Precommercial Thinning in Naturally Regenerated Scots Pine Stands in Northern Finland

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The effects of precommercial thinning on the quantity and external quality of young Scots pine stands were examined over two 10-year periods in an experiment comprising five stands growing on sub-dry sites in Finnish Lapland, northern Finland. The thinning treatments applied resulted in stand densities of 625, 1111, 1600, 2500 and 4444 stems ha^{-1} and a no-treatment, unthinned plot with a randomised block lay-out of two or tree replications in each stand. The dominant height of the stands varied between 4 and 8 m at the time of thinning.

The trees reacted only slightly to the increase in growing space during the first ten years following precommercial thinning. During the second 10-year period, increased growing space was reflected more clearly in diameter and volume increment. These reactions were more evident in stands thinned at an early stage. The increment of the thinnest 100–200 trees ha^{-1} in each treatment was poor. The results showed that when the main principle in precommercial thinning is to achieve even spacing, the remaining smallest trees fail to react positively to the increase in growing space. In other words, the target of precommercial thinning should be to concentrate the increment on the tallest trees, even though they are located in groups.

The external quality of the trees in stands where precommercial thinning was carried out at a later stage was high, and the diameter of the thickest branch along the butt log remained under 20 mm. Branch diameter was greater in stands thinned at an early stage. The effect of precommercial thinning on branch diameter when comparing the extreme treatments averaged 5 mm.

When the aim of stand management is to combine high quality and good yield in naturally regenerated Scots pine stands in northern Finland, precommercial thinning should not be carried out before the dominant height of 7–8 m. The intensity of precommercial thinning depends on the yield targets of the first commercial thinning. A spacing of 2500 stems ha^{-1} satisfies the requirements of both high quality and adequate yield.

Keywords branch diameter, early development, external quality, precommercial thinning

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1 Introduction

The forests where final cuttings are nowadays carried out in Finland are almost without exception naturally regenerated. This is especially true in Finnish Lapland, where artificial regeneration did not begin on a large scale until the end of the 1940s. High-quality Scots pine (*Pinus sylvestris* L.) sawtimber is thus mostly obtained from what can be referred to as *natural normal* stands grown, at least in their early stage of development, at a very dense spacing (see Ilvessalo 1937).

The most common forest site type in Finnish Lapland is pine-dominated, sub-dry type which accounts for 48.6 % of the region's mineral soil sites (Kuusela et al. 1986). In the Peräpohjola vegetation zone, the sub-dry forest site type is called the *Empetrum-Myrtillus* type (EMT) (Cajander 1949). When fully stocked, an EMT stand has a high stem number at the juvenile stage, an average of 20 000 stems ha^{-1} at the age of 20 years, 6000 stems ha^{-1} at 30 years and 4500 stems ha^{-1} at 40 years (Ilvessalo 1937). Sarvas (1950) studied selection stands in Lapland and found that EMT stands contained on average 11 000 seedlings ha^{-1}. Nowadays naturally regenerated young stands appear to be less dense. On sites with seed trees, and comprising mainly of EMT, there were, on the average, 4900 seedlings ha^{-1} in southern Lapland. In northern Lapland the corresponding figure was 1800 seedlings ha^{-1} 4–20 years after soil preparation (Norokorpi 1983).

According to current silvicultural guidelines for private forestry, precommercial thinning in naturally regenerated young stands should be carried out to give 1800–2000 stems ha^{-1} at a dominant height of 4–7 m (Luonnonläheinen metsänhoito 1994). In state forestry the target spacing is 1600–2000 stems ha^{-1} at an average height of 3–6 m (Metsänhoitosuositusten... 1994). High-quality sawtimber is an important silvicultural goal in the guidelines.

In naturally regenerated young Scots pine stands precommercial thinning has no effect on height development, but diameter increment is strongly promoted by the thinning intensity (Mäkinen 1959, Vuokila 1972, Vestjordet 1977, Parviainen 1978, Thernström 1982, Varmola 1982, Fryk 1984, Pettersson 1993). Furthermore, the earlier a stand is precommercially thinned, the greater is the increment reaction (Varmola 1982, 1993).

Earlier results obtained over a 10-year growing period based partly on the material of this investigation (Varmola 1987) showed that precommercial thinning resulting in stand densities of 625–4444 stems ha^{-1} had no effect on the increment of the dominant trees, i.e. the thickest 500 trees ha^{-1} or even the thickest 500–1000 trees ha^{-1}. The only reaction to thinning was in the branch diameter (4 mm) and crown ratio (10 % points) of the 500 thickest trees ha^{-1} between extreme treatments.

The density before precommercial thinning had a clear effect on the external quality of the trees. 5–10 years after precommercial thinning in stands with only 3000–5000 stems ha^{-1} before thinning the thickest branch along the butt log was, on the average, 8 mm thicker than that in fully stocked stands with 6000–10 000 stems ha^{-1}. The lack of growth reaction after thinning was attributed to the uneven age and size structure of the naturally regenerated stands, and the gaps in stands caused by seed trees. Competition from dominant and co-dominant trees with respect to trees of other tree classes was minor because of the free growing space around the gaps (Varmola 1987).

In the future, too, naturally regenerated stands of Scots pine on sub-dry sites will constitute the main source of sawtimber in Finnish Lapland. Therefore, it is important to know how precommercial thinnings should be made in these forests in order to ensure maximum quantity and quality of sawtimber, or whether they should be left unthinned. The aim of this paper is to study the effects of precommercial thinning on the increment and quality of naturally regenerated Scots pine stands in Finnish Lapland. The study is focused on the period from precommercial thinning to the first commercial thinning, i.e. the period covering the ages of 25 to 65 in stand development.

2 Material and Methods

The study material consisted of data collected from five, naturally regenerated young Scots pine stands growing in different parts of Finnish Lapland (Table 1). All the stands belonged to the sub-dry forest site type of the Peräpohjola vegetation zone, *Empetrum-Myrtillus* type (EMT) (Cajander 1949). The seed trees were removed from the stands in the early 1950s. The stands were subsequently left unthinned until the establishment of this experiment in 1972–73, when precommercial thinning was carried out.

The mean age of the dominant trees varied from 23 to 45 years in 1972(–73) (Table 1). Stands 1 and 5 in southern Lapland were precommercially thinned at a relatively late stage when the dominant height (average height of the 100 tallest trees) was already over 8 m. Precommercial thinning was carried out in the poorest stands (stands 2 and 4) when the dominant height was 4 m.

