# Impacts of Different Thinning Regimes on the Yield of Uneven-Structured Scots Pine Stands on Drained Peatland

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Drained peatlands in northern Europe comprise more than 10 million ha of forestland and thus constitute a considerable production potential in forestry. Much of this area consists of stands dominated by Scots pine and close to maturity regarding commercial thinning. The trees within these stands typically vary in terms of age, size, and growth rate. The impacts of silvicultural cuttings on these uneven-structured stands are inadequately known. We simulated the impacts of a control regime with no thinnings, and three different thinning regimes, involving different thinning intensities, on the development of fifteen pine-dominated stands in Finland. The simulations started from the first thinnings and were continued until regeneration maturity. The predicted total yields ranged from 244 to 595 $m^3ha^{-1}$, depending on site and thinning regime. The highest total yields were observed for the control regime in which 18–38% of the yield was, however, predicted to self-thin by the end of the simulation. Thus, the differences in the yields of merchantable wood were fairly small among the compared regimes. However, the regimes involving thinnings generally needed less time than the control regime to reach regeneration maturity. The mean annual increment of total stem volume was at its highest in the control regime. The highest mean annual increment of merchantable wood was obtained in the regime involving two moderate thinnings, but excluding the most low-productive sites where thinnings did not increase the yield of merchantable wood.

**Keywords** *Pinus sylvestris*, peatland forestry, silviculture, intermediate cuttings, growth and yield, stand structure

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# 1 Introduction

Drained peatlands comprise more than 10 million ha of forest land in northern Europe thus forming a considerable potential for production forestry. Much of this area consists of forests dominated by Scots pine (*Pinus sylvestris* L.) and close to maturity regarding commercial thinnings. In Finland alone, annual cutting removals mainly from thinnings in peatland stands may increase up to 15–20 million m$^3$ in the course of the next twenty years (Nuutinen et al. 2000).

Peatland stands typically include trees varying in terms of age, size, and growth rate due to the pre-drainage site conditions and stand properties, and post-drainage stand dynamics. Prior to drainage, the sites are characterized by high water levels and, consequently, sparse and spatially clumped tree stands with low levels of stocking and growth (Heikurainen 1971, Gustavsen and Päivänen 1986, Hökkä and Laine 1988). Following drainage, the growth rate of individual trees considerably increases (Seppälä 1969, Hökkä et al. 1997). This, together with the ingrowth of new trees, results in increased stocking (Keltikangas et al. 1986, Hånell 1988, Laiho and Laine 1997, Gustavsen et al. 1998, Hökkä and Penttilä 1999, Minkkinen et al. 2001) and inter-tree competition (Miina 1994, Penner et al. 1995). However, depending on site productivity, the stands tend to retain features of horizontal and vertical heterogeneity for several decades (Hökkä and Laine 1988, Hökkä et al. 1991, Sarkkola et al. 2004).

Two principal approaches may be possible in the management of drained peatland forests, i.e. 1) conscious maintenance and enhancement of the initial uneven structures by applying selection cuttings, and 2) applying a stand management system whereby thinnings can be feasible and final fellings are applied when the stands reach regeneration maturity. Currently, the management of peatland stands is generally based on applying standwise silvicultural thinnings, followed by a distinct regeneration phase involving a clear cut or some other regeneration cutting that dramatically reduces stand stocking and thus removes the main part of the yield. Thinnings are used to control inter-tree competition and to concentrate growth on fewer crop trees with the desired results of decreased self-thinning and increased yield and value of timber in the retained stand.

The impacts of thinnings on peatland stands are inadequately known, however. The aim of this study was to examine the structure, development and yield of pine stands initially uneven in structure and managed applying different thinning regimes. Our approach was to adjust the suggested management regimes to the currently prevailing stand management system within the constraints determined by the guidelines for production forestry in Finland (Hyvän metsänhoidon... 2001). Thus, the maintenance of uneven stand structures was not the primary management goal; on the other hand, neither was deliberate reduction of unevenness. The study was based on simulating the development of experimental stands by using a forest stand simulator with specific models for peatland forests. It was also possible to evaluate the simulation results using field data from two subsequent 5-year periods following the first treatments.

The study was part of a project called “Quality and Yield of Pulpwood in Drained Peatland Forests”, which was aimed at quantifying the variation in wood, fibre and pulp properties (Varhimo et al. 2003, Rissanen 2003) and yield in peatland stands, and at evaluating the relevance of the current guidelines for silviculture on drained peatland sites regarding their production potential and/or the quality of wood produced.

