Technical Properties of Mature Birch (*Betula pendula* and *B. pubescens*) for Saw Milling in Finland

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The purpose of this study was to investigate the variation in selected technical properties of mature (age > 60 years) birch stems in southern and central Finland. Technical properties were defined as the natural external characteristics that cause differences in the usability of a certain section of stem in the mechanical wood industry, saw milling in particular.

On mineral soils, birch stems in mixed stands were slightly larger than those in pure birch stands. On peatlands, however, birch stems in pure stands were larger than those in mixed stands. The average stem form of silver birch was straighter than that of white birch. Small-sized log sections of white birch, as well as those of codominant silver birch, typically contain many dead knots. On mineral soils, coniferous admixture had a positive effect on self-pruning of white birch. Self-pruning of silver birch was as good in pure birch stands as in mixed stands of spruce and birch. Occurrence of decay did not differ significantly between the two birch species.

Not only silver birch, due to the growth and yield of the stand, but also vigorous and good-quality white birch, because of the possibility to provide high-quality logs, can be maintained profitably as an admixture in coniferous forests until final cutting.

Keywords silver birch, white birch, technical properties, saw milling, log, small-sized log
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1 Introduction

In Finland, two birch species are used industrially in mechanical wood processing: silver birch (*Betula pendula* Roth) and white birch (*Betula pubescens* Ehrh.). Birch makes up 14.6 percent of the total volume of growing stock in Finland. Regionally, 67 percent of the birch stock (186 mill. m^3) and 73 percent (9.4 mill. m^3) of the annual growth of birch is located in southern Finland (Sevola 1999). Mature, pure birch stands are, almost without exception, of natural origin and situated in former burnt-over clearings. Silver birch makes up 32 percent of the total birch stock in southern Finland, which is the predominant production area for large-dimensioned birch. As silver birch makes up only 9 percent of the birch stock in northern Finland, white birch makes up most of the total birch supply in the country (Sevola 1999).

According to Niemistö (1991), only 45 percent of the supply of white birch grows in birch-dominated stands, the rest being an admixture in stands dominated by Scots pine or Norway spruce. Most of the silver birch supply also grows in mixed forests (Verkasalo 1997). Of the forest land area, silver birch is the dominant species on only 1.9 percent of the whole country and on 3.3 percent in southern Finland, whereas the corresponding percentages for white birch are 5.9 and 4.3 (Sevola 1999). Silver birch usually grows on fertile mineral soils; white birch also survives on peatlands in nutrient-poor and wet conditions.

Along with the raw material resources, the plywood factories and sawmills, which use birch, are also located in southern and central Finland. Birch is traditionally used in large quantities for veneer and plywood manufacture, 1–1.5 million m^3 annually since the 1960's (e.g., Heiskanen 1966, Verkasalo 1997). Of the annual volume of birch lumber production (50 000–100 000 m^3), more than 70 percent is produced in small private saw mills (Sevola 1999, Luostarinen and Verkasalo 2000). Most of the sawn wood is produced from large logs (top diameter ≥18 cm), where the aim is to obtain high-quality products with no or few knots. Some entrepreneurs who manufacture lumber with sound knots for furniture and parquetry have recently based their production on small-sized birch logs. Considering saw mills it is of special importance to obtain logs with no deformations such as crooks or forks.

The benefits of birch admixture for coniferous forests have been studied e.g., by Mielikäinen (1980, 1985), Hägg (1988), Lehtikangas (1989), Mielikäinen and Valkonen (1995), and Valkonen (2000). These studies examined mainly the effects of birch admixture on the growth and yield of conifers.

In most Scandinavian studies, the stem of silver birch is considered to be straighter than that of white birch (e.g., Kujala 1946, Heiskanen 1957, Verkasalo 1997). On the other hand, results on type and number of knots in different birch species vary. For example, Kujala (1946) and Heiskanen (1957) stated that knots are thicker in silver birch than in white birch. Verkasalo (1997) found the same type of difference, noting, in addition, that the difference increases with the age of the tree. The technical properties of birch veneer logs and their influence on the recovery and quality of rotary cut veneer were studied, e.g., by Heiskanen (1966), Meriluoto (1966) and Verkasalo (1997). The technical properties and quality of young (age <50 a) birch, as well as their growth and yield were studied, e.g., by Niemistö (1994, 1997a, 1997b), Niemistö et al. (1997), Verkasalo (1997) and Viherä-Aarnio and Velling (1999).