The material was relatively uniform as regards initial density, tree species composition, and site type. The stand density prior to precommercial thinning in all the stands averaged over 5000 stems ha^{-1}, and there was only a minor degree of species mix, mainly consisting of downy birch (*Betula pubescens* Ehrh.) (Table 1). The average site index (H_{100} = dominant height at the age of 100 years) estimated using the function developed by Gustavsen (1980) was 16 in all the stands; i.e. the sites represented the rich EMT site.

The layout of the experiment, randomised blocks, was the same in stands 1, 2, 4, and 5, with three replications in each stand. Stand 3 had only two replications. Each replication consisted of six square plots 50 × 50 m in size. The thinnings were randomised within each replication. The thinning treatments resulted in stand densities of 625, 1111, 1600, 2500, and 4444 stems ha^{-1}. The respective mean spacings were 4, 3, 2.5, 2, and 1.5 ms. One plot per replication was left unthinned.

The main principle in precommercial thinning was to achieve even spacing: trees from all height classes were removed in thinning. As a result of this, the mean stand height weighted by the basal area did not increase after thinning and this was seen also in height distribution after precommercial thinning (Fig. 1). Stands 1 and 5 had the

Table 1. Main characteristics of the experimental stands.

			Stand		
	1	2	3	4	5
			Location		
	Rovaniemi	Salla	Kolari	Inari	Rovaniemi
Latitude	66°11'	66°58'	67°12'	68°53'	66°53'
Longitude	26°48'	29°02'	24°13'	28°09'	25°03'
Height above sea level, m	210	220	200	160	140
Temperature sum, d.d.	902	803	854	756	902
Site index (Gustavsen 1980), m	15.6	16.4	16.5	15.8	15.6
Number of plots (blocks)	18 (3)	18 (3)	12 (2)	18 (3)	18 (3)
Mean age of dominant trees at thinning, a	45	23	26	24	39
Mean age of sample trees (s.d.), a	39 (6)	18 (3)	23 (4)	20 (3)	34 (5)
Dominant height at thinning (100 tallest trees ha^{-1}), m	8.6	4.4	5.1	4.1	8.1
Stem number before thinning, st ha^{-1}					
Scots pines	7300	11 000	7300	5700	8900
All species	7600	13 100	8200	6000	10 000
Range (Scots pines)	5025–9275	3750–11 425	4325–8775	2000–7750	4550–12 025
Time when thinned	spring –73	autumn –73	autumn –72	autumn –73	spring –73
Previous stand history	burnt 1830 seed tree cutting 1931 removal of seed trees 1951	not known	removal of seed trees 1955	not known	removal of seed trees 1954

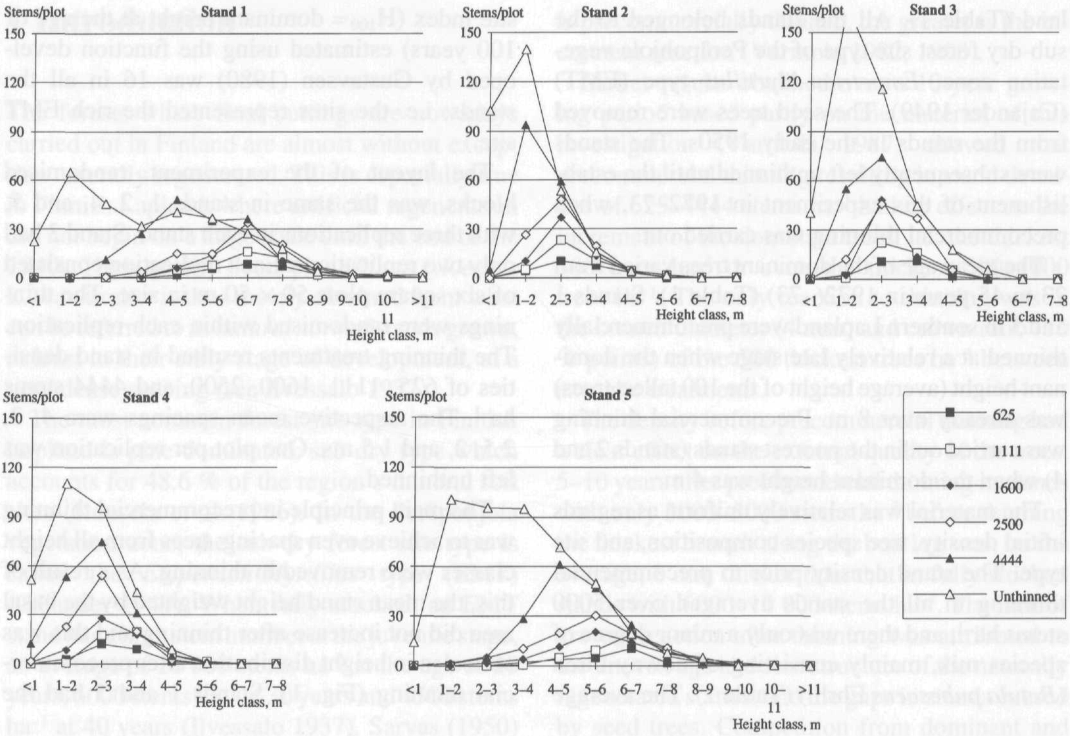

Fig. 1. Height distributions in the experimental stands after precommercial thinning 1972(–73).

broadest height distributions, with average heights of 7–8 m. Stands 2–4 had somewhat similar height distributions. All the plots, even those subjected to the heaviest treatments, retained small-diameter trees following precommercial thinning (Fig. 1).

The stands were measured in 1972 or 1973 before and after precommercial thinning. Four circles with a radius of 5.64 metres were marked out systematically in each plot along the plot diagonals. Tree species, mode of regeneration, height (dm), and the previous year's height increment (cm) were determined on every tree within the circles. Breast height diameter (DBH) was not measured.

The 1972(–73) measurements were repeated on the same circular subplots in 1982 and 1992. All the trees were mapped with respect to their orientation (1/360°) and distance (cm) from the centre of the circle. DBH was measured at an accuracy of 1 mm. One third of the tallied trees located closest to the centre of the circles were selected as sample trees. The following measurements were made: height (dm), upper diameter (mm, at 3.5 or 6.0 m height), the lower limit of the living and dead crown (dm), the diameter of the thickest living and dead branch (mm) (in 1982 along the butt log, i.e. first 4 m, and in 1992 along the whole stem), and the elevation of the thickest branch above the ground (dm). The state of health, technical quality of the trees, and tree layer (only in 1992) were estimated.