# 2 Material and Methods

The study sites were selected from a set of stands initially meant to be treated with commercial thinnings by the forest owners (i.e. the Finnish Forest Research Institute [Metla], the Finnish Forest and Park Service, Stora Enso, and non-industrial private owners). Metla had set up thinning experiments in these stands in the years 1987–1993. We selected fifteen sites representing oligotrophic to mesotrophic peatland forest types (i.e. almost the entire range of site types generally managed for pine) on areas drained for forestry in 1934–1973, and representing climatic regions from south-boreal to mid-boreal (Table 1). The stands were dominated by Scots pine and included

**Table 1.** Study site properties.

| Stand | Location N | Location E | Temp. sum, d.d. [a)] | Site type [b)] | Peat depth, m | First ditched | $H_{dom}$, m [c)] | Basal-area, [d)] $m^2ha^{-1}$ | SB-mix, % [e)] |
|---|---|---|---|---|---|---|---|---|---|
| Site group A, <900 d.d., medium-productive sites | | | | | | | | | |
| 5922 Pelkosenniemi | 67°17’ | 27°44’ | 769 | MT2 | >1 | 1969 | 12 | 18 | 2 |
| 5923 Pelkosenniemi | 67°17’ | 27°42’ | 761 | MT2 | >1 | 1969 | 11 | 21 | 4 |
| 5949 Kittilä | 67°22’ | 24°39’ | 776 | MT2 | 0.9 | 1971 | 9 | 14 | 6 |
| 5932 Rovaniemi | 66°21’ | 26°38’ | 862 | VT2–MT2 | 0.2–1.0 | 1934 | 11 | 12 | 0 |
| Site group B, 900–1025 d.d., medium-productive sites, low level of stocking | | | | | | | | | |
| 5953 Pudasjärvi | 65°41’ | 27°19’ | 905 | MT2 | 0.7–1.0 | 1937 | 13 | 20 | 13 |
| 5956 Puolanka | 64°49’ | 27°22’ | 939 | MT2 | 0.4–1.0 | 1967 | 13 | 20 | 2 |
| 5944 Simo | 65°47’ | 25°19’ | 962 | MT2 | 0.2 | 1961 | 12 | 16 | 36 |
| 5955 Kuhmo | 64°04’ | 29°20’ | 967 | VT1 | 0.1 | 1963 | 15 | 23 | 32 |
| 5945 Kuivaniemi | 65°34’ | 25°28’ | 982 | VT2 | 0.2–0.5 | 1957 | 13 | 20 | 20 |
| Site group C, 900–1025 d.d., medium-productive sites, high level of stocking | | | | | | | | | |
| 5960 Yli-Ii | 65°25’ | 25°41’ | 1000 | MT2 | >1 | 1939 | 16 | 30 | 18 |
| 5954 Yli-Ii | 65°21’ | 25°51’ | 1020 | VT2 | 0.3 | 1939 | 15 | 29 | 44 |
| Site group D, 1026–1150 d.d., medium-productive sites | | | | | | | | | |
| 5958 Pyhäjärvi | 63°38’ | 25°42’ | 1039 | VT2–MT2 | 0.6–1.0 | 1973 | 12 | 20 | 19 |
| 5770 Kannus | 63°60’ | 23°51’ | 1068 | VT1 | 0.2 | 1954 | 15 | 24 | 33 |
| Site group E, 1026–1150 d.d., low-productive sites | | | | | | | | | |
| 5916 Viitasaari | 63°16’ | 25°59’ | 1050 | DsT | 0.2–0.8 | 1958 | 14 | 20 | 0 |
| 7164 Ruovesi | 61°51’ | 24°16’ | 1127 | DsT | >1 | 1967 | 12 | 13 | 2 |

[a] Cumulative annual temperature sum with +5°C as threshold value

[b] Peatland forest site types according to Laine (1989): MT2 = *Vaccinium myrtillus* type 2 [Mtkg(II) in the Finnish nomenclature]; VT1 = *Vaccinium vitis-idaea* type 1 [Ptkg(I)]; VT2 = *Vaccinium vitis-idaea* type 2 [Ptkg(II)]; DsT = Dwarf-shrub type [Vatkg].

[c] Average dominant height of growing stock at the onset of the simulation in unthinned control stands

[d] Stand basal area at the onset of the simulation in unthinned control stands

[e] Proportion of spruce and birch of stand volume at the onset of the simulation in unthinned control stands

varying admixtures of pubescent birch (*Betula pubescens* Ehrh.) and Norway spruce (*Picea abies* (L.) Karst.) (Table 1). All stands had been treated with pre-commercial thinnings at an earlier stage of stand development. The basis for selecting the sites was that the true development of the stands on these sites after different thinning treatments had been monitored for ten years, making it possible to evaluate the validity of the simulations to some extent.