Several partially contradictory studies were made concerning the differences between the technical properties of the birch species. Silver birch were found to grow faster on fertile sites, which also explains why, on average, silver birch stems are bigger than those of white birch at the same age. So far, however, no studies have focused on the needs of sawmills. Nevertheless, according to, e.g., Kataikko (1996), the biggest problem in wood procurement for the Finnish birch saw mills is the shortage of high-quality raw material. The availability of raw material fluctuates over time and varies greatly in quality (Kivistö et al. 1999).

The purpose of this study was to investigate the variation in selected technical properties of mature (age >60 years) birch stems in southern and central Finland. Technical properties were defined as the natural external characteristics that cause differences in the usability of a certain section of stem in the mechanical wood industry, saw milling in particular. In this study, both birch species were studied and the most important growing conditions (forest site, stand structure by species) were taken into consideration. The results are intended to meet the needs and potential applications of the users of large or small-sized birch logs.

2 Material and Methods

Test stands representing typical birch stands in each planned stratum were sampled for this study. The material was composed of 261 sample trees measured and felled from 20 mature (age > 60 years) birch stands located in southern and central Finland. The locations of the stands are presented in Fig. 1, and some key characteristics are shown in Table 1. Sample trees from at least three stands were included in each of the following, predetermined strata:

– Pure silver birch stand, mineral soil (Stratum 1)
– Mixed silver birch–spruce stand, mineral soil (Stratum 2)
– Pure white birch stand, mineral soil (Stratum 3)
– Mixed white birch–spruce stand, mineral soil (Stratum 4)
– Pure white birch stand, peatland (Stratum 5)
– Mixed white birch–pine stand, peatland (Stratum 6).

Of the mineral soils, OMT and MT types (Lehto and Leikola 1987) were represented. Of the drained peatland forest site types, the herb-rich type (Rhtkg) and *Vaccinium myrtillus* type I (Mtkg) (Laine 1989) were included in the study.

Of the stands, thirteen were owned by the Finnish Forest Research Institute, six were privately owned and one was owned by the Forest and Park Service of Finland. The stands for each stratum were selected according to requirements

Table 1. Key characteristics of the sample stands.

Stand nr. (Stratum)	Tree species	Site	Age, a (mean)	Basal area, m^2/ha	$D_{1.3}$, mm (mean)	Height, dm (mean)
1 (4)	White birch	OMT	80	8	243	252
	Spruce		80	17	268	252
2 (4)	White birch	OMT	75	11	242	241
	Spruce		73	13	261	249
3 (1)	Silver birch	MT	77	28	208	239
4 (1)	Silver birch	OMT	90	34	253	271
5 (2)	Silver birch	OMT	90	12	250	260
	Spruce		90	26	210	220
6 (2)	Silver birch	MT	90	11	294	258
	Spruce		72	18	232	226
7 (5)	White birch	Mtkg	83	17	244	230
8 (5)	White birch	Mtkg	80	17	186	169
9 (6)	White birch	Mtkg	80	8	183	169
	Pine		90	16	255	192
10 (6)	White birch	Rhtkg	80	12	200	185
	Pine		98	18	271	212
11 (3)	White birch	MT	60	15	257	218
12 (3)	White birch	OMT	85	19	262	217
13 (3)	White birch	MT	70	15	182	230
14 (4)	White birch	OMT	70	9	224	217
	Spruce		70	18	255	226
15 (4)	White birch	MT	75	6	239	224
	Spruce		100	26	281	235
16 (5)	White birch	Mtkg	60	16	200	179
17 (1)	Silver birch	OMT	90	20	290	265
18 (2)	Silver birch	MT	70	4	232	207
	Spruce		100	27	264	228
19 (2)	Silver birch	OMT	75	13	281	255
	Spruce		79	8	253	222
20 (6)	White birch	Mtkg	78	5	240	241
	Pine		115	25	286	245
All stands: birch			76	20	231	224
Birch / conifer			78 / 86	10 / 19	234 / 256	224 / 224