In 1992 soil samples were taken from the mineral soil and organic layer. A plotwise sample consisted of 27 systematically located points per plot. A humus sample was taken from each plot with a cylinder 50 mm in diameter and a mineral soil sample with a cylinder 28 mm in diameter to a depth of 10 cm. The particle size of mineral soil was analysed from mineral soil samples. The ammonium acetate extraction method was used to study the amounts of extractable concentrations of the various nutrients.

The soil in stands 1, 2, and 5 was sorted (Table 2). The soil in stand 2 was coarse-grained and those in stands 1 and 5 were of fine-grained

Table 2. Type and nutrient contents of the soils in the experimental stands.

	Stand 1 Fine-grained	2 Coarse-grained	3 Soil type Sandy till	4 Sandy till	5 Fine-grained
N, %	0.72	0.36	0.81	0.83	0.69
K, mg kg^{-1}	500	272	714	439	517
P, mg kg^{-1}	145	57.1	210	89.8	93.4
Ca, mg kg^{-1}	997	503	1427	1122	960
Mg, mg kg^{-1}	140	69.9	217	178	157
Mn, mg kg^{-1}	106	50.0	267	82.0	129
Na, mg kg^{-1}	22.9	20.1	19.5	37.2	23.9
Zn, mg kg^{-1}	13.1	8.1	19.5	13.4	12.9
$\text{pH} - \text{H}_2\text{0}$	3.6	3.6	3.8	3.6	3.7

sand. Soils in stands 3 and 4 were sand-moraine and sorted to some degree. The extractable nutrient contents in the soils of the stands were clearly lower than those of sub-dry or dry sites in southern Finland (Tamminen 1991). The pH values of the humus layer were almost identical in all the stands, i.e. varying between 3.6 and 3.8 pH (Table 2).

DBH had to be estimated from the first measurements made in 1972(–73) in order to facilitate the computation of stand characteristics. A diameter-height function was fitted separately to each stand. The measurements made on the unthinned plots in 1982 and 1992 were used in the fitting. The function was obtained from a second-degree height-diameter curve by solving for DBH:

$$d = ((h - \alpha)/\beta)^2 \qquad (1)$$

where
d = breast height diameter, mm
h = tree height, dm
α and β = parameters

The parameter estimates for 1972(–73) (Table 3) were extrapolated standwise from a linear function using the parameters obtained for 1982 and 1992 from the function (1).

The statistical significance of the differences between the different thinning treatments was analysed using one-way analysis of variance of the standwise randomised blocks. The differences between the thinning treatments were analysed pairwise using Tukey's HSD test. The differences between the stands could not be tested using analysis of variance because the material consisted of two clearly different groups. Stands 1 and 5 in southern Lapland, which were growing in more favourable conditions, were thinned at a later stage than stands 2 and 4 in northern Lapland. Stand 3 represented intermediate conditions between these two groups.

Table 3. Parameters of the diameter function (1) in 1992, 1982 and 1972(–73). The 1992 and 1982 parameters were fitted using data from the unthinned plots. The 1972(–73) parameters were computed as a linear function using the 1992 and 1982 parameters. r^2 = coefficient of determination, n = number of observations.

	Stand 1	2	3	4	5
1992					
α	–32.21	–14.28	–26.13	–24.14	–21.14
β	13.79	10.53	12.53	11.59	12.17
r^2	0.892	0.829	0.846	0.769	0.848
n	242	497	296	335	322
1982					
α	–28.45	–9.45	–17.86	–10.30	–19.39
β	12.35	8.33	9.88	8.16	11.29
r^2	0.896	0.865	0.854	0.811	0.835
n	264	502	302	344	362
1972(–73)					
α	–24.68	–5.11	–9.59	2.16	–17.69
β	10.90	6.47	7.23	5.07	10.41

3 Results

3.1 Stand Development Following Precommercial Thinning

3.1.1 Mortality

Mortality on the densest plots during the 20-year measurement period increased with increasing stand height at the time of the precommercial

Table 4. The proportion of dead standing trees, fallen trees and trees broken below the stem midpoint in the experimental stands in 1992.

	Stand 1	2	3	4	5
	% of total stem number				
625	1.3	0.0	0.0	0.0	5.2
1111	0.0	0.0	0.0	0.0	0.7
1600	0.5	0.5	0.0	0.4	1.0
2500	1.9	0.6	0.5	0.6	2.9
4444	5.1	1.6	1.0	1.0	3.0
Unthinned	13.1	4.1	1.7	3.0	12.6

thinning. The proportion of completely dead standing trees, fallen trees, and trees broken below the stem midpoint in 1992 on the unthinned plots was 13.1 % in stand 1, 12.6 % in stand 5 but below 5 % in the other stands (Table 4). When stand density was reduced to 2500 stems ha^{-1} or less, there was no notable self-thinning in any of the stands. As there was no significant abiotic or biotic damage in the stands, the cause of tree mortality was mainly the competition between the trees. In stands 2 and 4, which had a dominant height of 9 m in 1992, self-thinning was still very low.

3.1.2 Stand Characteristics

According to Gustavsen (1980), the EMT forest site type corresponds to the site index H_{100} =15. The development of stands dominant height closely followed a line between the site index curves 15 and 18 (Fig. 2). Stand 5 was characterised by an exceptionally slow dominant height increment during the first ten years after precommercial thinning, when it was only 14 cm a^{-1}. During the second 10-year period, dominant height development was normal for the stand age. There were no significant differences in dominant height increment resulting from the thinning treatments.

The basal area after precommercial thinning varied from 0.5 to 10.4 m^2 ha^{-1}. The current annual basal area increment after thinning was higher during the first 10-year period than during the second, except in stand 2. The stands were therefore close to the culmination point of current annual basal area increment.

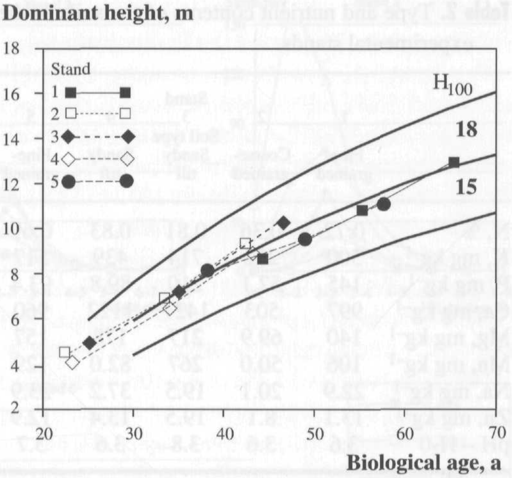

Fig. 2. The development of dominant height 1972(–73)–1992 in the experimental stands, mean of all plots. Site index curves according to Gustavsen (1980).

