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Stand Characteristics and External Quality of Young Scots Pine Stands in Finland

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The effects of silvicultural practices (regeneration method and young stand management) on the stand characteristics of young Scots pine (*Pinus sylvestris* (L.)) stands were studied. Stand density, mean diameter, crown ratio and external quality of young Scots pine stands were analysed on the basis of extensive inventory data. The study material consisted of 181 stands containing inventory growth plots, representing the most common site types for Scots pine and covering all the important wood production areas in Finland.

Intensive management practices, i.e. artificial regeneration and precommercial thinning, clearly enhanced mean diameter development of the stand. The overall stand density of the crop trees was relatively low in the material (1925 trees ha^{-1}). In more than one third of the stands, the stem number of crop trees was below 1500 trees ha^{-1}. Stand density was not affected by forest management, but it was slightly higher in Southern than in Northern Finland. The geographical location, in terms of annual effective temperature sum, affected the average slenderness and crown ratio. At a given mean stand diameter, the dominant height of the stand was lower, and the mean crown ratio was higher, in Northern than in Southern Finland.

The average external quality of the Scots pine trees was relatively low. The proportion of trees without any observed defects was 54%. The most common external defects were curved stems (23%) and branchiness (9%). Branchiness was more frequent among the largest trees, while curved stems were more common in smaller trees. Defects were the most frequent in planted stands, and in stands growing on fresh sites. The defects were more frequent in Northern Finland than in Southern Finland.

The relatively low stand density and poor external quality of the young stands emphasize the importance of stem quality as a tree selection criterion in commercial thinnings of Scots pine stands, if the goal is to produce high quality timber.

Keywords Scots pine, growth and yield, external stem quality, young stand management, precommercial thinning
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1 Introduction

In Fennosscandia, wood production is based on intensive forest management. The most important goal of the management of Scots pine stands is to produce high quality timber. The stand management regime is widely based on successive intermediate thinnings, the purpose of which is to increase the amount of merchantable wood, improve the timber quality, and thus to increase the harvest income.

The silvicultural practices applied in young stands form the basis for further stand management. Success or failure in young stand management has a long-term effect on stand development and on the profitability of forest management. In the regeneration phase, selection of the tree species to be grown and the regeneration method to be utilized are the most important decisions. Later on, precommercial thinning is of great importance in the management of young coniferous stands. The goal of precommercial thinning is to provide adequate growing space and resources to the most valuable portion of the growing stock by controlling the stand density and tree species composition. Furthermore, the management practices applied in young stands also strongly affect the timing and profitability of the first commercial thinning.

In Finland, the young stands that are currently approaching the first commercial thinning stage were established in the 1970s–1980s. During that period, about 30% of the regeneration felling area was regenerated naturally and about 70% artificially. The total felling area was 158 000 ha per year (Finnish Statistical... 2005). Artificially regenerated areas were mainly planted (82%), and only 18% were seeded. The proportion of Scots pine (*Pinus sylvestris* L.) in artificial regeneration was 78% and of Norway spruce (*Picea abies* (L.) Karst.) only 18% (Finnish Statistical... 2005). Precommercial thinning was carried out extensively in the 1970s, reaching a peak of 543 000 ha a^{-1} in 1977, but then gradually decreased to 151 000 ha a^{-1} in 1997 (Finnish Statistical... 2005). During the last decades, one of the main goals of forest policy has been to increase the areas of precommercial and first commercial thinnings. In 2005 the precommercial thinning area was 219 000 ha (Finnish Statistical... 2007). According to the latest Finnish National Forest Inventory, the total area in urgent need of precommercial thinning was increased 1.6-fold compared to the situation during the previous 10-year period (Korhonen et al. 2006).

The recent results of the 10th Finnish National Forest Inventory show that 39% of advanced seedling stands and 23% of young stands were classified as being of good silvicultural quality (Korhonen et al. 2006). An advanced seedling stand was defined as a stand where the mean height was over 1.3 meter and the mean diameter at breast height under 8 cm. A young stand was defined as the stand which was young and at the thinning stage, and the timber yield was mainly pulpwood (VMI10 Maastotyöohje... 2006). The most common reasons for classifying a stand in lower silvicultural quality classes were uneven stand density and different kinds of damage.

Stand density is one of the most important factors affecting external stem quality (e.g Varmola 1980). Kellomäki and Tuimala (1981) found that, when the total stem number in young Scots pine stands was 2500 trees per hectare, the sum of the branch cross-sectional area of a tree was only about one third of that in a stand of 1800 trees per hectare. Kellomäki (1984) reported that the smallest branch diameter was achieved with a total stem number of 3000 trees per hectare in young Scots pine stands. Kellomäki et al. (1992) suggested that a high initial stand density (4000 to 5000 trees per hectare), with precommercial thinning at a height of 5 m to a density of 2000 trees per hectare, leads to high timber quality. The timing of precommercial thinning has also been found to affect the quality. According to Varmola (1982), carrying out precommercial thinning at a dominant height of 5 to 6 m ensures that the diameter of the thickest branches will remain at a level of about 30 mm. According to Fahlvik et al. (2005), an increasing number of remaining trees after precommercial thinning resulted in a reduction in branch diameter, but the reduction was minor if the stand density was more than 3000 trees per hectare after thinning.

Generally, if the main goal is to produce a high timber yield, early or intensive precommercial thinning is recommended. The commonly applied stand density of 1600–2500 trees per hectare after precommercial thinning has been suggested in many Nordic studies, e.g. Vuokila (1972), Vestjordet (1977), Parviainen (1978), Pettersson (1993). Varmola and Salminen (2004) suggested early thinnings if the aim is high volume growth, but late thinnings if the aim is high external quality. Nilsson and Gemmel (1993) compared young Scots pine and Norway spruce stands and found that, when producing high quality timber, the spacing in young stands is more important for pine than for spruce.