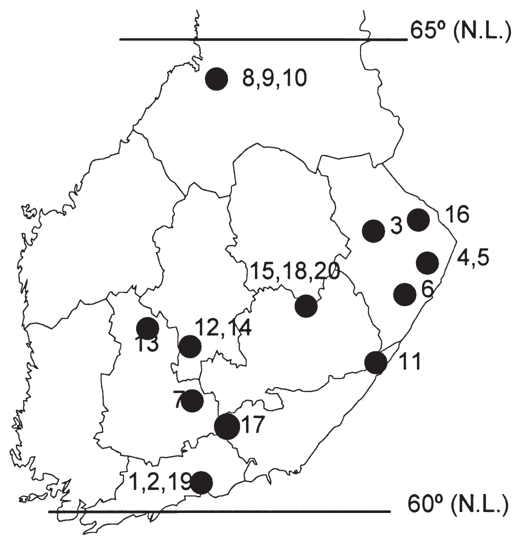

Fig. 1. Locations of the sample stands in southern and central Finland.

for minimum area, age and location. For each stand, good or fair silvicultural condition was also required. The locations of the stands followed the natural distribution of the birch resources.

After selection of the sample stand, the material was sub-divided into categories by forest site type and crown layer of individual sample tree. Thus, three different levels of growing conditions were studied: *stratum*, *site* and *crown layer*. Sample trees represented both dominant and codominant trees in each stratum. Sites represented both *Oxalis-Myrtillus* type (OMT) and *Myrtillus* type (MT) on mineral soil and herb-rich site (Rhtkg) and *Vaccinium myrtillus* type I (Mtkg) as corresponding drained peatland (Lehto and Leikola 1987, Laine 1989). Pure white birch stands on herb-rich sites were not, however, included in this study because no suitable stands were found (Table 2).

In each stand, *basal area* was measured for each tree species, as well as *number of stems per hectare* and *mean height* and *diameter*. Mature trees and undergrowth were measured separately. On average, 13 birch were selected as sample trees in a stand using stratified random sampling. The sample trees represented the entire diameter range from 14 cm upwards.

Table 2. Number of sample trees by stratum, site and crown layer.

Stratum	Site				
	OMT / Rhtkg Crown layer		MT / Mtkg Crown layer		
	1	2	1	2	
	Count				Σ
1	18	8	14	4	44
2	19	6	14	6	45
3	8	2	27	9	46
4	17	9	3	18	47
5			27	18	45
6	5	10	2	17	34
Σ	67	35	87	72	261

Before felling, the following characteristics were measured or evaluated for each sample tree:

- minimum and maximum $d_{1.3}$, mm
- maximum butt crook between 0 and 4 m, mm/4m
- crown layer (1 = dominant tree, 2 = codominant tree)
- assessment of quality of butt log (class 1, 2 or 3, reject)
- assessment of quality of intermediate and top logs (class 1, 2 or 3, reject).

For each sample tree, *distance* (dm) from, *direction* (°) to, $d_{1.3}$ (mm) and *tree species* of the five closest neighbour trees representing approximately similar age and size class were measured in order to determine the possible effects of competition on the variables studied. The *competition index* was calculated according to Hegyi (1974):

$$CI_j = \sum_{i=1}^{n} \left(d_i / d_j \right) / D_{ij} \quad (1)$$

where CI_j indicates the competition directed towards tree j, n is the number of measured neighbour trees, d_i is the diameter at breast height of neighbour tree i, d_j is the diameter at breast height of tree j, and D_{ij} is the distance between trees i and j.

After felling, the true length and the vertical locations of diameters 24, 20, 18, 14, 12, 10, and 7 cm were measured for each sample tree. The diameters represent alternative minimum commercial diameters of certain assortments made from birch stems. The stems were flush delimbed (i.e., close to the surface), and the knot bumps, scars and grooves were cut open so that their true appearance in the wood could be verified. Furthermore, the stem was systematically cut into two- or four-metre bolts. Each of the following characteristics was measured separately for each two-metre section from the stump to the height where the diameter was 12 cm: 1) the presence of heart-rot was verified at the cross-cut sections; 2) knot bumps, fresh, dry and rotten knots and vertical branches were counted; 3) the locations of the lowest dead and fresh knots were measured, as well as the location of the highest dead knot; 4) the diameter of the thickest knot of each knot type was measured; 5) the defects in stem form, including crook (mm/2m = maximum deviation from straight line between the base and the top of a bolt) were evaluated or measured, as were the defects on the surface of an individual log.