We arranged the sites into groups according to climatic location: Northern, Central, and Southern depending on the accumulated temperature sum: <900, 900–1025, 1026–1150 d.d., respectively. The northern group (<900 d.d.) was fairly homogeneous in terms of site type and stand stocking. The sites in central Finland however, were further divided into sub-groups due to differences in stocking (basal area), and the sites in southern Finland according to site type (Table 1). Post-drainage site types were determined according to Laine (1989).

When setting up the thinning experiments, the initial tree stands had been thinned to different levels of growing stock by applying the following treatments: 1) unthinned control, 2) light thinning, 3) moderate thinning, and 4) heavy thinning. In the following, these first treatments are referred to as ‘experimental thinnings’. They were applied in randomized blocks with 2–4 replicated experimental plots per treatment and site. After moderate thinning, the retained stand density, in terms of stem number or basal area in relation to stand dominant height, was similar to that recommended in the present guidelines for an upland pine stands of similar stand properties and site productivity (Hyvän metsänhoidon... 2001). Light and heavy thinning left the retained stand 30% denser or sparser, respectively. The experimental thinnings were designed to reduce stand density especially in clumps so that thinnings decreased horizontal rather than vertical heterogeneity. The

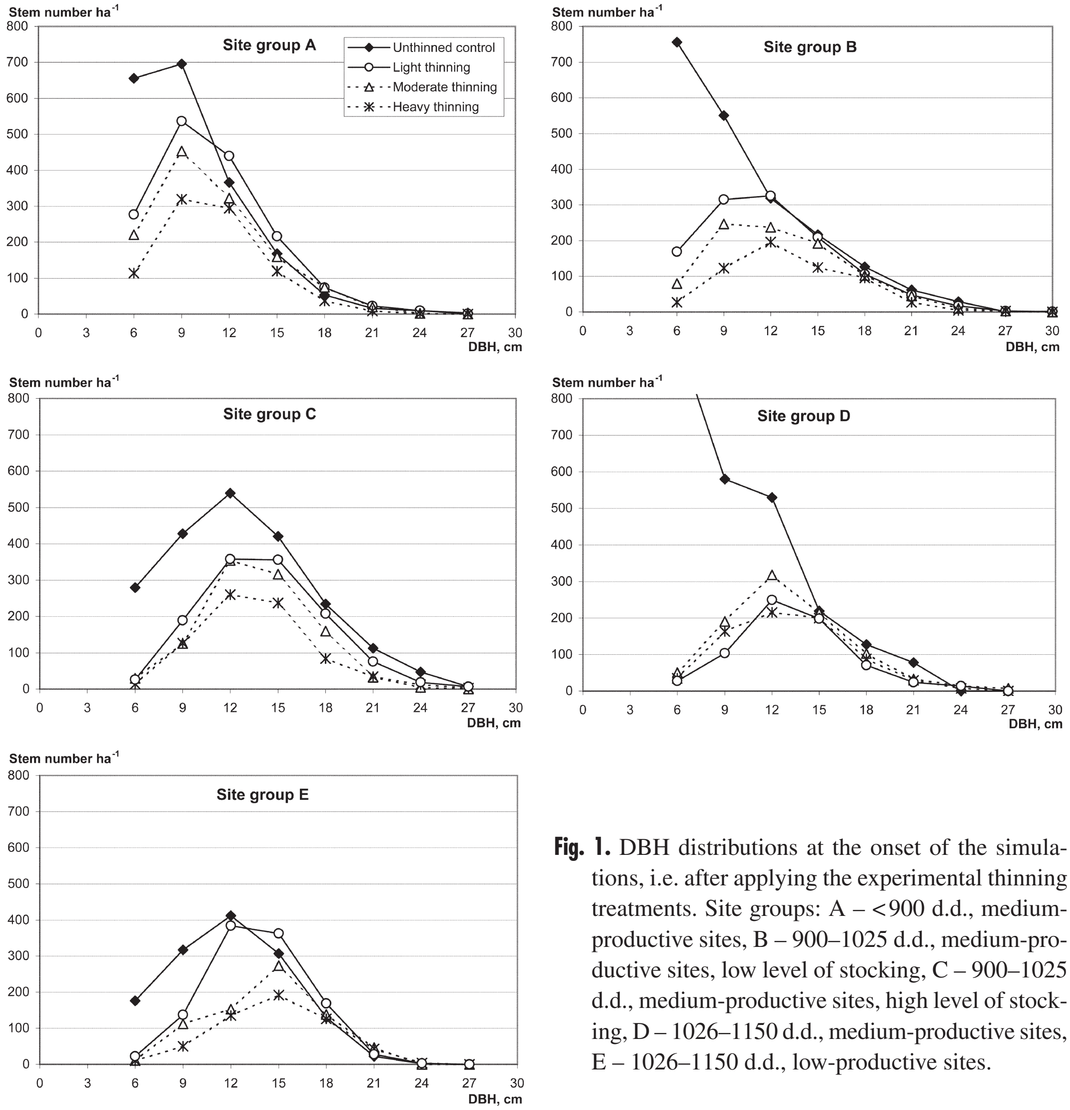

**Fig. 1.** DBH distributions at the onset of the simulations, i.e. after applying the experimental thinning treatments. Site groups: A – <900 d.d., medium-productive sites, B – 900–1025 d.d., medium-productive sites, low level of stocking, C – 900–1025 d.d., medium-productive sites, high level of stocking, D – 1026–1150 d.d., medium-productive sites, E – 1026–1150 d.d., low-productive sites.

selection of the retained trees was based on favoring individual pines possessing good external stem quality and applying thinning from below when selecting from otherwise similar candidates. The stand structures, in terms of distributions of diameter at breast height (DBH) after applying the experimental thinnings, are described in Fig. 1.