The regeneration method and site type have also been found to affect the external quality in terms of stand density and, furthermore, in branch diameter. Vuokila (1982) recommended natural regeneration, or when it was not possible, seeding. Varmola (1996) also preferred seeding, and Agestam et al. (1998) natural regeneration instead of planting when producing high quality timber. Turkia and Kellomäki (1987) recommended growing Scots pine only on relatively infertile *Myrtillus* or less fertile sites. Lämsä et al. (1990) found that increasing site fertility enhanced branch growth, especially in the upper crown. Uusvaara (1991) studied 20-year-old, planted Scots pine stands and reported that the mean diameter of the three thickest branches, over the section of the stem extending from the base to a height of 5 m, was lower than 20 mm only on *Calluna* and *Vaccinium* sites. In contrast, Varmola (1980) reported that the lowest external quality occurred on Vaccinium sites owing to the lower stand density than on more fertile sites.

Most of the Finnish growth and yield research is based on measurements made in specially designed experiments, in which the effects of alternative young stand management practices are compared in controlled conditions. So far, no research results have been published that are based on extensive and representative data collected in young commercial stands. There is a lack of reliable, research-based information about the results of management practices that have been widely applied in young stands in commercial forests. The relevant question for Finnish forestry is what is the current status of young stands from the point of view of growth and of yield and wood quality?

The aim of the study was to assess the effects of silvicultural practices, regeneration method and young stand management, on the characteristics of young Scots pine stands close to the first commercial thinning stage. We examined stand density, mean diameter, crown ratio and external quality of young stands using extensive inventory data for young Finnish Scots pine stands. In addition to silvicultural effects, the impact of site variables was also assessed.

2 Material and Methods

2.1 Study Material

Extensive inventory data from young, even-aged Scots pine stands in Finland were used in the study. The material consisted of inventory growth plots (TINKA) established by the Finnish Forest Research Institute during 1984–1986 (Gustavsen et al. 1988). TINKA data are a sub-sample of the stands measured in the 7th National Forest Inventory (NFI7) in Finland. NFI7 consisted of systematically located relascope defined sample plots covering the whole Finland. Only successfully regenerated, coniferous dominated young stands with a stand dominant height below five meters were accepted in the TINKA-dataset (Gustavsen et al. 1988). Thus poorly regenerated stands, which would need re-regeneration, were not included in the data set. The data included sample plots representing different regeneration methods: natural regeneration, seeding and planting. The selection criteria of the TINKA dataset excluded stands dominated by broadleaved tree species. As a consequence of this, managed sapling stands in which broadleaved trees had been removed were most probably accepted more frequently than unmanaged stands, which were originally regenerated for conifers but had subsequently been overtaken by broadleaved species. However, the silvicultural management history before establishment of the sample plots was not completely documented.

Only the most important site types for Scots pine and Norway spruce were included in the TINKA data. The site type classification is based on the forest site type theory of Cajander (1949). The sites were classified into fresh, dryish, and dry sites according Tonteri et al. (1990) corresponding to Cajander's (1949) forest site types *Myrtillus*, *Vaccinium* and *Calluna* types, respectively.

A cluster of three permanent sample plots was established in each stand included in the TINKA sub-sample of NFI7 stands. The sample plots were established as blind plots, so that the presence of the sample plots would not affect stand management. Circular (tally tree) plots were located systematically, with a distance of 40 m between the plots. The first plot was located in the centre of the NFI7 plot, and the other plots were located such that all the plots were inside the stand (Gustavsen et al. 1988). The plot size varied according to the stand density. Plot size was determined as a function of the stand density, which was estimated ocularly before the plot measurements. The plot size for the stand was then determined so that the total number of measured crop trees in each stand was approximately at least 100. Thus an average of ca 30 to 35 crop trees were measured as tally trees on each circular sample plot. A concentric, smaller circular sample tree plot was delineated within each tally tree plot, the area being equal to one third of that of the tally tree sample plot. Thus, ca. 30 crop trees were measured as sample trees in each stand.

A tree was defined as a crop tree, if it was assumed to reach merchantable stem size at the time of the first commercial thinning. The criterion for a crop-tree varied according to the regeneration method and management history of the stand. In managed stands all the coniferous trees (height over 10 cm) were classified as crop trees (Gustavsen et al. 1988). In addition, broadleaved trees were accepted as crop trees if they were shorter than the conifers. In naturally regenerated and seeded unmanaged stands, ca. 40 of the most vigorous trees per tally tree plot (corresponds to 3000 trees per ha, depending on sample plot size) were chosen as crop trees (Gustavsen et al. 1988).

After establishment, the plots were re-measured twice; 5 (1989–1991) and 15 years (2000–2001) after the first measurement. At the first measurement instance, site characteristics and information on stand management history were determined. At the first and second measurement instances, all the crop trees were measured for location, tree height and diameters at breast height ($d_{1.3}$), stump height ($d_{0.1}$) and 30% relative height ($d_{0.3h}$). At the third measurement instance, all the crop trees were measured for location and diameter at breast height was measured on all the crop trees. Tree height, diameter at 6 m height ($d_{6.0}$) and the height of the living crown base were measured on the sample trees. Age at breast height was measured on three trees per sample plot, and the total age was determined for one sample tree per plot. Tree age was determined either on the basis of the number of whorls or from increment cores. At each re-measurement instance, the stand treatment carried out after the last measurement occasion was recorded.

At the third measurement occasion, the crop trees were classified into quality classes based on external quality defects (Gustavsen et al. 1988). Tree quality determination was based on ocular assessment. The external quality was based on a classification consisting of either with or without defects. If there was a defect in the tree, it was classified into three different defect classes: branchy, curved or forked stem. If there was more than one defect in the tree it was classified as multiple defects in our analyses. A large number of field teams participated in the measurements. The effects of possible measurement and assessment errors were minimized before the start of the field work by providing the observers with detailed instructions, and by training the field teams.

Only the data from the third plot measurement were used in this study. The analyses were restricted to young Scots pine stands in which the first commercial thinning had not yet been carried out. This data set consisted of 181 stands (Fig. 1). The original data (3 measurements) included 192 Scots pine stands. The study material covers the whole area of commercial wood production in Finland, the effective temperature sum in the area ranging from 690 to 1305 d.d. All the typical site types for Scots pine on mineral soils, i.e. fresh (39%), dryish (47%) and dry (14%) sites, were represented in the data. The regeneration method included natural regeneration (40%), direct seeding (18%), and planting (42%). The age of the stands varied from 16 to 66 years, the average age being 28 years. Measurement data from the TINKA plots, with different terms, have been used earlier for growth modelling purposes by Hynynen et al. (2002) and Huuskonen and Miina (2006).