The crown limits were determined on the basis of the true type of knots; i.e., types of knots were defined from the surface of a bolt after flush delimbing. *Knotfree section* means the stem part from the stump to the lowest knot bump or knot. *Section of dead knots* means the stem part from the lowest knot bump or dead knot to the lowest fresh knot. *Section of fresh and dead knots* means the stem part from the lowest fresh knot to the beginning of the *fresh-knot section*. The top of the tree is the section that contains only fresh knots; at most, one small ($d \leq 10$ mm) dead knot was allowed per metre.

In this study, the *log section* was defined as the stem section where the diameter exceeds 18 cm. The *small-sized log section* was defined as the stem section where the diameter is 12 to 18 cm. The *tapers* (mm/m) for the log section (T_l) and small-sized log section (T_{sl}) (mm/m) were calculated according to the following formulae:

$$T_l = \frac{d_{1.3} - 180\ \text{(mm)}}{h_{18} - 1.3\ \text{(m)}} \tag{2}$$

$$T_{sl} = \frac{180 - 120\ \text{(mm)}}{h_{12} - h_{18}\ \text{(m)}} \tag{3}$$

where $d_{1.3}$ indicated the diameter at breast height (mm), h_{18} the height where the diameter was 180 mm (m) and h_{12} the height where the diameter was 120 mm (m). Only those trees where the log section or the small-sized log section was longer than two metres were included in the calculations.

The volumes of log and small-sized log sections were calculated by Newton's formula:

$$V = \frac{1}{6}\sum_{i=1}^{n}\left(g_{0i} + 4g_{0.5li} + g_{1i}\right)l_i \tag{4}$$

where g_{0i} indicates the basal area at the butt end of section i, $g_{0.5li}$ the basal area in the midpoint of section i and g_{1i} the basal area at the top of section i. The length of section i is marked as l_i. According to Kangas and Päivinen (1994), Newton's formula produces unbiased estimates for the volumes of trees or bolts.

Those variables that were not normally distributed were either *logarithm* or *square root* transformed for the statistical analyses. When the transformed variables were returned into their original scales, the biases were minimised by adding either $s^2/2$ (with *logarithm* transformed variables) or s^2 (with *square root* transformed variables) to the transformed predicted values before the predicted values were calculated in the original scale (Lappi 1993).

The between-stand variation in those background factors that could have effects on the studied properties of sample trees was equalised by analysis of covariance. The principle of analysis of covariance is to use information about the relationship of the variable (Y) for the covariant (X) in order to estimate what would be the values of the variable in each treatment, if all measurements were made at the same value of X (Underwood 1997). Covariants, which turned out to be significant, were included in the model. In other words, differences between stands were adjusted to the mean value of the covariant. The covariants tested were:

- Number of stems / hectare (mean 516)
- Basal area, m^2/ha (mean 25.2)
- Competition Index (mean 0.133)
- Mean age of birch, a (mean 77)

Due to the uniformity of the results, in each analysis stratum (1–6), site (1 and 2) and crown layer (1 and 2) were separated systematically, whether there turned out to be significant differences between the categories or not. The difference was determined to be significant at the

Table 3. ANCOVA-table for the analyses on diameter and volume (F = fixed factor; C = covariant; I = interaction).

Variable	Source	df	MS	F	p
$d_{1.3}$, mm	Stratum (F)	5	8576.776	5.814	0.000
R^2=0.524	Site (F)	1	1.553	0.001	0.974
	Crown layer (F)	1	87359.145	59.222	0.000
	Mean age (C)	1	16832.431	11.411	0.001
Tree volume, dm^3	Stratum (F)	5	210.033	14.964	0.000
R^2=0.654	Site (F)	1	0.342	0.024	0.876
	Crown layer (F)	1	838.509	59.739	0.000
	Mean age (C)	1	254.631	18.141	0.000
	Nr of stems / ha (C)	1	198.298	14.128	0.000
	Stratum × crown layer (I)	5	33.314	2.373	0.040

0.05 risk level. Only significant interactions are presented along with the other results in the ANCOVA-tables.

3 Results

3.1 Stem Size

Stands were adjusted to conform to each other by using mean age of birch trees as covariant. Analyses of covariance concerning the diameters and volumes are presented in Table 3. Diameters at breast height (Table 4) differed significantly between the strata and the crown layers. Differences between the sites, however, were not significant.