We simulated stand development according to four thinning regimes (Table 2, Fig. 2), starting from the stage where the experimental thinnings had just been applied. The average stand volumes at the onset of the simulations ranged from 44 to 202 $m^3ha^{-1}$, depending on site group and thinning regime (Table 2). The ‘control regime’ (I), applied to the unthinned stands, involved no stand management at all. Following the experimental thinnings (light in Regime II, moderate in Regime III, and heavy in Regime IV), Regimes II and III involved a moderate thinning, II at the phase when the stand basal area had exceeded the thinning limit by 30% and III at the phase when the stand density met the thinning limit. Regime IV, in turn, involved another heavy thinning at the phase when the thinning limit was met again. In some

**Table 2.** Average growing stock, $m^3ha^{-1}$, at the onset of the simulations, by site group and thinning regime.

| Site group [a)] | Thinning regime [b)] I | II | III | IV |
|---|---|---|---|---|
| A | 79.1 | 82.0 | 63.0 | 43.6 |
| B | 108.7 | 88.4 | 75.8 | 53.3 |
| C | 202.0 | 139.4 | 103.5 | 75.1 |
| D | 125.1 | 110.8 | 88.4 | 68.7 |
| E | 100.6 | 110.3 | 81.5 | 66.6 |

[a] See Table 1

[b] I – Control regime with no thinnings
II – Light thinning + delayed moderate thinning
III – Moderate thinning + moderate thinning
IV – Heavy thinning + heavy thinning

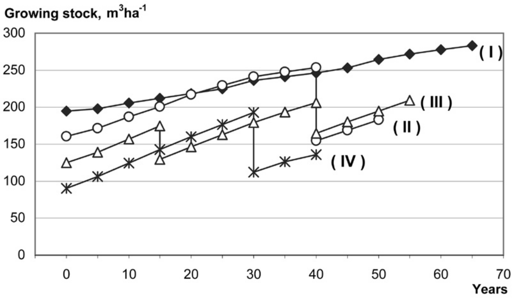

**Fig. 2.** An example of applying the different thinning regimes in the simulations of stand development. Thinning regimes: I – Control regime with no thinnings, II – Light thinning + delayed moderate thinning, III – Moderate thinning + moderate thinning, IV – Heavy thinning + heavy thinning.

stands in Regime III, a third moderate thinning was applied if the thinning limit was met again before regeneration maturity, and in some cases the second thinning for Regimes II and IV could not be applied. The thinning limit refers here to a site-type-specific relation of stand basal area to stand dominant height as defined in the silvicultural guidelines (Hyvän metsänhoidon... 2001), corresponding approximately to 70% of the self-thinning limit of Scots pine according to Hynynen (1993). For the site in Ruovesi (#7164 in Table 1), only the control regime was simulated as there had been a delay of several years in the application of the experimental thinnings on this site, and the site in Kittilä (#5949 in Table 1) lacked light experimental thinning and, consequently, the simulation according to Regime II.