Table 1. Number of stands by stand management, regeneration method, site type and location in Southern Finland (SF) and Northern Finland (NF).

Stand management	Regeneration method	Site type Fresh SF	Fresh NF	Dryish SF	Dryish NF	Dry SF	Dry NF	Total
No pre-	natural	2		7	8	5	8	30
commercial	seeded	1	2	2	2			7
thinning	planted	9	18	5	11			43
Total		12	20	14	21	5	8	*80*
Precommercial	natural	6	1	18	5	10	2	42
thinning	seeded	6	3	15	2			26
	planted	12	10	6	5			33
Total		24	14	39	12	10	2	*101*
Grand total		36	34	53	33	15	10	*181*

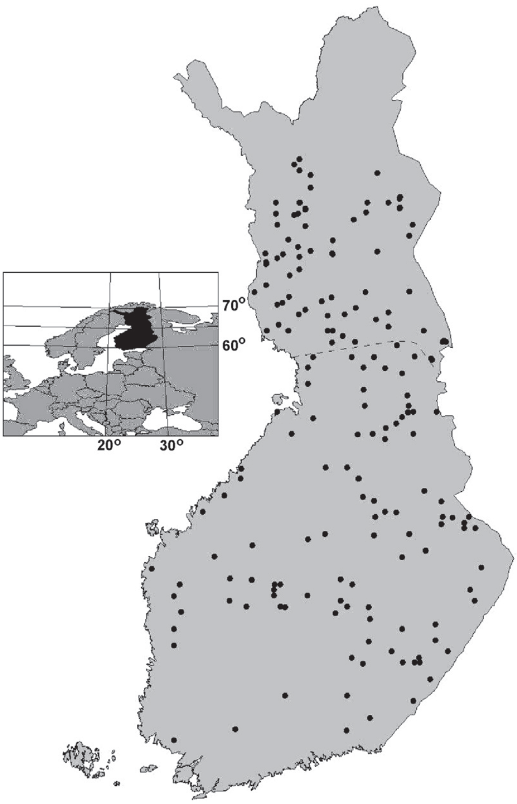


Fig. 1. Location of the TINKA inventory growth plots (N = 181). The dashed line depicts the borderline between Southern and Northern Finland.

The data and the results of the analyses are illustrated in Figs. 1–6. For this purpose the stands were classified into four dominant height classes: H_{dom} less than 6 m ($N = 30$), H_{dom} from 6 m to 9 m ($N = 66$), H_{dom} from 9 m to 12 m ($N = 51$) and H_{dom} over 12 m ($N = 34$). The stands were classified further into the two geographical regions: Southern Finland (104 stands, mean 1065 d.d.) and Northern Finland (77 stands, mean 815 d.d.) (see Fig. 1). In this classification, the border between Southern and Northern Finland was set to about 860 d.d., approximately corresponding to latitude 65.4°N.

Precommercial thinnings were carried out in 56% of the stands. Stand management varied according to location, site type and regeneration method. In Southern Finland 70% and in Northern Finland 36% of the stands were thinned. Precommercial thinning was more common on fresh (54%) and on dryish (59%) site types than on the dry site type (48%) (Table 1). Furthermore, precommercial thinning was carried out in the majority of the seeded stands (79%), but in only 43% of the planted stands (Table 1). Infilling was performed in 6% of the stands. Infilling was more frequent on relatively fertile (fresh) than on dry site types. Infilled stands had typically been regenerated by planting (91%).

The stands were clearly dominated by pine. The proportion of pine was, on the average, 77% of the crop trees. The admixed species were mainly Norway spruce, silver birch (*Betula pendula* Roth) and pubescent birch (*Betula pubescens* Ehrh.). The proportion of birch and other deciduous trees was the highest on the relatively fertile site types (fresh site), in Southern Finland and in planted stands.

2.2 Data Analysis

Stand characteristics were calculated using the KPL software developed at the Finnish Forest Research Institute (Heinonen, 1994). In the calculation, the plots within the same stand were pooled. The heights of the tally trees within a given plot were obtained using a height model based on the height measurements of the sample trees on a plot using Näslund's height curve (Näslund 1936). The dominant height was calculated as the mean height of the 100 largest trees ha^{-1} of the main tree species. The mean diameter was calculated as the arithmetic mean diameter of the crop trees. The long-term average (1951–1980) of the annual effective temperature sum (Celsius degree days, d.d., threshold +5ºC), was predicted for each stand using the interpolation method of Ojansuu and Henttonen (1983). The interpolation was based on a grid of the measurement data from the official measurement stations of the Finnish Meteorological Institute. The stand-level average of the tree crown ratios was calculated as the arithmetic mean of the Scots pine trees within a stand.

General linear models were developed to analyze the effect of regeneration method, site type and precommercial thinning on the stand density (stem number), mean diameter, mean crown ratio and the external quality characteristics. Categorical variables depicting regeneration method, precommercial thinning, and site type were included as independent variables. Mean diameter, dominant height and temperature sum were included as continuous covariates. The analyses of stand density, mean diameter and mean crown ratio were performed using the GLM procedure of SAS (SAS institute Inc. 1999). The models for stand density, mean diameter and mean crown ratio were formulated as follows:

$$N_{crop\ trees} = \beta_0 + \beta_1 X_1 + ... + \beta_n X_n + \delta_R + \delta_S + \delta_{PCT} + \varepsilon \quad (1)$$

$$D_{1.3} = \beta_0 + \beta_1 X_1 + ... + \beta_n X_n + \delta_R + \delta_S + \delta_{PCT} + \varepsilon \quad (2)$$

$$CR = \beta_0 + \beta_1 X_1 + ... + \beta_n X_n + \delta_R + \delta_S + \delta_{PCT} + \varepsilon \quad (3)$$

where $N_{crop\ trees}$ is the stem number (crop trees per hectare), $D_{1.3}$ the arithmetic stand mean diameter, CR the average of the crown ratios of Scots pine trees, β_0 the constant, β_1–β_n regression coefficients, X_1–X_n the potential continuous independent variables and their interactions, δ_R, δ_S, δ_{PCT} the effects of regeneration method, site type and precommercial thinning, respectively, and ε the random error. The potential continuous independent variable were the annual temperature sum (d.d./1000) TS, the number of crop trees in the stand per hectare $N_{crop\ trees}$, the mean diameter (cm) $D_{1.3}$, and the dominant height (m) H_{dom}.

