frequent spring frost damage, if the general climatic warming is not accompanied by a decrease in the incidence of late spring frosts (Cannell & Smith 1986).

The *timing of growth cessation* has also been shown to depend on temperature sum accumulation (Koski & Selkäinaho 1985, Koski & Sievänen 1985), even though it is often considered to be regulated solely by the prevailing photoperiod. Growth cessation is accelerated as the accumulation of temperature sum is increased. Consequently, the growth cessation occurs earlier, and the increased part of the growing season favourable for growth remains unutilized in the growing processes. The risk of early autumn frost damage could, however, decrease since the length of the hardening period is increased.

The growth cessation of the trees is followed by a period of rest, where the buds do not start to grow, even if the environmental factors are favourable for growth. The growth competence is resumed through a prolonged exposure to chilling temperatures (Worrall & Mergen 1967, Nienstaedt 1966, 1967, Landsberg 1974). After the chilling requirements of dormancy release have been met bud development is promoted by exposure to high temperatures (Sarvas 1974, Kobayashi & Fuchigami 1983b). Therefore the rise in air temperatures during autumn and winter could result in considerable dehardening, even flushing and subsequent frost damages.

Computational example

The effects of the climatic warming on the growth rhythm of the trees can be quantitively studied with the aid of the simulation models as done by Hänninen et al. (1985) and Hänninen (1987), who studied the effect of climatic warming based on the model developed by Sarvas (1972, 1974). In the model, the annual cycle is described in three sequential parts in terms of developmental units (i) during the active period, by the accumulation of a period unit (PU sum), (ii) during autumn dormancy, by the accumulation of a chilling unit sum (CU sum), and (iii) during winter dormancy, by the accumulation of a dormancy unit sum (DU sum).

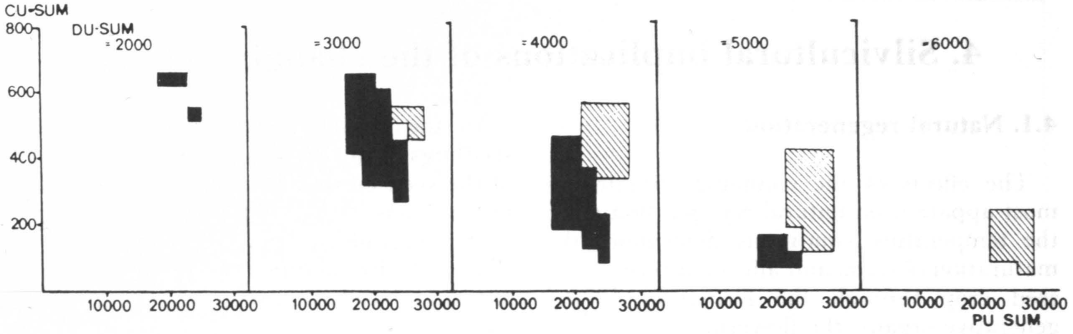

Fig. 4. Effect of climatic warming on the annual growth rhythm of trees. PU, CU and DU sum are the parameters of the model developed by Sarvas (1972, 1974) describing genetical properties of the trees. The shaded areas indicate acceptable parameter combinations through which the modelled development of the trees was syncronized with the seasons during a ten years period. Dark shading represents the simulation with measured temperature observations, light shading the simulatiton with temperature observations with hourly values increased by +2 °C (Hänninen et al. 1985, Hänninen 1987).

The accumulation of developmental units is a temperature dependent function which is specific for each developmental phase. Each phase terminates, and the next begins, when a particular amount of the developmental units are accumulated, i.e. the critical sums of PU, CU and DU. The critical sums of PU, CU and DU are the parameters of the model representing the genetical properties of the trees. The values of the parameters should be combined in such a way that the timing of the developmental phases is syncronized with the annual weather pattern of a selected time period.

This premise was studied by simulations extending over a ten-year period. The input of the model was comprised of two sets of temparature regimes. First, the simulations were carried out using the original temperature observations for the years 1962–1971. Second, the simulations utilized modified temperature observations, the climatic warming was approximated by assuming the hourly temperatures to be two degrees higher than the original values.

In both cases acceptable parameter combinations were found, but the combinations of the two simulations did not overlap (Fig. 4). This implies that trees will no longer be capable of surviving at the present growing locations if the temparature regime is changed as assumed. The annual rhythm of trees probably does not change as radically as presented by the computations because Sarvas' model (1972, 1974) does not include the syncronizing effect of photoperiod (Koski & Selkäinaho 1985). The computations support, however, the claim that the annual growth rhythm of trees could change under changing environmental conditions. This will generate uncertainty inregard to the future functioning and structure of the forest ecosystem.