The largest trees were the dominant silver birch in mixed stands (stratum 2). On MT sites, silver birch stems were even slightly thicker than on OMT sites. There is, however, no logical explanation for this finding.

The stem volumes for the strata 1 to 6 were adjusted by using mean age of the birch and number of stems per hectare as covariants. Volumes differed significantly between the strata and the crown layers. Differences between sites were not significant. A significant interaction was observed between the stratum and the crown layer. Volumes of log section and small-sized log section were not satisfactorily predictable on the basis of stand-level information. Thus, in Fig. 2 the percentages of log and small-sized log volumes are presented according to the original, non-adjusted data. In the case of large silver birch, the theoretical proportion of log section, assessed with the diameter as the only limitation, was nearly 90% of the total volume of the tree. The percentage of small-sized logs was greatest in small trees that had only a small log section.

Table 4. Means (and *standard errors*) of stem diameters at breast height by stratum, site and crown layer.

Stratum	Site			
	OMT / Rhtkg		MT / Mtkg	
	Crown layer		Crown layer	
	1	2	1	2
	$d_{1,3}$, mm			
1	273 (*11*)	229 (*14*)	258 (*10*)	233 (*19*)
2	292 (*9*)	221 (*16*)	300 (*10*)	208 (*16*)
3	253 (*14*)	178 (*28*)	247 (*8*)	225 (*13*)
4	259 (*9*)	225 (*13*)	266 (*22*)	221 (*9*)
5			236 (*8*)	182 (*18*)
6	228 (*17*)	199 (*12*)	220 (*27*)	179 (*9*)

3.2 Stem Form

On average, in 50 percent of silver birch the log section was assessed as straight. Considering white birch on mineral soils, the corresponding percentage was 41 and on peatland 35. Fig. 3 presents the distributions of trees by assessed shape of the log section and the small-sized log section. The proportion of straight small-sized log sections was largest in pure birch stands on

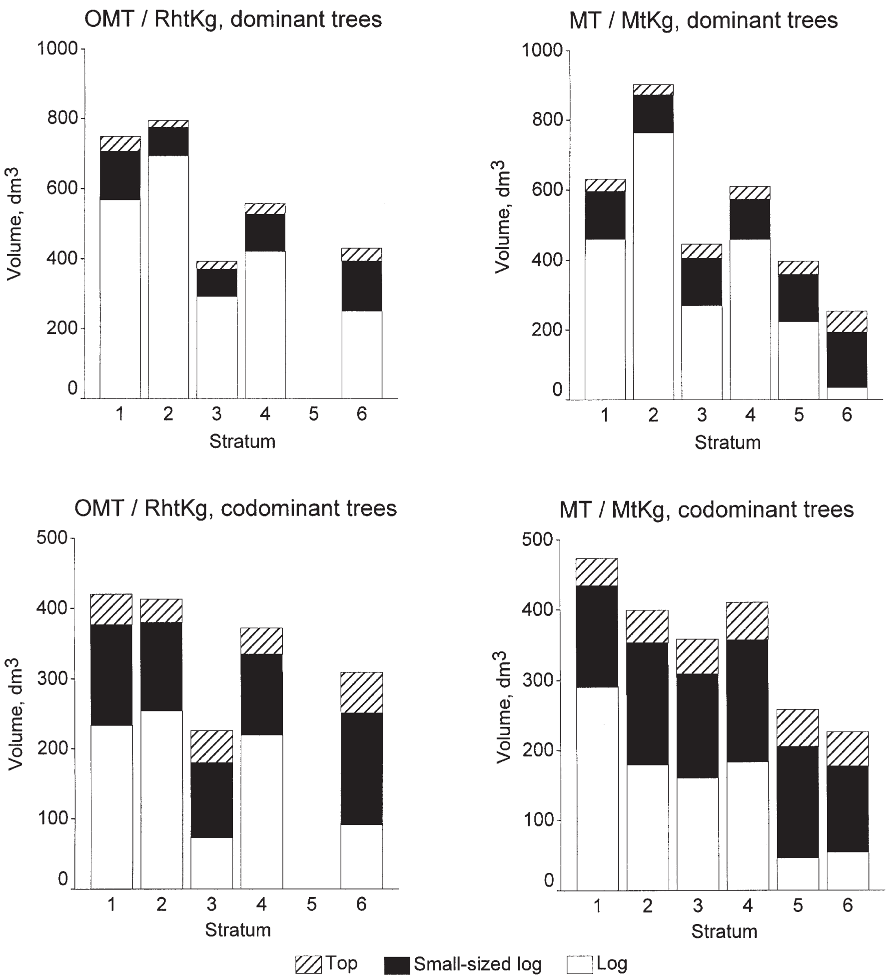

Fig. 2. Mean volumes of log, small-sized log and top sections of stem by stratum, site and crown layer. Notice the different scales of volume for dominant and codominant trees.

