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Comparison of thinning methods in a Scots pine stand on drained peatland. A simulation study.

Harvennusmenetelmien vertailu ojitetun turvemaan männikössä. Simulointitutkimus.

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The post-drainage growth of a simulated model stand according to different thinning methods was predicted for 84 years by spatial single-tree growth models. In thinnings, the post-thinning stand density varied as a function of the distance of the ditch. The best yield and income were obtained by leaving the stand near ditches and extraction road midway between ditches denser than elsewhere.

Keywords: growth model, *Pinus sylvestris*, stand management

INTRODUCTION

There are many single-tree growth models for pure and mixed stands of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula pendula* and *B. pubescens*) on mineral soils (e.g., Adlard 1974, Mielikäinen 1978,1980, Pukkala 1989b, Pukkala and Kolström 1991, Pukkala et al. 1994) but only a few for drained peatlands (Saramäki 1977, Hånell 1988, Miina et al. 1991, Miina 1994). There are many differences between forest stands on uplands and drained peatlands: e.g., ditches create high and systematic spatial variation in growing conditions, peatland stands are generally all-aged and all-sized stands, and the spatial distribution of trees on peatlands is often clustered.

Trees revive and grow quicker the closer they are to a ditch (Lukkala 1929). This is because of wider growing space and better aeration of the substrate which results in more rapid decomposition of organic matter. A spatial growth model for a drained peatland forest should account for the growth variation due to the distance between trees and, in addition, distance to the ditch and the time since drainage.

Nowadays, thinning models of upland forests are applied also to peatland forests assuming that the sites are of similar fertility. However, due to the better growing conditions near ditches it may be profitable to leave more trees near the ditches than elsewhere in the thinning (Miina et al. 1991, Miina 1994). So far, long-term growth predictions for different thinning regimes have not been done with non-spatial or spatial models. The need for calculations is essential because more than 75% of drained and 60–70% of all peatland stands on forest land are at the stage of the first commercial thinning or are about to reach this stage (Keltikangas et al. 1986, Paavilainen and Tiihonen 1988).

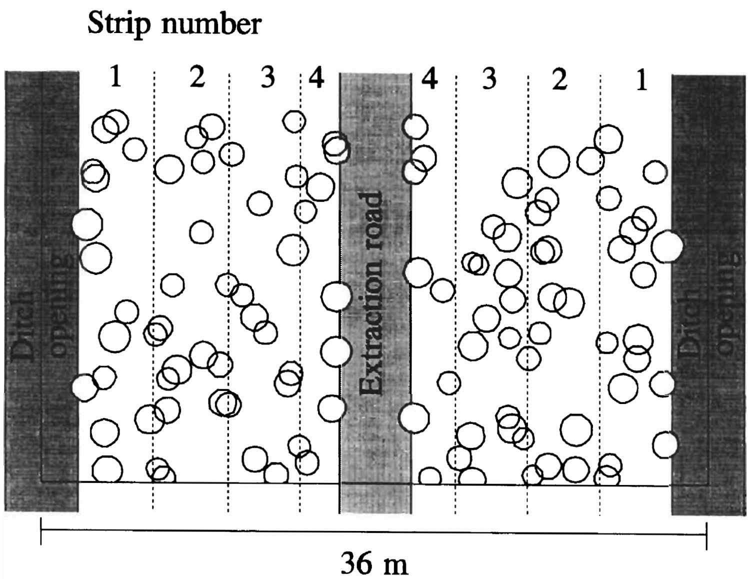

Fig. 1. The model stand was a 36 m wide rectangular plot between two adjacent ditches. The ditch lines were 4 m wide. A 4 m wide extraction road was cut in the first thinning. The remaining basal area was defined separately for 4-m strips parallel to the ditches.

Kuva 1. Mallimetsikkö oli 36 metrin levyinen koeala, joka rajoittui kahteen ojaan. Ojalinjojen leveys oli 4 m. Ensimmäisessä harvennuksessa saran keskelle hakattiin 4 metrin ajoura. Jäävä pohjapinta-ala annettiin erikseen ojan suuntaisille 4 metrin kaistoille.

The study aimed at analyzing the effect of thinnings on the yield of a Scots pine stand on drained peatland. Spatial growth models were used to predict the growth of a simulated stand. The calculations covered the whole rotation. The stand was thinned according to different principles by letting the post-thinning stand density vary as a function of the distance from the ditch.

SIMULATION MODEL

Model stand

The model stand used in calculations was simulated by a method that predicts tree diameter from stand characteristics and the locations of neighbour trees (Pukkala 1989a; Eqn 10). The stand was 60 m wide in direction of the ditches and 36 m wide in direction perpendicular to the ditches. Tree coordinates were generated by a Poisson process with a hard core of 0.3 m.