4. Silvicultural implications of the changing climate

4.1. Natural regeneration

The effects of the changing climate are most apparent on natural regeneration since the temperature conditions determines the maturation of seeds and affects the size of the seed crop through the formation of the generative organs, the flowering of trees and the formation of seeds after fertilisation (Table 2). The positive effects of the climatic change are probably enhanced by the excess precipitation and moist soil conditions which improve the germination of seeds and the establishment and growth of the seedlings.

The role of the improved temperature conditions can be evaluated on the basis of the model by Pukkala (1987) assuming that the temperature change affects the size of the seed crop and the maturation of seeds. The model comprehensively incorporates the results of the studies carried out in Finland concerning the relationships between the seed crop and the climatic conditions as follows

$$TAI(t) = S \cdot TM(t) \cdot TS \cdot TO \cdot PR \cdot OI. \qquad (1)$$

Table 2. Expected effects of the changing climate on the results of natural regeneration.

Subprocess	Temperature	Precipitation
Formation of seeds		
– Formation of generative buds	+	+
– Flowering and amount of pollen	+	–
– Pollen dispersal	+	–
– Fertilisation	+	?
– Maturation	+	+
Seed dispersal	+	–
Establishment		
– Germination	+	+
– Growth of germinants	+	+
Growth of seedlings	+	+
Mortality	–	+

Legend: + = positive effect and – = negative effect on the process, ? = difficult to evaluate.

In the model TAI(t) is the amount of seedlings (1 m^{-1}) born in the year t, S the size of the seed crop, TM(t) the amount of bare mineral soil (%) susceptible for seeding, TS the amount of fully developed seeds, TO the share of the mature seeds (%), PR the amount of seeds surviving pathogenous fungi and insects and OI the amount of seeds (%) germinated successfully. The size of seed crop and the amount of mature seeds are functions of temperature sum. The results based on the climatic conditions given in Fig. 1 are shown in Fig. 5.

Computations show that higher temperature could increase the probability of obtaining sufficiently dense (seedling number/ha > 2000) seedling stands at a proper time, particularly in northern Finland, but the effect is also recognisable in southern Finland. This could also be expected on the basis of empirical studies showing the seed crop and its quality at the Scandinavian timber line to be very dependent on temperature conditions (Hustich 1948, Mikola 1952, Koski & Tallqvist 1978, Henttonen et al. 1986).

4.2. Artificial regeneration

The problems of the changing climatic pattern regarding artificial regeneration are mainly problems concerning the selection the provenance of the local tree species, the introduction of exotic tree species and the survival of seedlings in plantations (Table 3). If the temperature rises, the selection of a *provenance* could represent a wider geographical variation than today. In fact, one can expect that the southern influence on the genetic structure of the tree populations could become more frequent than is now the case. Particularly, in southern and central Finland this would be due to the common gene flow from central Europe through the pollen dispersal. Similarly, it is possible that the temperature rise could make it possible to import a wider selection of *exotic* tree species with a lower risk to their survival than now exists.

The *survival* of seedlings seems to increase if the temperature conditions are improved as suggested by the positive relationship between the temperature and success of planting at high latitudes (Pohtila 1977). The increasing humidity associated with the temperature rise could, however, diminish the favourable effects of temperature since moist and warm climatic conditions support the spread of many pathogenic fungi. This is probably enhanced by excess snow accumulation. In particular, in northern Finland the risk of pathogenous fungi could be increased specifically by the excess snow accumulation.