mineral soils (40%). The proportion of bolts that were deformed by vertical branches was very large in pure white birch stands on mineral soils. On the other hand, on mineral soils, both silver birch and white birch had a straight small-sized log section more frequently in pure birch stands than in mixed stands.

Taper (mm/m) was calculated separately for the log section (diameter > 18 cm) and the small-sized log section (18 > d ≥ 12 cm). None of the covariants studied had a significant effect on the taper of the log section. On the other hand, tapers of small-sized log sections were adjusted to conform to each other by using the average competition index as a covariant. The ANCOVA-table for the stem form characteristics is presented in Table 5.

The taper of the log section ranged from 12 to 24 mm/m (mean 16 mm/m). Tapering of the log section was largest in white birch stems on peatlands. Differences between the strata were significant, but sites and crown layers did not differ significantly from each other. In mixed stands, average taper of the log section was 5 to 15 percent smaller than in pure birch stands. Butt swelling was, as expected, most obvious in the

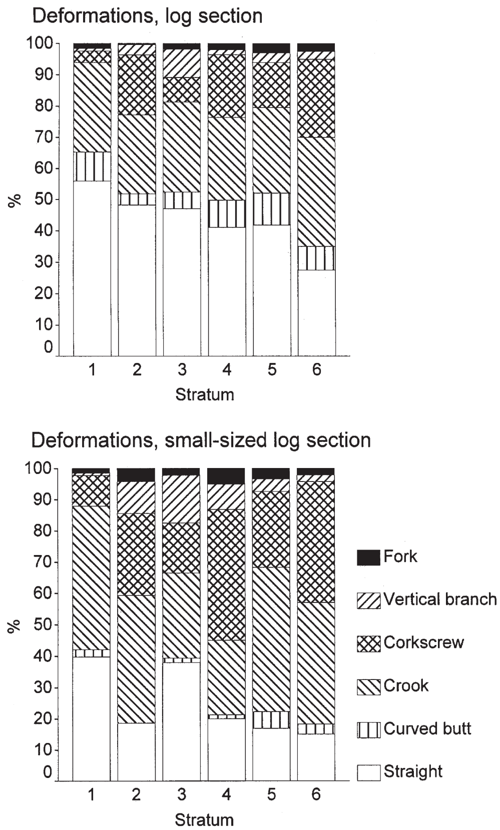

Fig. 3. Distributions of birch stems by the deformation of log (d ≥ 18 cm) and small-sized log (12 ≤ d < 18 cm) section by stratum, assessed in two-metre sections.

largest silver birch stems.

The taper of the small-sized log section ranged from 11 to 16 mm/m (mean 13 mm/m). Small-sized log tapers differed significantly between strata. Differences between sites and crown layers, however, were not significant. In general, the variation in small-sized log taper was small and corresponded to the average taper of the whole stem. In white birch stems on peatlands, the small-sized log section consisted mainly of butt logs, whereas in birch stems on mineral soils, the small-sized log section was located in the top of the stem, because of the larger size of trees. This could not, however, be seen from the results on taper.

Amount of butt crook from stump to height of four metres ranged from 30 to 67 mm (mean 47 mm). No significant differences could be seen between the strata and the crown layers. Sites, on the other hand, differed significantly from each other. On average, the four-metre butt section of trees growing on OMT or Rhtkg sites had a 10 to 20 mm larger crook than trees on MT or Mtkg sites.

3.3 Crown Limits

Coniferous mixture had virtually no effect on the heights of the crown limits of silver birch. On the other hand, white birch was considerably better

Table 5. ANCOVA-table for the analyses of taper and crookedness of log section and small-sized log section (F = fixed factor; C = covariant; I = interaction).