The purpose of this study was to assess the effect of stand management on stands close to the first commercial thinning stage. We have used the dominant height instead of the age of the stand to depict the stage of stand development. In Finnish forestry, stand dominant height together with stand density (N) are used as the criteria for the timing of the first commercial thinning. Thus, in this context, results related to dominant height are more useful than those related to age. When dominant height is a covariant in the mean diameter model, the other independent variables measure anomalies from the expected mean diameter with fixed dominant height, i.e. differences in the average slenderness of the trees. The stand growth models of Huuskonen and Miina (2006), based on mainly the same data, depict stand development as a function of stand age.

The proportion of trees with each external defect was used as the measure of the external quality: $N_r = N_{def}/N_{crop\ trees}$ where N_{def} is the number of crop trees with certain external defects and $N_{crop\ trees}$ the total number of crop trees in the stand per hectare. The generalized linear model approach was used with the logit link function, $g(u) = \ln(N_r / (1 - N_r))$:

$$g(u_i) = \beta_0 + \beta_1 X_{i1} + ... + \beta_n X_{in} + \delta_R + \delta_S + \delta_{PCT} \quad (4)$$

where X_{i1}, ... X_{in} are the response variables for the i^{th} observation.

Table 2. Statistical analyses of stand density, arithmetic mean diameter and arithmetic average of the tree crown ratio.

Variable		Stand density of crop trees, trees ha^{-1}		Mean diameter, cm		Tree crown ratio	
		Estimate	Pr > F	Estimate	Pr > F	Estimate	Pr > F
Intercept		420.6	0.3639	2.388	0.0003	0.895	<.0001
Number of crop trees, trees ha^{-1}		–	–	-0.622	<.0001	–	–
Dominant height, m		–	–	1.364	<.0001	–	–
Mean diameter, cm		–	–	–	–	0.008	<.0001
Temperature sum, d.d./1000		2414.2	<.0001	–	–	–	–
Dominant height x Temperature sum		–	–	–0.418	<.0001	–0.032	<.0001
Regeneration method	*natural*	–96.2	0.5768	–1.817	<.0001	0.021	0.0577
	seeded	–202.3	0.2766	–1.065	0.0003	0.005	0.6902
	planted	0.0	–	0.0	–	0.0	–
Site type	*fresh*	49.7	0.8355	0.935	0.0131	–0.017	0.2456
	dryish	27.1	0.8969	0.672	0.0410	–0.011	0.3799
	dry	0.0	–	0.0	–	0.0	–
No precommercial thinning		164.3	0.2146	–0.479	0.0307	0.002	0.8045
Precommercial thinning		0.0	–	0.0	–	0.0	–

The proportion of trees with defects was assumed to follow the binomial distribution. The analysis of external quality was carried out using the GENMOD procedure of SAS (SAS institute Inc. 1999).

In all the statistical tests, variables were considered as significant if the p value was less than 0.05 (5% risk level).

3 Results

3.1 Stand Characteristics

Stand Density

The average spacing of the stands was relatively sparse. The mean stand density was 1925 crop trees per hectare. In 37% of the stands the stem number of crop trees was less than 1500 trees ha^{-1}, and in 12% of the stands less than 1000 trees ha^{-1}.

Stand density varied statistically significantly with temperature sum ($p < 0.0001$) (Table 2). On the average, the stand density of crop trees was higher in Southern Finland (high temperature sum) than in Northern Finland (low temperature sum) (Fig. 2A). The difference was the greatest in more advanced stands. For example, in the dominant height class from 9 to 12 m, the average stand density in Southern Finland was 2153, and in Northern Finland 1256 trees per hectare. Regeneration method, site type or precommercial thinning had no statistically significant effect on crop tree stand density (Table 2, Fig. 2B, 2C, 2D). Dominant height, age or the interaction between dominant height and temperature sum were not significant predictors of the number of crop trees.

Mean Diameter

The arithmetic mean diameter varied significantly according to the regeneration method, site type, precommercial thinning, stand density and temperature sum, at a given dominant height (Table 2). A larger stand density resulted in a lower mean diameter ($p < 0.0001$). Arithmetic mean diameter at a given dominant height was slightly higher in Northern than in Southern Finland (Fig. 3A). This indicates that the trees are more slender in the south than in the north when other conditions are equal. Regeneration method affected the mean diameter at a given dominant height: in planted stands the mean diameter at a certain dominant height was greater than that in seeded stands ($p = 0.0003$), and in seeded stands greater than that in naturally regenerated stands ($p < 0.0001$)