3.2 The Effect of Thinning Intensity on Increment

3.2.1 Mean Height

The current annual increment of height corresponding to the basal-area based median diameter was 0.17–0.27 m as the mean for all treatments during the first 10-year period after precommercial thinning (Table 5). During the second 10-year period, the corresponding increment was 0.18–0.29 m. During the first 10-year period after thinning annual increment was not dependent on stand density. During the second 10-year period the increase in mean height was the greater, the more widely spaced were the trees on the plots. The northernmost stand 4 was an exception in this respect. In general, the treatment 4444 stems ha^{-1} or no thinning differed significantly from the other thinning treatments (Table 5).

Table 5. Current annual increment of the stand characteristics during the first 1972–(73)–1982 and second 1983–1992 10-year period following precommercial thinning. x̄ = mean of all treatments.

	Stand 1		2		3		4		5	
	72–82	83–92	72–82	83–92	72–82	83–92	72–82	83–92	72–82	83–92
Current annual increment of height corresponding to the basal-area based median diameter, m										
x̄	0.22	0.19***	0.21	0.27***	0.27**	0.29**	0.22	0.22*	0.17	0.18**
Unthinned	0.24^{a}	0.16^{ab}	0.16^{a}	0.19^{a}	0.26^{ab}	0.22^{a}	0.20^{a}	0.21^{ab}	0.05^{a}	0.13^{a}
625	0.21^{a}	0.25^{c}	0.24^{a}	0.30^{b}	0.26^{ab}	0.31^{b}	0.24^{a}	0.19^{a}	0.20^{a}	0.19^{b}
1111	0.22^{a}	0.22^{cd}	0.25^{a}	0.30^{b}	0.28^{a}	0.30^{b}	0.24^{a}	0.23^{ab}	0.18^{a}	0.22^{b}
1600	0.23^{a}	0.19^{ad}	0.24^{a}	0.29^{b}	0.27^{b}	0.32^{b}	0.21^{a}	0.24^{ab}	0.19^{a}	0.19^{b}
2500	0.21^{a}	0.20^{bd}	0.21^{a}	0.27^{bc}	0.28^{b}	0.30^{b}	0.22^{a}	0.24^{b}	0.16^{a}	0.18^{b}
4444	0.22^{a}	0.15^{a}	0.19^{a}	0.25^{c}	0.28^{b}	0.27^{ab}	0.22^{a}	0.23^{ab}	0.16^{a}	0.17^{ab}
Current annual increment of basal-area based median diameter, cm										
x̄	0.34***	0.16***	0.35**	0.34***	0.44**	0.31***	0.41*	0.24**	0.33**	0.17***
Unthinned	0.29^{a}	0.10^{a}	0.17^{a}	0.17^{a}	0.33^{a}	0.15^{a}	0.32^{a}	0.18^{a}	0.22^{a}	0.09^{a}
625	0.49^{b}	0.27^{b}	0.51^{b}	0.52^{b}	0.53^{b}	0.49^{b}	0.56^{b}	0.24^{ab}	0.48^{b}	0.26^{b}
1111	0.41^{bc}	0.22^{c}	0.43^{ab}	0.43^{c}	0.46^{bc}	0.41^{bc}	0.44^{ab}	0.28^{b}	0.39^{bc}	0.19^{c}
1600	0.33^{ac}	0.16^{d}	0.44^{b}	0.39^{c}	0.48^{bc}	0.37^{c}	0.36^{ab}	0.26^{bc}	0.36^{ab}	0.16^{cd}
2500	0.26^{a}	0.12^{ad}	0.32^{ab}	0.29^{d}	0.45^{bc}	0.27^{d}	0.42^{ab}	0.24^{ab}	0.29^{ac}	0.16^{cd}
4444	0.26^{a}	0.10^{a}	0.25^{ab}	0.25^{ad}	0.39^{ac}	0.19^{a}	0.35^{ab}	0.20^{ac}	0.25^{ac}	0.12^{ad}
Current annual basal area increment, m^2/ha										
x̄	0.78***	0.45*	0.58***	0.80***	0.84***	0.84*	0.68	0.62	0.68***	0.45**
Unthinned	1.02^{a}	0.46^{ab}	0.86^{a}	0.99^{a}	1.39^{a}	0.92^{a}	1.06^{a}	0.61^{a}	0.90^{a}	0.51^{ab}
625	0.43^{b}	0.37^{a}	0.31^{b}	0.55^{b}	0.31^{b}	0.57^{b}	0.32^{b}	0.66^{a}	0.42^{b}	0.33^{c}
1111	0.64^{bc}	0.48^{b}	0.41^{b}	0.71^{c}	0.47^{bc}	0.74^{ab}	0.54^{ab}	0.43^{a}	0.54^{bc}	0.40^{ac}
1600	0.73^{c}	0.46^{ab}	0.52^{bc}	0.82^{cd}	0.66^{cd}	0.92^{a}	0.61^{ab}	0.66^{a}	0.67^{ac}	0.43^{abc}
2500	0.84^{ac}	0.48^{b}	0.67^{ac}	0.86^{d}	0.89^{d}	0.91^{a}	0.73^{ab}	0.69^{a}	0.80^{a}	0.54^{b}
4444	1.03^{a}	0.47^{b}	0.66^{ac}	0.89^{ad}	1.31^{a}	0.99^{a}	0.86^{ab}	0.68^{a}	0.79^{a}	0.53^{ab}
Current annual volume increment, m^3/ha										
x̄	4.50***	3.84**	1.98**	4.20**	3.19**	5.22**	2.37	3.34	3.35**	3.16*
Unthinned	5.99^{a}	4.08^{a}	3.01^{a}	4.83^{a}	5.43^{a}	5.96^{ab}	3.60^{a}	3.72^{a}	4.28^{a}	3.49^{a}
625	2.33^{b}	2.76^{b}	1.11^{b}	2.87^{b}	1.12^{b}	3.07^{c}	1.09^{a}	2.93^{a}	2.08^{b}	2.10^{b}
1111	3.43^{bc}	3.63^{ab}	1.53^{bc}	3.85^{ab}	1.71^{bc}	4.20^{ac}	2.04^{a}	2.45^{a}	2.70^{bc}	2.92^{ab}
1600	4.21^{cd}	3.75^{ab}	1.80^{bc}	4.49^{a}	2.37^{bc}	5.39^{ab}	2.18^{a}	3.54^{a}	3.42^{abc}	2.97^{ab}
2500	5.29^{ad}	4.74^{a}	2.36^{ac}	4.77^{a}	3.40^{cd}	5.94^{ab}	2.40^{a}	3.65^{a}	3.97^{ac}	3.76^{a}
4444	5.75^{a}	4.06^{a}	2.12^{ab}	4.35^{a}	5.13^{ad}	6.77^{b}	2.89^{a}	3.72^{a}	3.69^{ac}	3.69^{a}