The simulated thinnings reduced the stocking of all tree species and trees in all DBH-classes equally, with only a very slight tendency towards thinning from below. In all stands and regimes, the simulations were continued until the stand reached regeneration maturity, i.e. basal-area-weighted mean DBH of 24–27 cm, depending on site type, which is the regeneration criterion generally used for peatland stands (Hyvän metsänhoidon... 2001). An example of the development of stand structure is shown in Fig. 3. In addition to the stand management options, ditch network maintenance and its positive impact on tree growth were included in the simulations of all regimes, as this would correspond to standard Finnish peatland forestry practices on most sites.

We performed the simulations using the stand simulation software MOTTI (Salminen and Hynynen 2001) developed in Metla. For peatland stands, the MOTTI simulator applies distance-independent, individual-tree basal-area growth models by Hökkä et al. (1997), height-diameter models by Hökkä (1997), and tree-mortality models by Jutras et al. (2003). Tree basal-area growth responses to thinning and to ditch network maintenance are accounted for as in Hökkä et al. (1997). The need for ditch network maintenance was predicted using the model by Hökkä et al. (2000). MOTTI applies a 5-year time step in the simulations. For more details about the functioning of the growth and mortality models included in MOTTI, see Hynynen et al. (2002).

The DBH distributions (including trees with DBH ≥ 45 mm) for each site and regime, required for the simulations of stand development, were obtained from data collected from the experimental stands. The measured heights of sample trees, representing the entire DBH distribution on each plot, were provided for the simulation software for computations of the average heights for the trees in each 1-cm DBH-class.

The simulated fellings (including the growing stock at the end of the simulation period) were divided into sawlogs, pulpwood, and wastewood based on stem dimensions. Predicted self-thinnings were included in the total yield. For sawlogs, the minimum top diameters were 15 cm for pine and 17 cm for spruce. Birch sawlogs were not considered because of the generally poor

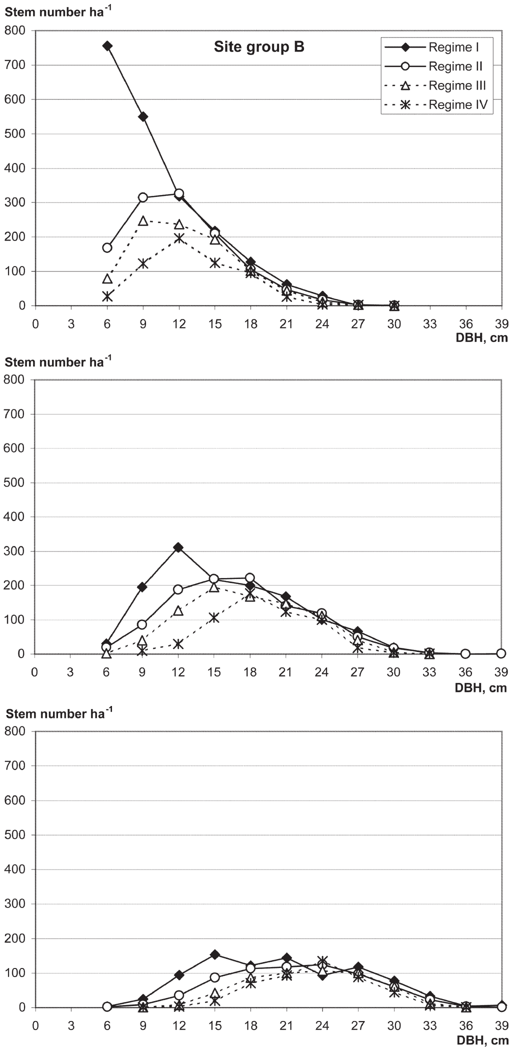

**Fig. 3.** DBH distributions in different stages of simulated stand development for site group B. Top: At the onset of the simulations, i.e. after the experimental thinning; Middle: Half-way between the onset of the simulations and regeneration maturity; Bottom: At the stage of regeneration maturity. Thinning regimes: I – Control regime with no thinnings; II – Light thinning + delayed moderate thinning; III – Moderate thinning + moderate thinning; IV – Heavy thinning + heavy thinning.

technical quality of pubescent birch on peatlands (Verkasalo 1997). The length of the pulpwood logs was set at three meters and the minimum top diameters were 7 cm for pine and birch and 8 cm for spruce. An average correction factor, based on the national forest inventory (NFI) data, was used to include part of the sawlog volume as pulpwood because in practice part of harvest having sawlog dimensions is of unacceptable quality.