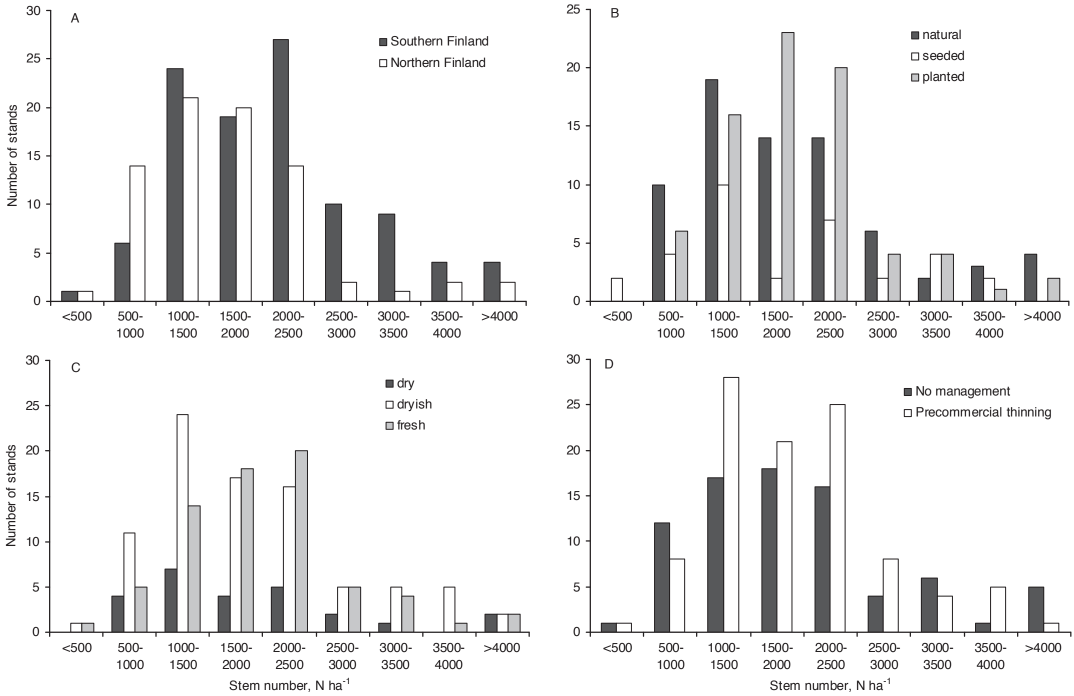


Fig. 2. Number of stands by stem number (crop trees) class and by A) geographical location, B) regeneration method, C) site type and D) precommercial thinning.

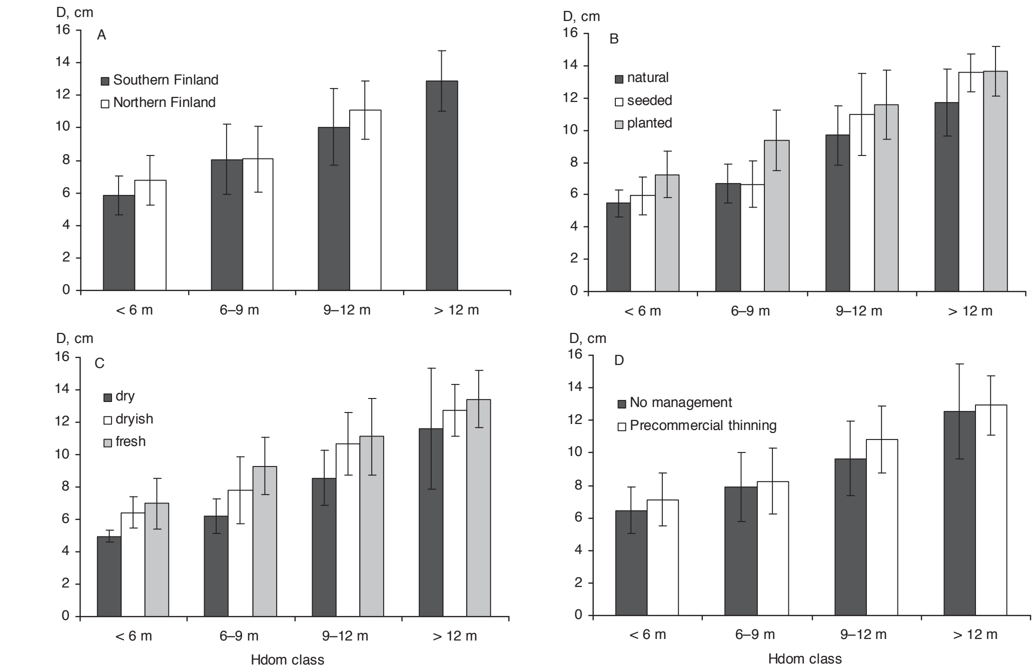


Fig. 3. Arithmetic mean diameter by dominant height class and by A) geographical location, B) regeneration method, C) site type and D) precommercial thinning. Vertical bar represents standard deviation of the mean.

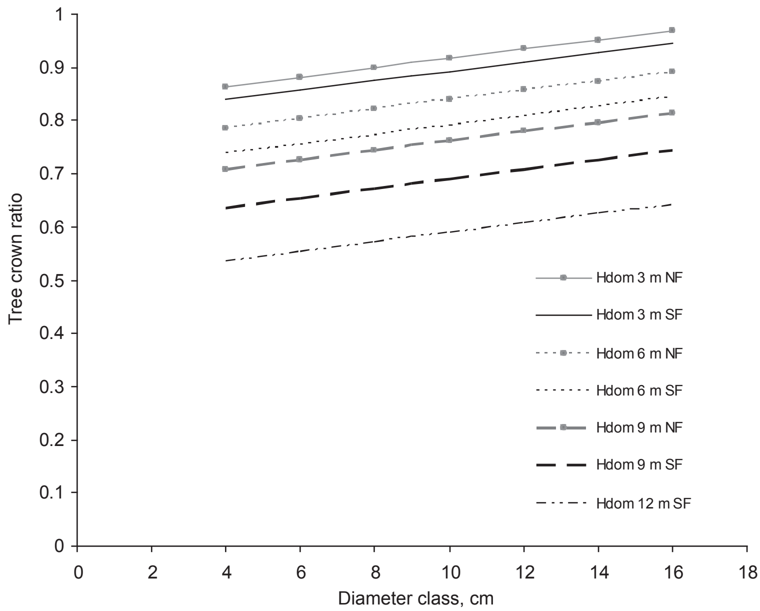


Fig. 4. Tree crown ratio by diameter class and by dominant height class in Southern Finland (SF) and Northern Finland (NF). The lines represent the predicted values of the tree crown ratio model at certain dominant height class (Model 3). In the estimation, the following constant values were applied: temperature sum 1065 d.d. (SF) and 815 d.d. (NF), dryish site type, natural regeneration and no precommercial thinning.