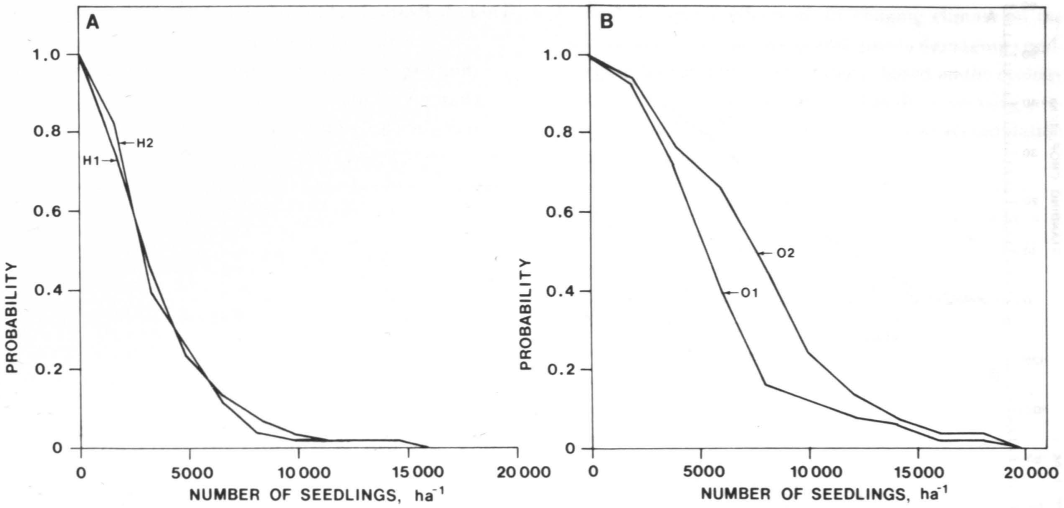

Fig. 5. Effect of changing temperature conditions on the success of natural regeneration in southern and northern Finland. Specifications for the computations: *Vaccinium* site (medium fertility) on sandy soil, parent trees 100 pines per hectare, dominant height of the parent trees 22 m, regeneration period 10 years (total time since seed tree cutting), soil treated with disk plough (percentage of bare mineral soil 10). Results are mean values of 50 separate model runs.

Table 3. Expected effects and results of the changing climate on planting and its results.

Subprocess	Temperature	Precipitation
Species selection		
– Origin of exotic species	More southern	More maritime
– Provenance of local tree species	More southern	More maritime
Establishment	Improved	Improved
Gorwth	Increased	Increased
Mortality	Decreased	Increased

The success of planting and the growth of seedlings are probably also affected by the enhanced growth of herbs and grasses. On nutrient rich sites, in particular, the productivity of herbs and grasses could be a great obstacle towards the successful establishment of seedlings and result in more investments being needed for establishing the competitive power of the seedlings. In particular, as compared with the present situation, more care of small seedlings should be taken in the future in coniferous plantations to eliminate the detrimental effects of other plant species.

4.3. Tending of seedling stands

The effects of the changing climate on the need to tend seedling stands are closely related to the tree species invading to regeneration areas, most problems probably occurring in the coniferous stands invaded by deciduous tree species. For example, the simulations of the succession of the tree stand under the changing climatic pattern show that decidu-

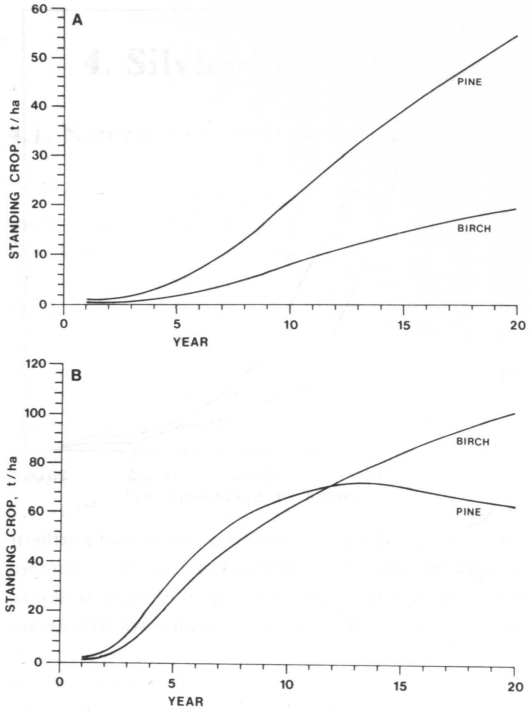

Fig. 6. Example of the impact of the climatic change on the co-existence of Scots pine and birch in the same stand. The simulation represents the condition given in Fig. 1 for Oulu. The density of the initial stand was 2000 pines and 1000 birches per hectare, the diameter of both species being one centimeter at the breast height. A: present situation. B: future situation.

ous tree species ought to be cut at higher temperatures and with more plentiful precipitation more often than under the present conditions, if the goal is to grow conifers on fertile sites (Fig. 6). Obviously, the climatic change will favor a tree species composition dominated by deciduous species. Similarly, the need to tend the seedling stands is probably increased by the competition of herbs and grasses which suppress seedlings at the initial phase, as discussed above.

4.4. Thinning

The accelerated growth of trees will result in a need for shorter intervals between thinnings and a greater thinning intensity at each thinning, otherwise the natural mortality of trees will be enhanced with a loss of production (Table 4). Consequently, the rotation of the forestry will be shorter with more output from the forest ecosystems in biological and monetary terms. Apparently, the shortening turnover of a biomass in the forest ecosystem will increase the use of nutrients and the risk of decreasing productivity in the long run unless the nutrient management of the site is specifically considered in the silvicultural management. This risk is also enhanced by the accelerated nutrient cycle and excess precipitation, which easily increase the nutrient loss through leaching.