To facilitate ranking of the different regimes within the site groups regarding the considerations generally used in production forestry, we calculated the mean annual increment of total stem volume ($MAI_{tot}$) and the merchantable stem volume ($MAI_{merch}$), over the period from first ditching to regeneration maturity as follows:

$$MAI_{tot} = (V_{final} + V_{thinned} + V_{mort})/DA_{final} \qquad (1)$$

where:
$V_{final}$ = Growing stock at the end of simulation
$V_{thinned}$ = Accumulated sum of thinning fellings
$V_{mort}$ = Accumulated sum of self-thinnings
$DA_{final}$ = Drainage age, i.e. time elapsed since first ditching to end of simulation (regeneration maturity)

$MAI_{merch}$ was calculated as $MAI_{tot}$ but excluding wastewood and self-thinning.

# 3 Results

The simulated total yields ranged from 244 to 595 $m^3ha^{-1}$ and those of merchantable wood from 217 to 364 $m^3ha^{-1}$, depending on site group and regime (Fig. 4). The control regime (I) resulted in the highest total yield in all site groups. However, 18–38% of the total yield, depending on the site group, was predicted to self-thin by the end of the simulation. The simulated total yields for Regimes II, III, and IV were 75–99%, 66–92%, and 60–80% of that for the control regime, respectively, depending on site group (Fig. 4). In the regimes involving thinnings, the simulated proportion of self-thinning declined with increased thinning intensity in all site groups, from 8–24% (II) to 3–7% (IV).

The regimes involving thinnings generally needed less time than the control regime to reach

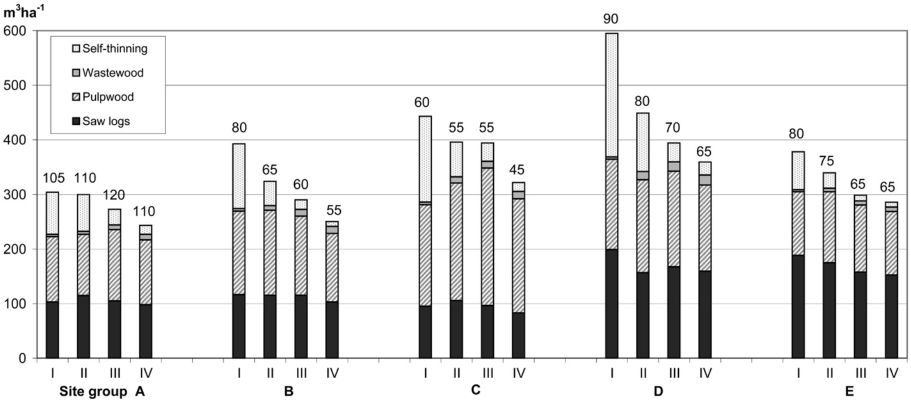

**Fig. 4.** Total yield, by timber assortment, according to different management regimes and site groups. Numbers above the bars indicate the simulation time in years from the experimental thinning until regeneration maturity. Thinning regimes: I – Control regime with no thinnings; II – Light thinning + delayed moderate thinning; III – Moderate thinning + moderate thinning; IV – Heavy thinning + heavy thinning. Site groups: A – < 900 d.d., medium-productive sites; B – 900–1025 d.d., medium-productive sites, low level of stocking; C – 900–1025 d.d., medium-productive sites, high level of stocking; D – 1026–1150 d.d., medium-productive sites; E – 1026–1150 d.d., low-productive sites.

the basal-area-weighted mean DBH required for final cuttings (Fig. 4). In this respect, the greatest temporal advance obtained with thinnings was 25 years.

On average, the highest yields of merchantable wood were obtained by applying Regimes II and III (Fig. 4). However, the differences among the regimes were relatively small, except for the stands with a high level of stocking for thinning (site group C) where the control regime produced clearly less merchantable wood than did Regimes II and III. The estimated proportion of sawlogs in the volume of merchantable wood was, on average, the smallest (28–36%) in the stands with high level of stocking (site group C) and the largest (56–62%) in the southern, low-productive sites (site group E, Fig. 4). The thinning regimes did not have a consistent effect on sawlog proportions.

The mean annual increment of total stem volume ($\mathrm{MAI}_{\mathrm{tot}}$) was at its highest in the control regimes in all site groups (Table 3). Reductions in growing stock, as affected by the different regimes, had the effect of decreasing $\mathrm{MAI}_{\mathrm{tot}}$. The clearest difference between control and the other regimes occurred in the most productive site group D. Thinnings did not increase the mean annual increment of merchantable volume ($\mathrm{MAI}_{\mathrm{merch}}$) in site groups A and E, which represented the lowest productivity potentials (Table 3). In the other site groups, however, the highest $\mathrm{MAI}_{\mathrm{merch}}$ was reached in Regime III involving two moderate thinnings.