In Tukey's HSD test, the treatments indicated by different letters differed from one another at the 5 % significance level. The stand means denoted by asterisks indicate that the treatments differed from the standwise mean at the level of 5 % (*), 1 % (**) or 0.1 % (***).

3.2.2 *Mean Diameter*

The current annual increment of basal-area based median diameter was 0.33–0.63 cm a^{-1} during the first 10-year period (Table 5). The increment was lower in all the stands during the second 10-year period after thinning, 0.16–0.34 cm a^{-1}. There were significant differences between the thinning treatments during both 10-year periods after thinning. The differences were somewhat more marked during the second 10-year period. The weakest reaction occurred in stand 4 during both 10-year periods. The more widely spaced the trees grew, the higher was the current annual increment of the mean diameter. The differences were significant especially between the thinning treatment 625 stems ha^{-1} and the other treatments, and between no thinning and the thinning treatments (Table 5).

3.2.3 Basal Area and Volume

Both basal area and volume increment were closely connected to the growing stock level during the first 10-year period after thinning. The higher the growing stock level, the higher were the current annual increment of basal area and volume. The standwise means were 0.45–0.84 $m^2\ ha^{-1}\ a^{-1}$ for basal area and 1.98–4.50 $m^3\ ha^{-1}\ a^{-1}$ for volume (Table 5). The differences between the treatments were significant, except for both basal area and volume increment in stand 4. The differences between the thinning treatments were the greater, the higher the basal-area increment levels. In all stands except stand 4 the treatment 625 stems ha^{-1} differed significantly from no thinning and treatments 4444 and 2500 stems ha^{-1} (Table 5).

During the second 10-year period, the differences between the thinning treatments diminished (Table 5). This was a result of the reaction of the trees to the increased growing space. Especially in treatments 2500 and 4444 stems ha^{-1} and no thinning, the current annual increment was at a constant level. In stands 2 and 4, which were thinned at an early stage of development, and also partly in stand 3, the current annual increment of both basal area and volume increased during the second 10-year period after thinning. In stands 1 and 5, the situation was the opposite. Stands 1 and 5 had passed the culmination point of current annual basal area and volume increment. The trees were noticeably larger in stands 1 and 5, and the competition between the trees already stronger than that in stands 2–4.

3.2.4 Increment in Different Parts of the DBH Distribution

The effect of thinning on stand characteristics was examined in more detail on the basis of the DBH distribution. According to graphical analysis, the annual increment of stand characteristics differed clearly from stand to stand (see also Table 5). However, the shape of increment level as a funtion of stem number in the different stands was rather equal. Therefore the standwise data were combined by treatments for further analysis.

The trees were arranged into groups of 100 trees starting from the top of the DBH distribution of each treatment. There were no clear differences between the thinning treatments as regards current annual height increment during the first 10-year period after thinning (Fig. 3a). Notable was the equal increment of almost all tree groups with thin trees growing as much as thick ones. During the second 10-year period, the average height increment was slower both on the densest plots and in the lower part of the DBH distribution (Fig. 3b).

The current annual diameter increment differed from the mean on plots thinned to 625 stems ha^{-1} or to 4444 stems ha^{-1} and on the unthinned plots during the first 10-year period after thinning (Fig. 3c). During the second 10-year period, there were clear differences between all the thinning alternatives; only the plots with 4444 stems ha^{-1} and the unthinned plots were close to each another (Fig. 3d). During both periods, diameter increment decreased as tree diameter diminished along the DBH distribution. The somewhat equal increment obtained in the different thinning treatments during the first 10-year period after thinning is seen to be evidence of a very slow reaction by trees to increased growing space after thinning.

The shape of the graphic presentation of the current annual volume increment along the DBH distribution was equal to that of the diameter increment (Figs. 3e and 3f). The annual volume increment for a specific tree group was the greater, the more widely spaced were the trees in the stand during the second 10-year period after thinning. The volume increment of the groups comprising the 100 or 200 thinnest trees ha^{-1} was very poor. This indicated that the smallest trees could not react to the increase in growing space. The dominant trees (100 thickest ha^{-1}) always had a much faster increment than the next 100 trees. The reactions in volume increment were clearer in stand 2–4, which had been thinned at an earlier stage of development, than in stands 1 and 5.

3.3 External Quality

3.3.1 Crown Characteristics

The study material was separated into two groups according to crown ratio (Fig. 4a) and living