Table 4. Example of the impact of the climatic change on the growth and mortality of trees when the same thinning pattern was applied under present and changing climatic conditions. The simulations represent the situation given in Fig. 1 for Oulu.

Scenario	Production and mortality, t/ha	Amount of mortality, % of total production
Present situation		
Net production	115	
Mortality	10	8
Total production	125	
Future situation		
Net production	248	
Mortality	48	16
Total production	296	

4.5. Risk of damages by fungi and insects

Higher temperature and increased precipitation could probably increase the risk of a tree dying earlier than in the present situation. This is due to the accelerated growth and maturation of the trees, which will shorten their lifespan and increase the probability of an *attack by pathogenous fungi and insects* in the early phases of the development of tree stands. Consequently, the natural rate of the death of trees will increase in the succession. This process could also be enhanced by changes in the populations of fungi and insects and the invasion of new pathogenous species related to the climatic change.

The implications of the climatic change in the form of the risk of attacks by fungi and insects are also connected with the amount of precipitation coming in the form of snow and the snow accumulation which affect the occurrence of fungi during the winter and the occurrence of snow-damaged trees susceptible to the fungal and insect attacks. The increasing precipitation is probably also associated with the increase in wind velocity blowing down trees and, thus, increase the size of populations of bark beetles and other organisms dependent on the occurrence of dying trees (Table 5).

The occurrence of fungi and insects in relation to the climatic change is not the same since most insects favour higher temperatures with decreased precipitation as opposed to fungi, which favour cool and moist weather conditions. For example the occurrence of epidemics of *Ascocalyx abietina* and *Melampsora pinitorqua* are preceded by cool and moist summers. The occurrence of epidemics of *Phacidium infestans* are related to the exceptionally great accumulation of snow. These damages could also be modified by the changing pattern of late and early frosts, probably taking place due to the changing climate.

Table 5. Expected effects of the chaging climate on the occurrence of some fungi and insects damaging conifers in boreal forests. The table is based on the ecology of these organisms assuming that the increasing precipitation also implies increasing snow accumulation and wind velocity.

Damaging organism	Temperature	Precipitation
Fungi		
Phacidium infestans	−	+
Melampsora pinitorqua	−	+
Heterobasidion annosum	+	+
Ascocalyx abietina	−	+
Insects		
Hylobius abietis	+	−
Neodiprion sertifer	+	−
Ips spp.	+	+
Tomicus spp.	+	+

Legend: + = increasing risk, − = decreasing risk.

5. Conclusions

Silvicultural management of the forest ecosystem could be defined as a control mechanism for making the ecosystem to produce items desired in forestry. The management procedure is closely incorporated into the successional process of the forest ecosystem as determined by the regeneration, growth and death processes of trees. Thus, the silvicultural implications of the changing climate could be evaluated only if the effects of the changing climate on the processes of the forest ecosystem are known.

As far as forest regeneration is concerned, one could expect that the changing climate could improve the establishment of seedlings in plantations and areas regenerated naturally. In northern Scandinavia this could allow the timber line to move further north. The rising precipitation could also support the regeneration process, if the seedling stands are treated properly after the establishment of the seedlings.

From the stand point of growth and yield it could be expected that the effects of the changing climate could be beneficial and increase the productivity of the forest ecosystem. This is due to the increase in the growth of the local tree species and the improved possibilities for introduce exotic tree species of high productivity. The improved productivity of the forest ecosystem will emphasize the need for regular and frequent thinnings in the future management of the forest ecosystem. Obviously, special care should also be taken in regard to the nutrient management of the forest sites.

The increased productivity of the forest ecosystem could, however, be associated with a great uncertainty, since the temperature rise could change the annual growth rhythm of the local tree species. For example, the temperature rise in autumn and winter could result in considerable dehardening in local tree species, even flushing and subsequent frost damages. The risk of early autumn frost damages could, however, decrease since the length of the period for the autumn hardening is increased.

The changing climate will also change the populations of pathogenic fungi and insects to which the local tree species are adapted. Therefore it is possible that changing climate could give rise to more epidemics of fungi and insects and increasing loss of growth and yield. Thus, it is possible that future management of the forest ecosystem will need to place greater emphasis than is now the case on the pest management integrated with all the phases of the silvicultural management of the forest ecosystem. Warm and moist conditions near the ground could, in particular, enhance the spread of fungi and other organisms capable of damaging seedlings in the initial phase.

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