Comparing the simulated and measured stand volumes 10 years after the onset of simulations showed that the simulator underestimated growth in most stands (Fig. 5). On average, the simulation error did not depend on thinning intensity.

# 4 Discussion

The simulated development of stands dominated by Scots pine on drained peatland sites clearly demonstrated that unthinned stands result in the highest total yield, but also considerably more self-thinning when compared to any of the thinning regimes. Obviously, a significant proportion of the greater total yield of the unthinned stands results from a longer period of growing due to delayed regeneration maturity. The clearest evidence of a positive thinning impact was the result that thinning produced similar or larger yields

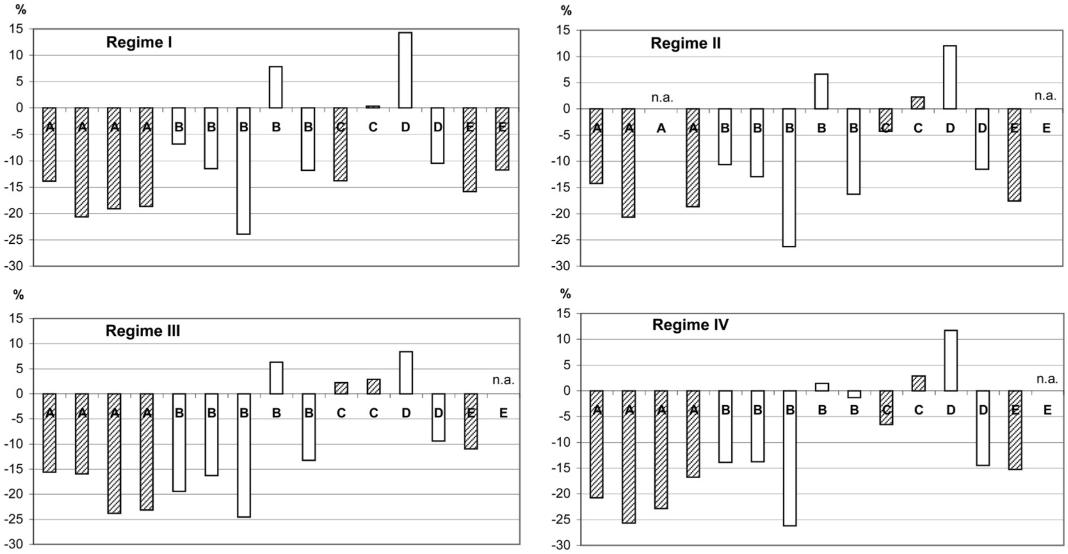

**Fig. 5.** The difference (%) between simulated and measured stand volume of live trees after 10 years of development by thinning regime and site group. Negative values indicate underestimates of the stand volume predicted by the simulations. For the acronyms, see Fig. 4.

of merchantable wood in a shorter time than did the unthinned control regime, i.e., the $\mathrm{MAI}_{\mathrm{merch}}$ in the regimes involving thinnings were generally greater. This, however, did not apply to the northernmost sites or the southern nutrient-poor sites, both having fairly low production potentials. One must bear in mind that our results only apply to stands treated with pre-commercial thinnings in their early stage of development.

The yields, in terms of MAI, predicted for moderately thinned regimes were generally fairly equal to those of similar sites in Sweden (Hånell 1988). Further, the overall levels of the simulated yields corresponded quite well to the results presented by Gustavsen et al. (1998) and Miina and Pukkala (1995), when accounting for the variation in climate and stand quality.

Despite the increased $\mathrm{MAI}_{\mathrm{merch}}$, the regimes with thinnings showed only slightly larger or similar yields of sawlogs than did the control regime. Generally, the predicted proportion of sawlogs in the total of merchantable wood was less than 50%. This somewhat surprising result may be attributed to the initial uneven structure of the stands, which was more or less retained during the simulations in all the thinning regimes. An additional reason for the similarity in sawlog proportion is that the trees in all regimes were grown until they reached the same target mean diameter. The especially low sawlog productivity in the only site group consisting of stands with a high level of stocking, considered to be over-mature for the first thinning (site group C), suggested that a delay in the application of the first commercial thinning may lead to undesirable reductions in the value of the total yield. The delay in the first thinning also coincided with a high proportion of low-in-value admixture of birch in the stand. On the other hand, it was in this very site group that the thinnings showed the most distinct increase in the overall yield of merchantable wood, which obviously implies a high silvicultural advantage even for a delayed first thinning.