(Fig. 3B). The effect of site type on mean diameter was also statistically significant: on the fresh site type the mean diameter was greater than on the dryish ($p=0.0410$) or dry site type ($p=0.0131$) (Fig. 3C). The precommercial thinning had a significant effect on mean diameter ($p=0.0244$). The mean diameter at a given dominant height was greater in precommercially thinned stands than in unthinned stands (Fig. 3D).

Mean Crown Ratio

In the young Scots pine stands, the average proportion of living crown out of tree height was almost 70% (mean crown ratio 0.69), and varied according to stand dominant height, mean diameter ($p<0.0001$) and temperature sum ($p<0.0001$) (Table 2). As expected, crown ratio decreased with increasing stand dominant height. Furthermore, at a given height, the crown ratio increased with increasing tree diameter (Fig. 4). In Northern Finland, where the temperature sum is lower, the average tree crown ratio was higher (0.78) than in Southern Finland (0.62) (Fig. 4). The effect of regeneration method, site type or precommercial thinning on tree crown ratios were not statistically significant.

The variation in tree crown ratio was examined in different stand mean diameter and stand dominant height classes in Southern and in Northern Finland (Fig. 4). At a given diameter and dominant height class, the tree crown ratio was lower in Southern Finland than in Northern Finland. In addition, the differences in tree crown ratio between dominant height classes were smaller in Northern Finland than in Southern Finland.

3.2 External Quality

Different kinds of external defect were common in the young pine stands. The proportion of trees with no defects was 54%. The most common defects were curved stem (23% of trees with defects), multiple defects (13%), branchiness (9%) and forking (1.6%). Multiple defects consisted mainly of branchy and curved trees.

The temperature sum significantly affected the proportion of external defects (Table 3). Branchy and forked stems were more frequent when the temperature sum was low ($p<0.0001$). On the other hand, more curved and multiple-defect trees occurred when the temperature sum was high ($p<0.0001$).

The proportion of defects was higher in planted stands than in seeded or in naturally regenerated stands (Fig. 5A). The effect of regeneration method was statistically significant on the following defects: branchiness ($p<0.0001$), curved stem ($p<0.0001$), forked stem ($p=0.0048$) and multiple-defect trees ($p<0.0001$) (Table 3). The proportion of branchy, forked or multiple-defect trees was highest in planted stands. Trees with curved stems were more common in naturally regenerated and seeded stands than in planted stands.

When comparing the site types, the highest proportion of defect-free trees occurred on the dryish site type (Fig. 5B). The proportion of branchy ($p=0.0011$), curved ($p<0.0001$) and multiple-defect trees ($p<0.0001$) was significantly different between the site types (Table 3). Curved stems were the most infrequent on the dryish site type. However, the proportion of branchy or multiple-defect trees was the highest on the relatively fertile site types.

External quality of the trees was improved only slightly by precommercial thinning. The proportion of curved trees was smaller in stands where precommercial thinning had been carried out ($p<0.0001$), but in precommercially thinned stands the proportion was not significantly less or more than that of other external defects. According to Fig. 5C, in Southern Finland precommercially thinned stands had less defects than stands with no precommercial thinning.

Examination of the defect frequencies by diameter classes showed some size-related patterns in the occurrence of defects (Fig. 6). In Southern Finland, the share of trees without defects was relatively unaffected by tree diameter, whereas in the north the occurrence of defects increased with increasing tree diameter. Of the different defect classes, branchiness was more frequent among the largest trees, while curved stems were more common in smaller diameter classes. Especially in Northern Finland, branchiness was the major cause of defects in the largest trees.

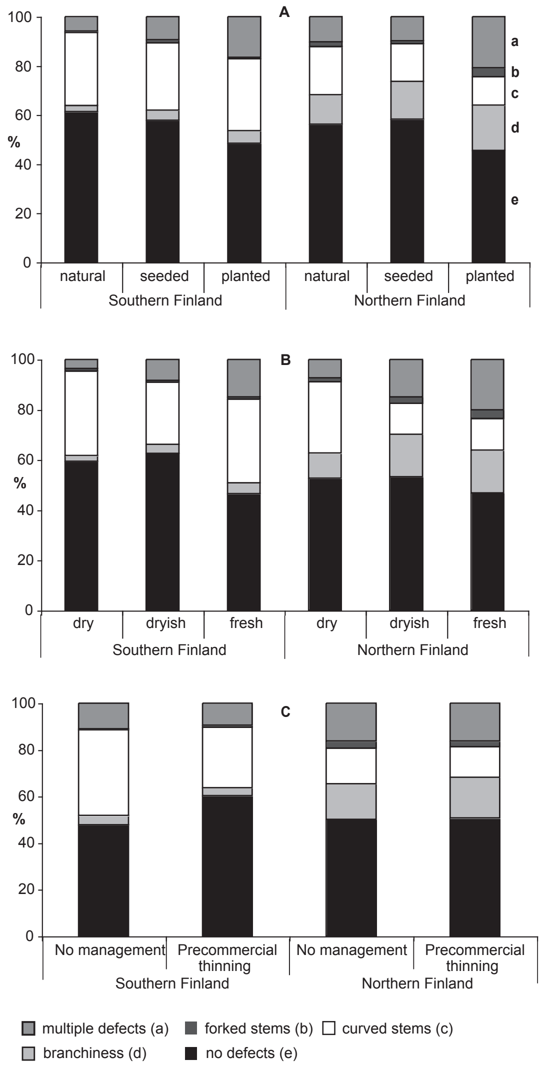
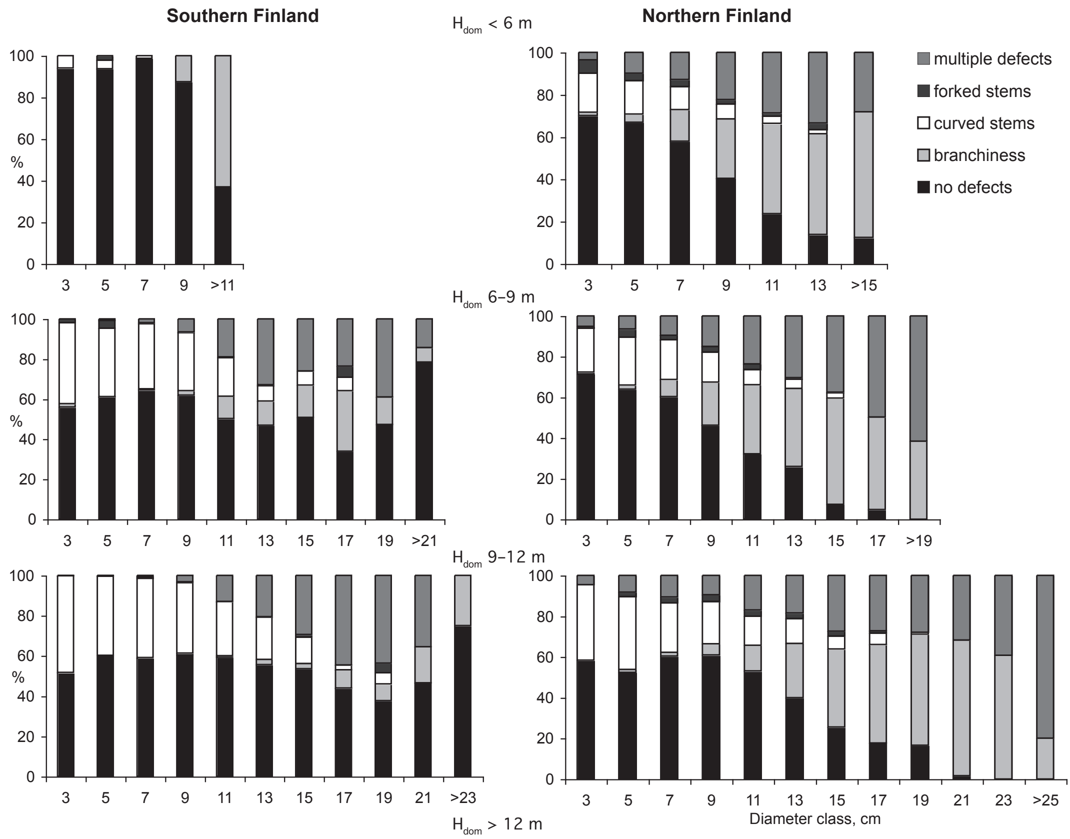