After producing tree coordinates and dimensions, all trees were removed from 4 m wide ditch lines, 36 m apart (Fig. 1). The tree height was computed with the model of Pukkala (1989b; Eqn 14). Pulpwood, sawtimber and total stem volume were computed with the taper curve model of Laasasenaho (1982). No deductions due to defects were made.

The number of stems of the model stand, after cutting the ditch lines, was 1778 trees ha^{-1}, stand basal area 4.0 m^{2}ha^{-1}, and stand volume 12.4 m^{3}ha^{-1}. The mean diameter and age were 5.8 cm and 26 years, respectively. The diameter of trees varied between 3.3 and 7.6 cm. Thus, the model stand corresponds to a young, naturally regenerated pine stand on recently drained peatland of rather poor fertility.

Growth models

During the first 14 years after drainage, the growth of the model stand was calculated by the model of Miina (1994). This spatial model accounts for the variation in diameter growth due to the competition between trees, distance of ditch, and time since drainage:

$$i_d = f(g, t, CI, s, DIST, DRAIN, G) \quad (1)$$

in which i_d is annual diameter growth, g is tree basal area, t is tree age, CI is competition index, s is relative size of the subject tree, $DIST$ is distance of the nearest ditch, $DRAIN$ is number of years since draining, and G is stand basal area.

After the period of 14 years, tree growth was predicted with the model by Miina et al. (1991). With this model, basal area growth is first predicted using a spatial single-tree growth model prepared for mineral soils in even-aged stands. The prediction is then adjusted on the basis of the adverse effect of ground water (Fig. 2). The distance to the ground water table is calculated from the local stand volume and the distance of the nearest ditch.

The height growth was calculated by the model of Ojansuu et al. (1991). The model has been prepared for mineral soils.

The used growth models are the most reliable on rather poor sites because the models are based on the material collected in stands representing poor site fertility. Thus, the growth predictions of the model stand correspond to the growth of Scots pine stand on a drained dwarf-shrub pine mire.

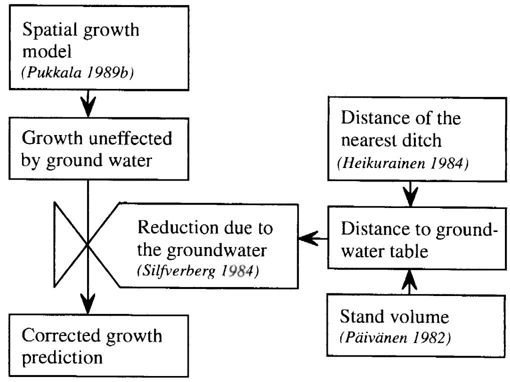

Fig. 2. Steps in the calculation of growth prediction with the model of Miina et al. (1991). The mentioned studies have been used in the formulation of the sub-models.

Kuva 2. Kasvuennusteen laskenta Miinan ym. (1991) mallilla. Mainittuja tutkimuksia on käytetty osamallien laadinnassa.

Thinning model

The area between ditch openings was divided into 4-m-wide strips, parallel to the ditches, to define the post-thinning stand density as a function of the distance of the ditch. Because of the symmetry, the number of strips with different stand density was four. In the first thinning, a 4-m-wide extraction road was cut midway between two adjacent ditches (Fig. 1). Thus, the strips along the extraction road were only 2 m wide after the first thinning.

The post-thinning stand basal area and the relative basal areas were defined for each strip. When simulating thinning, a tree was removed from that strip on which the basal area exceeded most the target basal area. For example, if the relative remaining basal areas of the strips were defined to be 1.0, 1.0, 1.0 and 1.0, i.e., the post-thinning basal area was the same on every strip, a tree was removed from the strip with the highest basal area. On the selected strip, the tree with the smallest relative growing space was removed (Isomäki and Niemistö 1983). Trees were removed until the post-thinning basal area of the stand was achieved.

Stumpage prices

The stumpage prices used in the study were those of the cutting season 1990/91, when the prices of pine sawtimber and pulpwood were 225 and 100 FIM m^{-3}, respectively. The stumpage prices were adjusted on the basis of average size of removed stems and total volume removed per hectare. The stumpage price adjustments were obtained from the stumpage price agreement for the cutting season 1990/91.

SIMULATION EXPERIMENTS

Thinning methods

The growth of the model stand was simulated for 84 years. In each case, two thinnings and a clearcut were simulated at the ages of 65, 90 and 110 years, respectively. The first thinning was simulated with the dominant height of 12.3 meters (basal area 19.5 m^2ha^{-1}). The extraction road was cleared and the stand was thinned to a remaining basal area of 13.5 m^2ha^{-1}. At the time of the second thinning the dominant height was 14.6 m and the basal area about 22 m^2ha^{-1}. The stand was thinned to a remaining basal area of 16.0 m^2ha^{-1}. Before the clearcut, the basal area was about 22 m^2ha^{-1}.