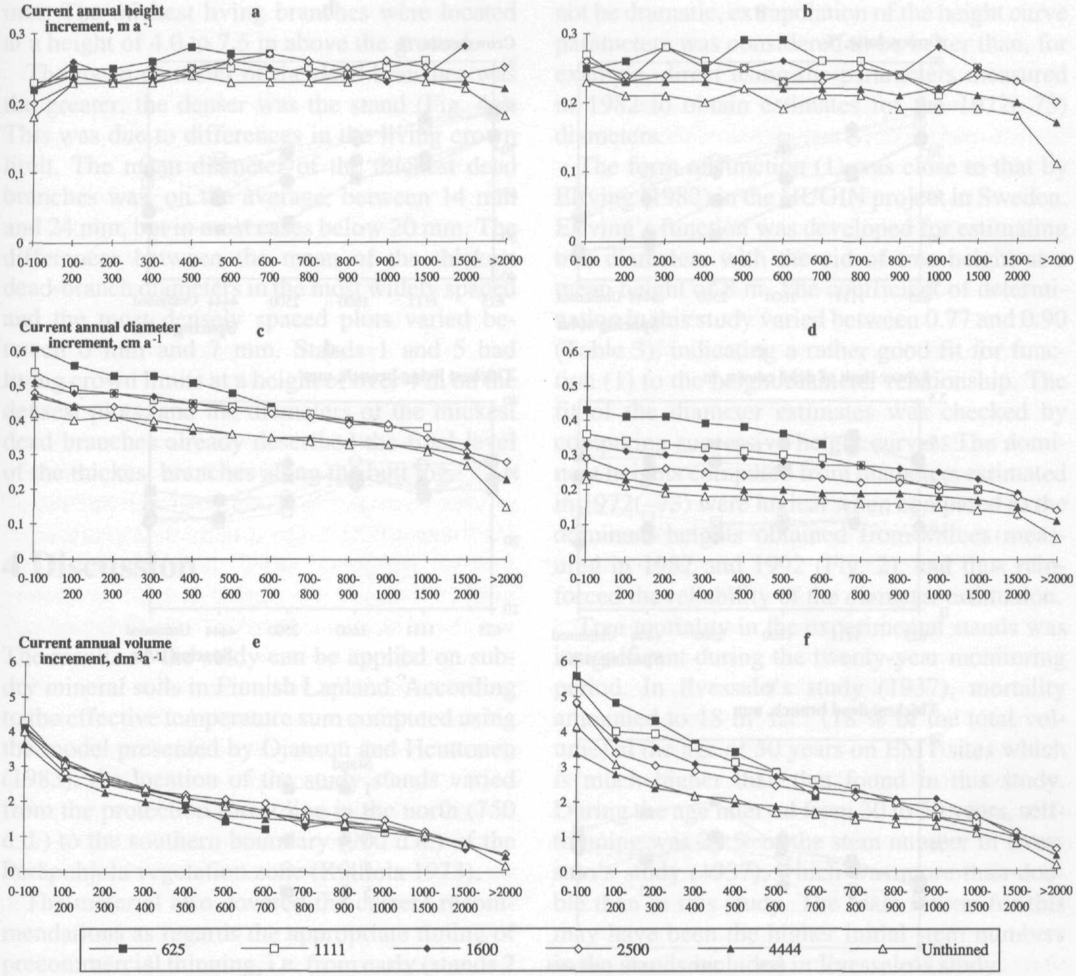

Fig. 3. The current annual increment of height, diameter and volume 1972(–73)–1982 (a, c, e) and 1983–1992 (b, d, f) in tree classes from the upper side of the DBH distribution. Values counted as means for all stands.

crown limit. Twenty years after precommercial thinning, the trees in stands 1 and 5, which had been thinned at an older age, had 5 % to 20 %-units smaller crown ratios than the trees in stands 2–4, which had been thinned at younger age.

The mean crown ratio of the 500 thickest trees was clearly higher than that of all the trees twenty years after the precommercial thinning. The plots with 625 stems ha^{-1} were exceptions in this respect (Figs. 4a and 4b). The crown ratios of the 500 thickest trees differed significantly by thinning treatment in stands 1–3 and 5, but not in stand 4. A pairwise comparison revealed significant differences between those thinning alternatives which were not closest to one another. The elevation of the living crown limit was the higher, the denser were the trees growing on the plot (up to the spacing of 2500 stems ha^{-1}). The living crown limit was above 4 m only on the densest plots in stands 1 and 5.

The differences in the elevation of the dead crown limit (i.e. the distance from the ground to the first, lowermost dead branch at least 10 mm in diameter among the 500 thickest trees ha^{-1}) among the stands were small despite differences in tree height (Fig. 4c). In stands 2–4, this limit was at a height of 1.0 m and in stands 1 and 5 at 1.6–2.1 m. There were no clear differences among

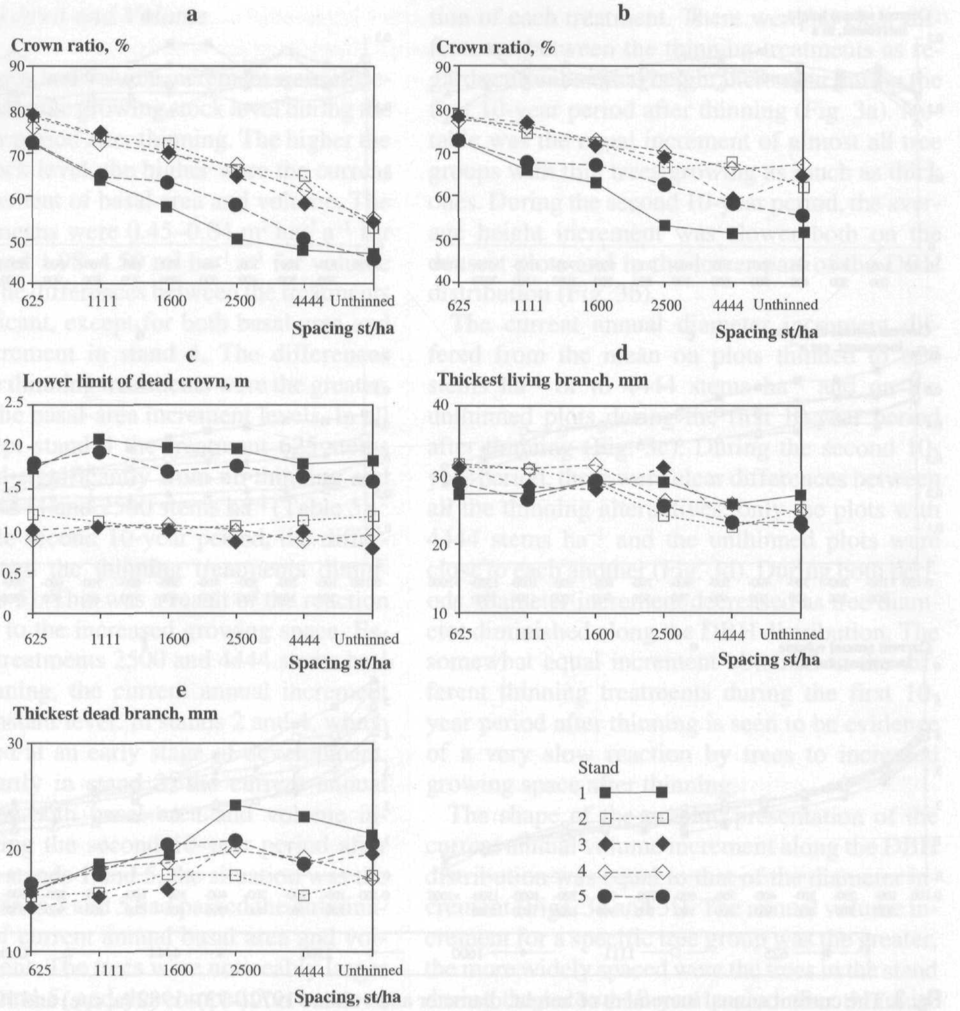

Fig. 4. The external quality in the experimental stands in 1992. a) Living crown ratio for all trees. b) Living crown ratio for 500 thickest trees ha^{-1}. c) Lower limit of dead crown, i.e. distance from ground level to first dead branch at least 10 mm in diameter for 500 thickest trees ha^{-1}. d) Diameter of thickest living branch for 500 thickest trees ha^{-1}. e) Diameter of thickest dead branch for 500 thickest trees ha^{-1}.