In the management regimes currently applied in pine stands, the time needed to reach the required regeneration maturity may play an essential role regarding the profitability of the management. According to our simulations, the time for reaching regeneration maturity markedly shortened with increased thinning intensity. This was evidently due to the increased basal-area growth rates of the trees following thinnings. Given the levels of merchantable yields for the different thinning regimes discussed above, the earlier harvesting

**Table 3.** Mean annual increment of total stem volume ($MAI_{tot}$) and merchantable stem volume ($MAI_{merch}$), $m^3ha^{-1}a^{-1}$, over the period from first ditching to regeneration maturity, according to the stand simulations by site group and thinning regime.

| Site group and thinning regime [a)] | $DA_{final,}$[b)] years | $MAI_{tot,}$[c)] $m^3ha^{-1}a^{-1}$ | $MAI_{merch,}$[d)] $m^3ha^{-1}a^{-1}$ |
|---|---|---|---|
| Site group A | | | |
| I | 133 | 2.3 | 1.7 |
| II | 143 | 2.1 | 1.6 |
| III | 146 | 1.9 | 1.6 |
| IV | 138 | 1.8 | 1.6 |
| Site group B | | | |
| I | 108 | 3.6 | 2.5 |
| II | 96 | 3.4 | 2.8 |
| III | 91 | 3.2 | 2.9 |
| IV | 85 | 3.0 | 2.7 |
| Site group C | | | |
| I | 110 | 3.9 | 2.4 |
| II | 105 | 3.8 | 3.1 |
| III | 105 | 3.8 | 3.3 |
| IV | 93 | 3.5 | 3.2 |
| Site group D | | | |
| I | 115 | 5.2 | 3.2 |
| II | 102 | 4.4 | 3.2 |
| III | 95 | 4.2 | 3.6 |
| IV | 90 | 4.0 | 3.5 |
| Site group E | | | |
| I | 109 | 3.5 | 2.8 |
| II | 111 | 3.1 | 2.7 |
| III | 101 | 3.0 | 2.8 |
| IV | 101 | 2.8 | 2.7 |

[a] For the acronyms, see Tables 1 and 2
[b] Time elapsed since first ditching to end of simulation (regeneration maturity)
[c] $MAI_{tot}$ – calculated using Eq. 1
[d] $MAI_{merch}$ – calculated as $MAI_{tot}$ but excluding wastewood and self-thinning

income suggests that applying regimes involving thinnings would most probably increase the profitability of the management, especially if net income can be obtained already from the thinnings as such. However, proper economic analyses would be needed for comparing the true profitability of the different thinning regimes.

We were able to test the reliability of the early stages of the simulations by comparing the predicted yields against the measured 10-year growth data of the same stands that constituted the initial tree stands for the different thinning regimes. The comparisons revealed clear underestimates in the predicted growth rates. This may have been partly due to the procedure of calibrating the MOTTI growth models with the Finnish NFI-data sets, resulting in generally lower levels of predicted growth. The NFI calibration is a general precaution used with growth models that are meant to be used in forest management planning tools. This is due to the experience that modelling data sets tend to represent better growing trees than those generally found in production forestry stands. As our experimental sites most probably represented better-than-average productivity levels in regard to their climatic location and edaphic properties, the overall underestimates in the growth predictions were expected. The predictions for the regimes involving thinnings resulted in relatively similar underestimates for all regimes, thus suggesting that the models in the MOTTI simulator performed fairly well in predicting the thinning response impact for the examined 10-year period in peatland stands.

Stand development involved changes in stand structure from the initially reverse-J-shaped distributions towards bell-shaped distributions in all the regimes. In the control regimes, this was obviously due to processes related to growth and mortality as predicted by the simulation models. We lacked the empirical data to verify the changes in stand structures, but evidence of this kind of development is available from long-term monitoring of similar stands (Sarkkola et al. 2004). In the regimes involving thinnings, the most distinct changes were due to the implementation of the experimental thinnings. Eventually, however, the stand structures evolved to very similar, bell-shaped but wide DBH distributions in all regimes. This suggests that the thinnings, either experimental or simulated, had minor impact on the long-term structural development of the stands and that they just captured the proportion of the yield otherwise destined to self-thinning.

As for practical forestry, our results imply that on moderately productive peatland sites management of pine involving thinnings would generally increase the yields of merchantable wood, mostly of pulpwood. Differences in the merchantable yields among the regimes involving thinnings were small, however, which suggests that a large variability in the thinning intensity may be acceptable. Nevertheless, a sufficiently high level of growing stock should be regarded to be a pre-requisite for applying heavy thinnings as the retained stands may otherwise become under-stocked and subjected to significant growth losses. In the most low-productive site groups, thinnings produced little or no advantage in yields, probably due to low stand stockings and production potentials.

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