The stand was thinned according to the following methods, which were applied in both

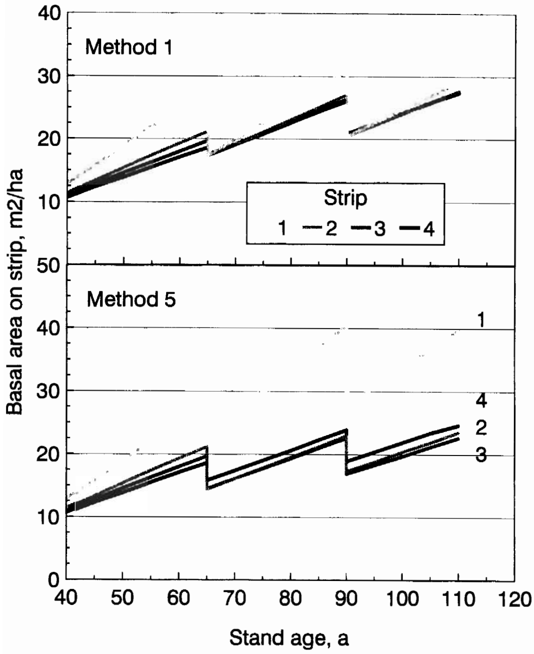

Fig. 3. Basal area on 4-m-wide strips with thinning methods 1 and 5. With method 1, the remaining basal area is the same on all strips. Method 5 is the most productive. Strips 1, 2, 3 and 4 are 2–6, 6–10, 10–14 and 14–18 m away from the ditch, respectively.

Kuva 3. Pohjapinta-ala neljän metrin levyisillä kaistoilla harvennusmenetelmissä 1 ja 5. Menetelmässä 1 jäävä pohjapinta-ala on sama kaikilla kaistoilla. Menetelmässä 5 kokonaistuotos on suurin. Kaistat 1, 2, 3 ja 4 ovat 2–6, 6–10, 10–14 ja 14–18 metrin etäisyydellä ojasta.

thinnings (Fig. 3).

(0) Thinning without strips.
(1) Post-thinning basal area is the same on every strip (Relative basal areas: 1.0–1.0–1.0–1.0).
(2) Post-thinning basal area decreases from the ditch border towards the midway between ditches (1.7–1.4–1.2–1.0).
(3) Post-thinning basal area decreases from the ditch border towards the midway between ditches (2.0–1.2–1.1–1.0).
(4) Post-thinning basal area increases from the ditch border towards the midway between ditches (1.0–1.1–1.2–1.6).
(5) Post-thinning basal areas near ditches and extraction roads are higher than elsewhere (1.6–1.0–1.0–1.1).

Results

The best total removal was obtained with method 5, which left the growing stock near ditches and extraction road denser than elsewhere (Table 1, Fig. 3). Method 5 produced about 7% more sawtimber than method 1, in which the post-thinning basal area was constant between ditches (Table 1). In method 0, the realised relative basal areas were 1.5–1.0–1.0–1.2 after both thinnings. Therefore, the results of method 0 and 5 were quite similar. Removal was the lowest with method 4, in which the growing stock near ditches was thinned more heavily than elsewhere.

The present value of a thinning method at the time of drainage was calculated with 0% and 3% discounting rates. In both cases, the highest present value was obtained with method 5 and the lowest with method 4 (Table 1).

The use of lower stumpage prices corresponding to the cutting season 1992/93 (sawtimber 190 FIM m^{-3} and pulpwood 66 FIM m^{-3}) did not affect the ranking of the thinning methods.

DISCUSSION

Validity of the models

The study was based on two spatial single-tree growth models discussed in more detail in the studies of Miina et al. (1991) and Miina (1994). The model used first (Miina 1994) predicted the revival of tree growth after drainage, whereas the other model (Miina et al. 1991) predicted the tree growth in an old drainage area. The models predict the effect of the spatial distribution of trees, and growth variation due to the distance of ditches and extraction roads. The effect of thinning on the tree growth is taken into account through the competition index of the growth model: the thinning decreases the competition between trees and the basal area of stand. The effect of rising groundwater table after thinning is also taken into account by the model.

In the model of Miina et al. (1991), the groundwater depth is predicted by the distance of ditch and the local stand volume. The groundwater depth is affected also by weather conditions, peat properties, gradient of the ground surface, ditch condition, etc., which were not accounted for. Ditches were assumed to be kept fully effective but the maintenance costs were ignored.

The effect of groundwater table on the tree growth was estimated from the results obtained on over 100 years old stands in which the mean diameter and dominant height were about 11 cm and 8 m, respectively (Huikari and Paarlahti 1967). In simulations, the estimated relationship between the groundwater table and the tree growth was assumed to be similar through the whole rotation.