the different stand spacings. The dead crown limit appeared to be dependent on the tree height rather than on spacing at this stage of stand development.

3.3.2 *Thickest Branches*

The mean diameters of the thickest living and dead branches of the 500 thickest trees ha^{-1} measured in 1992 were used as the branch-diameter variables. The diameter of the thickest living branches varied considerably from tree to tree within a plot, from 15 to 50 mm. In all the stands, the mean diameter of the thickest living branches in the different treatments were very similar (Fig. 4d). Branch diameter was slightly higher on the more widely spaced plots, the difference between stand density of 625 stems ha^{-1} and the unthinned plot being from 0 mm to 9 mm. The thickest living branches were located at a height of 4.0 to 7.5 m above the ground.

The mean diameter of the dead branches was the greater, the denser was the stand (Fig. 4e). This was due to differences in the living crown limit. The mean diameter of the thickest dead branches was, on the average, between 14 mm and 24 mm, but in most cases below 20 mm. The differences between the mean of the thickest dead-branch diameters in the most widely spaced and the most densely spaced plots varied between 0 mm and 7 mm. Stands 1 and 5 had living crown limits at a height of over 4 m on the densest plots, and the diameters of the thickest dead branches already described the final level of the thickest branches along the butt log.

4 Discussion

The results of the study can be applied on subdry mineral soils in Finnish Lapland. According to the effective temperature sum computed using the model presented by Ojansuu and Henttonen (1983), the location of the study stands varied from the protection forest line in the north (750 d.d.) to the southern boundary (900 d.d.) of the Peräpohjola vegetation zone (Kalliola 1973).

The material also covered the current recommendations as regards the appropriate timing of precommercial thinning, i.e. from early (stands 2 and 4) to late (stands 1 and 5) in terms of stand development stage. Because the stands thinned at an early stage of development were located in the severest conditions in terms of the temperature sum, the results obtained could not be compared statistically in relation to the timing of thinning. The intensity of thinning varied from extremely widely spaced (625 stems ha^{-1}) to overdense (4444 stems ha^{-1}) and unthinned, thus covering all the possible thinning alternatives.

An obvious shortcoming in the material was that DBH was not measured at the time of establishment of the experiment in 1972(–73). The method used in estimating DBH is based on the fact that the height/diameter curves for Scots pine change with changing stand age, and that the change is in the same direction in relation to time. Although the change within ten years may not be dramatic, extrapolation of the height curve parameters was considered to be better than, for example, direct using the parameters measured in 1982 to obtain estimates for the 1972(–73) diameters.

The form of function (1) was close to that by Elfving (1982) in the HUGIN project in Sweden. Elfving's function was developed for estimating tree diameters with the aid of tree height at a mean height of 8 m. The coefficient of determination in this study varied between 0.77 and 0.90 (Table 3), indicating a rather good fit for function (1) to the height/diameter relationship. The fit of the diameter estimates was checked by comparing successive height curves. The dominant heights computed from diameters estimated in 1972(–73) were logical when compared to the dominant heights obtained from values measured in 1982 and 1992 (Fig. 2), and thus reinforced the reliability of the diameter estimation.

Tree mortality in the experimental stands was insignificant during the twenty-year monitoring period. In Ilvessalo's study (1937), mortality amounted to 18 m^3 ha^{-1} (18 % of the total volume) at the age of 50 years on EMT sites which is much higher than that found in this study. During the age interval from 30 to 50 years, self-thinning was 29 % of the stem number in Ilvessalo's study (1937), which was more than double than in this study. The main reason for this may have been the higher initial stem numbers in the stands included in Ilvessalo's study.

The current annual increment of the mean diameter on the unthinned plots was 0.17–0.33 cm during the first 10-year period and 0.10–0.18 cm during the second 10-year period following precommercial thinning (Table 5). Stand 2 was the only stand where the annual increment remained unchanged. In the other stands, the current annual diameter increment appeared to have already passed the culmination point. According to Ilvessalo (1937), the current annual increment of the basal-area-weighted mean diameter in natural normal stands on EMT sites is at its maximum not earlier than at the age of 50–60 years, when it reaches the value of 0.2 cm. The trees in stands 2–4 were clearly younger than this. Therefore, diameter increment in this study may have been slightly overestimated for the first 10-year period.

The stand volumes on the unthinned plots in 1972(–73) were lower than those presented by Ilvessalo (1937) for natural normal stands (Fig. 5). This was partly due to the smaller stem number in the experimental stands. Volume development during the 20-year monitoring period was clearly faster that that reported by Ilvessalo (1937) in stands of the same age on EMT sites (Fig. 5). The lower mortality in the experimental stands explained only a small part of the differences. A widespread increasing growth trend has been reported in European forests during this century (Spieker et al. 1996a). However, Spieker et al. (1996b) state that no positive trend has been recorded in northern Fennoscandia. Possible climatic change has not yet had any effect on the growth level of Scots pine stands in northern Finland (Zetterberg et al. 1996), and therefore it cannot be the reason for the faster growth compared to Ilvessalo's study (1937).

The reaction of the trees to increased growing space during the first 10-year period following precommercial thinning was slow (see also Varmola 1987). Only a slight reaction was seen in the breast height diameter increment. However, the reactions were clear during the second 10-year period following thinning. The increment in mean height was the greater, the more widely spaced were the trees in the stand. This was partly the result of differences in tree size between the treatments.