Fig. 5. The proportion of trees classified into different external quality classes in the stands by geographical location, and by A) regeneration method, B) site type and C) precommercial thinning.

Table 3. Statistical analyses of external quality characteristics (proportion of trees with defects).

Variable		Branchiness Estimate	Branchiness Pr > ChiSq	Curved stems Estimate	Curved stems Pr > ChiSq	Forked stems Estimate	Forked stems Pr > ChiSq	Multiple defects Estimate	Multiple defects Pr > ChiSq
Intercept		1.6613	<.0001	–6.2501	<.0001	–0.6387	0.1622	–2.8605	<.0001
Temperature sum		–4.4690	<.0001	4.7876	<.0001	–3.5391	<.0001	0.6360	<.0001
Regeneration	*natural*	–0.6677	<.0001	0.5280	<.0001	–0.5816	0.0019	–0.8031	<.0001
method	*seeded*	–0.2788	0.0010	0.2880	<.0001	–0.3026	0.1188	–0.9493	<.0001
	planted	0.0	–	0.0	–	0.0	–	0.0	–
Site type	*fresh*	0.4465	0.0003	0.0558	0.4205	0.0703	0.7842	0.9454	<.0001
	dryish	0.3712	0.0008	–0.3966	<.0001	–0.1246	0.5850	0.6685	<.0001
	dry	0.0	–	0.0	–	0.0	–	0.0	–
No precommercial thinning		0.0385	0.5018	0.5789	<.0001	0.1111	0.3802	0.0853	0.0847
Precommercial thinning		0.0	–	0.0	–	0.0	–	0.0	–



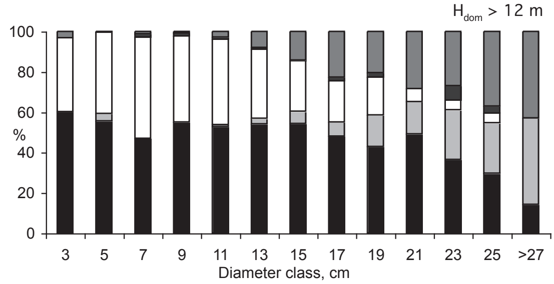


Fig. 6. The proportion of trees classified into different external quality classes in the stands by geographical location, dominant height (H_{dom}) class and by diameter class. Each class included 250 crop trees, on the average, and varied between 5 to 773 crop trees.

4 Discussion

The aim of the study was to determine the effect of stand management on young Scots pine stands in Finland based on extensive inventory data. In the material, the stand densities were relatively moderate despite the fact that almost half of the stands had not been managed during the observation period. This finding suggests that many of the stands might have been treated already before the first measurement. Cleaning of young sapling stands, at a mean stand height of less than two meters, was a common practice in Finnish forestry during the 1970's and 1980's (e.g. Takala 1978). In unmanaged stands, stem numbers have been reported to be much higher than those recorded in this study. In previous research reports, the stem number in unmanaged, naturally regenerated or seeded stands varied from 3000 up to over 10 000 trees per hectare (e.g. Parviainen 1978, Varmola 1982, 1996, Huuri et al. 1987). This being the case, the main results of this study are primarily applicable to managed young pine stands.

The accurate assessment of external tree quality requires detailed and time-consuming measurements of stem form, stem defects, branch dimensions and their location along the stem. However, these kinds of detailed measurement could not be performed during collection of the extensive inventory data of this study. Instead, tree quality assessment was based on ocular assessment, in which the trees were classified into quality classes. Therefore, the results provide only a general overview of external tree quality. Because of the large area inventoried for this study, a large number of field teams participated in the measurements. There are a lot of error sources related to the ocular assessments made by the individual observers (e.g. Haara 2005). In this study, the effects of possible measurement and assessment errors were minimized before the start of the field work by providing the observers with detailed instructions, and by training the field teams.