Logging damages to the remaining trees and deductions due to defects were ignored although they may be more important in peatlands than in upland forests. Tree growth and timber price were assumed to be deterministic, and timber price was constant over time.

The self-thinning model of Hynynen (1993), prepared for stands on mineral soils, was used to predict the mortality caused by competition between trees, but the self-thinning boundary was never reached. The mortality model describes the relationship between the maximum number of stems and mean diameter. Because the stand density between ditches varied due to different thinning intensities of strips, it would be better to determine the self-thinning boundary separately for each strip, and not for the whole stand.

Results

The model stand used in simulations differs from the typical uneven-aged and all-sized stands on peatland. Even-aged Poisson stand was used in simulations to see clearly the effect of thinning method on the yield of Scots pine stand. The other reason is that the growth models are valid only for even-aged stands. Thus, the results are valid for young pine stands which are naturally regenerated before drainage.

The average post-drainage growth of the model stand was about 2.7 $m^3ha^{-1}a^{-1}$. The stand growth, especially at the end of rotation, was lower than presented for dwarf shrub type by e.g. Keltikangas et al. (1986). Because no results from thinning experiments on drained peatland

Table 1. Removal and incomes with six different thinning methods. See the text for explanation of thinning methods.

Taulukko 1. Harvennus- ja avohakkuupoistuma sekä -tulot kuudella eri harvennusmenetelmällä. Harvennusmenetelmät on kuvattu tekstissä.

	Thinning method — *Harvennusmenetelmä*					
	0	1	2	3	4	5
Removal, m^3ha^{-1}						
Poistuma, m^3ha^{-1}						
1. thinn. — *1. harv.*	31.5	31.9	31.2	31.2	32.4	31.2
2. thinn. — *2. harv.*	38.8	37.1	38.2	38.4	35.8	39.0
Clearcut — *Avohakkuu*	158.1	157.7	159.5	160.0	156.5	159.9
Total — *Yhteensä*	228.4	226.7	228.9	229.6	224.7	230.1
Sawtimber removal, m^3ha^{-1}						
Tukkipuupoistuma, m^3ha^{-1}						
Total —*Yhteensä*	118.0	112.1	116.4	115.6	107.8	119.8
Net present value, FIM ha^{-1}						
Nykyarvo, mk ha^{-1}						
0% discounting rate	38474	37556	38348	38302	36793	38873
3% discounting rate	3078	3026	3053	3035	2996	3087

are available it is difficult to evaluate the reliability of the thinning simulations conducted in this study. Hånell (1988) calculated the productivity of a peatland forest by simulating the post-drainage stand development. The post-drainage development of the stand volume and increment, as simulated in this study, is in accordance with that presented for dwarf shrub type by Hånell (1988).

According to the simulations, it is advisable to leave the remaining growing stock near ditches and extraction roads denser than elsewhere. The most productive thinning schedule is shown in Figure 3. In the first thinning, the growing stock near ditches was thinned more lightly and in the second thinning more heavily than elsewhere which results in reasonable removal from both thinnings and a high production of sawtimber.

It is probable that the post-thinning basal areas used in this study are not optimal. The relative basal areas, which were the same in both thinnings, were chosen mainly to illustrate the spatial aspect of the thinning of a peatland forest rather than to find out the optimal thinning schedule. An optimization algorithm combined with the growth simulator of this study may be used to determine the optimum management schedule for Scots pine stand on drained peatland (e.g., Valsta 1992).

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TIIVISTELMÄ:

Harvennusmenetelmien vertailu ojitetun turvemaan männikössä. Simulointitutkimus.

Tutkimuksessa tarkastellaan harvennuksin käsitellyn männikön tuotosta ojitetulla turvemaalla. Tulokset perustuvat spatiaalisilla puun kasvumalleilla mallimetsikölle tehtyihin simulointeihin. Simuloinneissa käytettiin tasaikäisrakenteista, tilajärjestykseltään satunnaista metsikköä, jotta harvennuskäsittelyn vaikutus saatiin selvemmin esille.

Mallimetsikkö harvennettiin 65 ja 90 vuoden iällä ja avohakattiin 110 vuoden iällä. Ensimmäisen harvennuksen jälkeen metsikön pohjapinta-ala oli 13,5 m^2ha^{-1} ja toisen 16 m^2ha^{-1}. Metsikölle simuloitiin kuusi erilaista harvennuskäsittelyä siten, että jäävän puuston pohjapinta-ala vaihteli ojaetäisyyden mukaan. Paras tuotos ja parhaat kokonaishakkuutulot saatiin harvennuskäsittelyllä, jossa jäävän puuston pohjapinta-ala oli korkeampi ojan ja keskisaralla sijaitsevan ajouran varrella kuin muualla saralla. Myös suurin tukkipuumäärä kiertoajan aikana saatiin ko. harvennuskäsittelyllä.

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