According to Vuokila (1972, 1980), Näslund (1983), and Pettersson (1993) the decrease in height increment in dense stands of Scots pine is primarily a result of increased light competition. Height increment may also decrease in very widely spaced stands of Scots pine because tree growth is then concentrated to the branches due to reduced competition for light (Vuokila 1980). Varmola (1982) and Salminen and Varmola (1990) did not find any effect of stand density on height increment in stands growing on sub-dry sites in southern Finland. The results of this study showed that competition between the trees was not yet severe enough to have any clear effect on the decrease in height increment even on the densest plots.

Differences in diameter increment between the thinning treatments only became clearly evident during the second 10-year period following precommercial thinning. This was also the case with basal area increment and volume increment, although the differences between the treatments were smaller than those reported in many other studies conducted in more southerly locations (Vuokila 1972, Vestjordet 1977, Varmola 1982, Fryk 1984, Salminen and Varmola 1990, Pettersson 1993). The reaction to increased growing space was clearer in stands thinned early in their development compared to stands thinned at a later stage (see also Thernström 1982, Varmola 1982).

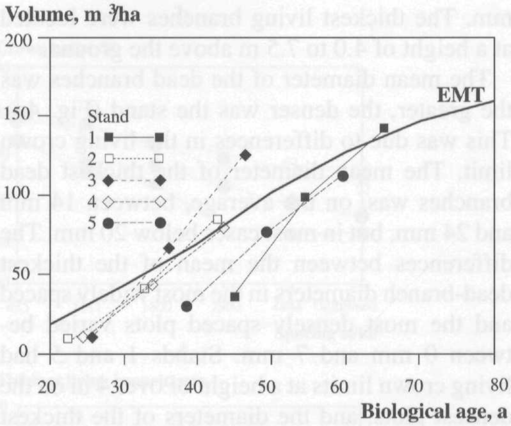

Fig. 5. The volume development of unthinned plots in the experimental stands 1972(–73)–1992. Volume development of forest site type EMT according to Ilvessalo (1937).

The analysis based on diameter distributions gave a good picture of the reactions of different-sized trees to precommercial thinning. Analysis of the reliability of the method based on the exact position of a tree within the DBH distribution was examined in successive measurements. The position of a individual trees was found to change only slightly, and the change within the 100 trees ha^{-1} classes was so small that this had no effect on the results.

According to the analysis on the 100 trees ha^{-1} classes, precommercial thinning had no effect on diameter or volume increment until the second 10-year period following precommercial thinning. The reaction of the trees to thinning showed a delay of ten years. Such a delay in growth reaction following thinning, although a shorter one, has been reported only by Niemistö (1991) in young stands of downy birch growing on peatland sites in northern Finland. The size and the increment rate of the trees varied from stand to stand (see Fig. 1 and Table 5). Therefore the graphical analysis (Fig. 3) could only give an average picture of the differences in increment along the diameter distribution.

On sub-dry sites in southern Finland, both diameter and volume increment following precommercial thinning were clearly the higher, the more widely spaced was the stand when corresponding groups of 100 trees were examined (Salminen and Varmola 1990). The increment reaction was seen immediately following precommercial thinning. The extremely slow reaction of the trees in this study could be a result of the differences in competition conditions in northern Finland as compared to those in southern Finland. The critical factor restricting tree increment is more likely to be competition at the root level rather than for light. It can take years for root systems of trees to occupy the vacated growing space, and the increment reactions in stems begins even later.

The volume increment of the 100 thickest trees ha^{-1} was higher than was expected on the basis of the size differences. No exact reason for such a high increment of the dominant trees could be found. It would be expected that the biggest trees do not suffer from any competition and therefore grow well. On the other hand, the increment of the 100–200 thinnest trees ha^{-1} was clearly poorer than that of trees in the next larger DBH distribution class. This result showed that if the main principle used in precommercial thinning is the attainment of even spacing, then the smallest trees cannot react positively to the increase in growing space. In other words, increment following precommercial thinning should be concentrated on the tallest trees even though it may result in grouped spacing.

The external quality of the trees was good. Ten years after precommercial thinning the thickest branches along the butt log of the 500 thickest trees ha^{-1} averaged 16–20 mm in diameter, depending on the spacing (Varmola 1987). Another ten years later the thickest branches in the same tree groups were 26–30 mm in diameter and located along the whole tree stem. In stands thinned at a late stage, the living crown limit was already at a height of over 4 m. The quality of the butt logs in these stands will be high even in widely spaced stands following precommercial thinning. This is due to high initial density combined to a late precommercial thinning (see Varmola 1987). In stands thinned at an early stage, however, the thickest living branches located along the butt log will continue to grow and quality will deteriorate.

According to the results obtained in earlier studies, the thickest living branches are linearly the thicker, the more widely are the trees spaced in the stand (Varmola 1980, Kellomäki and Tuimala 1981, Jokinen and Kellomäki 1982, Andersson 1985, Turkia and Kellomäki 1987, Kellomäki et al. 1992). In the present study, the differences resulting from extremes in spacing averaged 5 mm in branch diameter. This is small, and can be explained by the rather slow increment reaction in breast height diameter. In stands 2–4 the trees had not yet self-pruned to 4 m. This means that the thickest branches along the butt log will still grow and final conclusions cannot be made.

Twenty years after the precommercial thinning, the effect of spacing on the crown ratios of the trees was clearly evident, although the effect was weaker among the 500 thickest trees ha^{-1}. According to Vuokila (1980), Scots pine can achieve maximum increment if its crown ratio is over 40 %. It is obvious that in stands such as those examined in this study longer crowns are required for optimum growth.

Combining rapid development and high volume increment in order to produce large trees is not an easy task. Trees become thick when widely spaced, but this means a loss in the total volume yield. The diameter increment of trees is promoted by early precommercial thinning; the earlier the thinning, the greater the diameter increment. On the other hand, if external quality is one of the targets in concern, a Scots pine stand should be kept unthinned until the branches along the length of the butt logs have died. In northern Finland precommercial thinning should not, therefore, be made before the stand dominant height is ca. 7–8 m. At that point in time, precommercial thinning has only a minor effect on the thickness of branches along the butt log.

A growing density of 2500 stems ha^{-1} seems to be sufficient for volume increment because denser spacings do not produce any advantages in yield. In practical forestry, the need to reduce costs and to increase the degree of mechanisation in commercial thinning operations both favour late and rather intensive precommercial thinning. Late precommercial thinning at the dominant height of 8 m, and reducing stand density to 1600 stems ha^{-1}, could postpone the first commercial thinning by at least 5–10 years when compared to a spacing of 2500 stems ha^{-1}.

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