Most of the studied stands had been regenerated naturally or by planting. This corresponds rather reliably to the situation with respect to practical regeneration in the 1980s in Finland. Since then, the most marked change has occurred in the tree species that are planted. In the 1980s, the prevailing regeneration method was planting with Scots pine, whereas nowadays Norway spruce is preferred in planting, and the most common regeneration method for pine is seeding or natural regeneration (Finnish Statistical... 2005).

The stand density in Southern Finland was close to the current recommendations in the practical silvicultural guidelines (Hyvän metsänhoidon suositukset 2006). According to Varmola and Salminen (2004), a density of 1600–2200 trees ha^{-1} after precommercial thinning is adequate to ensure a high level of wood production and profitable forest management in pine stands. However, in Northern Finland the average stand density was lower than that recommended in practice (Hyvän metsänhoidon suositukset 2006). Ruha and Varmola (1997) proposed a clearly higher density (2500 trees ha^{-1}) than those inventoried in this study, if the aim is to produce high quality and an adequate yield. The stem number in more than one third of the stands of this study was below 1500 trees ha^{-1}. It is likely that, with such a sparse stocking in a young stand, the wood production capacity of the site will not be fully utilized.

The stand density of crop trees varied only according to temperature sum, and no other variables were found to be significant, (e.g. age, dominant height, site type, regeneration method or precommercial thinning). This was a logical result, because the selection of crop trees was based on the assumption that all the crop trees will grow until the first commercial thinning. The difference in location may indicate that in Northern Finland abiotic factors caused the death of some crop trees, or that in practice some of the crop trees were also removed in precommercial thinning.

The stand diameter development was significantly affected by artificial regeneration, site type and precommercial thinning. The results from the analysis on the stand mean diameter showed that the intensive methods applied in regeneration and young stand management, which include stand density control, accelerate the diameter development of pine stands. The findings of this study are consistent with earlier results (e.g. Ruha and Varmola 1997, Varmola and Salminen 2004, Huuskonen and Hynynen 2006). The results also demonstrated differences in the height-diameter ratio between the stands in Southern and Northern Finland. At a given stand mean diameter, the dominant height of a stand is smaller in the north than in the south. This difference was also reported by Huuskonen and Miina (2006) when modelling the same TINKA data, with different terms.

The average tree crown ratio in our data was relatively high (69%), as can be expected in young stands with a moderate stand density. Due to the relatively narrow variation in stand densities, however, the management practices were not found to have affected the tree crown ratio. The average crown ratio of this study was significantly higher than that reported by Salminen and Varmola (1990). According to their results, the crown ratio of young pine stands (mean height variation from 4 to 14 m) varied between 45–65% depending on the stand density. Nilsson and Gemmel (1993) found that young pines reacted strongly to competition (e.g. stand density), when the reaction to competition was assessed as the number of current shoots. Hynynen (1995) reported that thinning resulted in longer living crowns on pines at a dominant height of 10–20 m. In contrast, Kellomäki et al. (1992) concluded that the dying of branches was mainly dependent on the location of the branch whorl, and that spacing had only a minor effect.

The most prominent difference in the mean crown ratio was found between the stands in Southern and Northern Finland. The earlier results of Kalliola (1971), discussed by Hakkila (1971), show higher crown ratios in Northern than in Southern Finland, but Hakkila suggests that this could be caused by the sparser stands in Northern Finland. Hynynen et al. (2002) found, however, a latitudinal effect in their model for the crown ratio when the effect of stand density was included in the model. In addition, our study shows that the differences in tree crown ratio between dominant height classes were smaller in Northern Finland.

External quality was relatively low in the young pine stands of this study. Defects were most frequent in stands located in Northern Finland, planted stands, and also in stands growing on fresh sites. The most common external defects in our study were curved stems and branchiness. Varmola (1980) reported that, in planted pine stands, 25–29% of the trees were branchy and 3–7% curved, depending on the site type. In Southern Finland the trees were more curved, while in Northern Finland the trees were more branchy. This result may be due to the lower stand density in Northern Finland.

The number of branchy trees was the highest in the planted stands, which is in agreement with the results of Vuokila (1982) and Varmola (1996), who recommended natural regeneration or seeding when the aim is to produce high quality saw timber. According to Strand et al. (1996), the regeneration method has only a small effect, while stand density has the greatest influence on achieving a good external quality. The regeneration method generally affects stand density.

Site fertility was not as important a factor as regeneration method with respect to the proportion of branchy trees. However, the data of this study covered only the most typical sites (relatively infertile) for pine (Gustavsen et al. 1988). Therefore the most fertile sites, such as herb-rich site types, were not included in the TINKA data. In earlier studies, high site fertility was found to be related to low external quality in terms of branchiness (Turkia and Kellomäki 1987, Lämsä et al. 1990, Uusvaara 1991).

In Southern Finland, the proportion of good quality trees was the greatest in stands where precommercial thinning had been done, as expected. However no corresponding difference was found in Northern Finland. This may be due to the lower stand density and, because of this, there was no need to carry out precommercial thinnings. Furthermore, the results showed that only the proportion of curved stems was statistically significantly improved by precommercial thinning.

In Northern Finland, the proportion of defects increased with increasing diameter at a given dominant height. Approximately less than 20% of the dominant trees had no defects. The most important type of defect was branchiness. This will most probably lead to the situation where, even after the first commercial thinning, the external quality of these stands will remain relatively poor. Therefore, in order to improve the saw timber quality in the final felling, quality tree selection should be emphasized in commercial thinnings throughout the rotation.

This study clearly demonstrated, using extensive inventory data, the contradictory effect of moderate stand density and external quality. The moderate density of young stands permits late first commercial thinnings in managed young stands, thus increasing the commercial drain from the first thinning. On the other hand, a moderate or low density makes the stand quality worse and results in a lower yield of high quality saw timber during the rotation time. If the goal is to produce high quality timber in Scots pine stands, then the relatively low stand density and poor external quality of the young stands emphasize the importance of stem quality as a tree selection criterion in commercial thinnings.

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