Variable	Source	df	MS	F	p
Taper of log	Stratum (F)	5	73.837	4.933	0.000
section, mm/m	Site (F)	1	24.479	1.635	0.203
R^2=0.285	Crown layer (F)	1	21.097	1.409	0.237
	Stratum × site (I)	4	51.316	3.428	0.010
Taper of small-sized	Stratum (F)	5	27.965	4.583	0.001
log section, mm/m	Site (F)	1	10.874	1.782	0.183
R^2=0.225	Crown layer (F)	1	0.857	0.140	0.708
	CI (C)	1	186.800	30.615	0.000
Crook, mm/2m	Stratum (F)	5	0.028	0.734	0.599
R^2=0.152	Site (F)	1	0.509	13.547	0.000
	Crown layer (F)	1	0.001	0.041	0.840
	Basal area (C)	1	0.540	14.389	0.000
	Stratum × site (I)	4	0.100	2.561	0.039

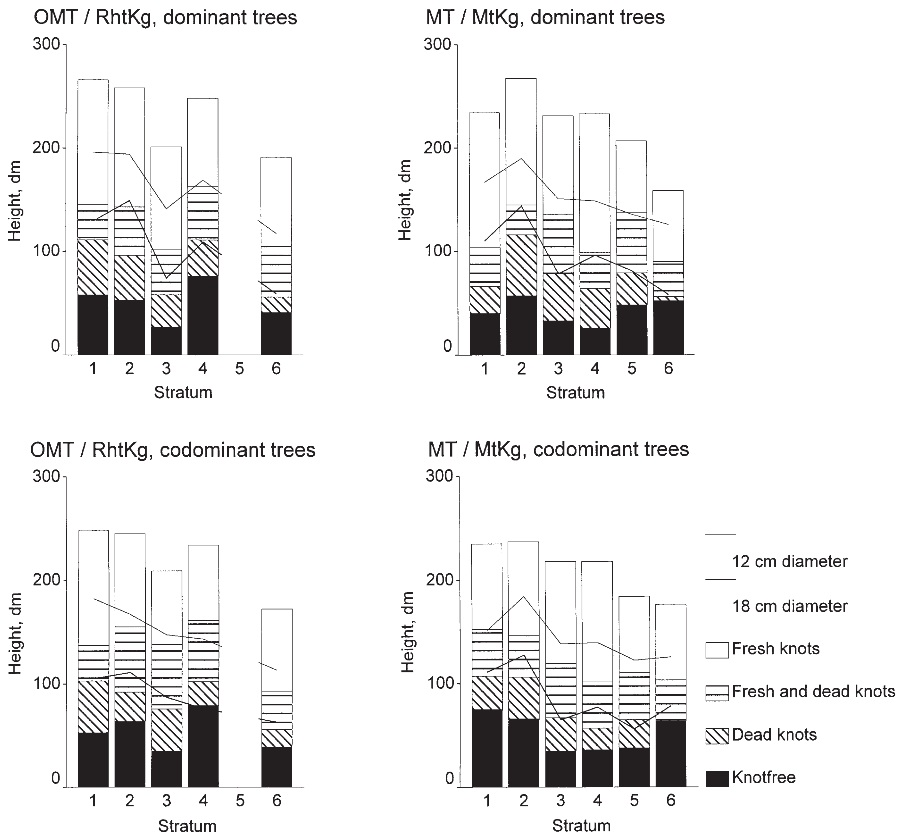

Fig. 4. Mean heights of crown limits, and log and small-sized log sections by stratum, site and crown layer.

naturally pruned in mixed stands than in pure birch stands. In general, the log section contained no knots or, at its most, some knot bumps or dead knots on mineral soils. On drained peatlands, the log section was usually totally knotfree, which is due to the small size of the trees and, consequently, the small size of log section. Fig. 4 presents average crown limits by stratum, site and crown layer. Mean vertical positions of log and small-sized log diameters are also presented. The total height of the bar shows the mean height of birch stems in the stratum in question.

According to the analysis of covariance (Table 6), the length of the knotfree section differed significantly between strata. Differences between sites and crown layers were not significant. Competition index was the only significant covariant. Thus, the more competition occurs with birch, the more effective the self-pruning process is. The growth of the tree, on the other hand, decreases as the number of living branches decreases.

The lengths of the stem sections that contained only dead knots differed significantly between strata, sites and crown layers. Competition index was used as covariant. The lengths of stem sections with dead and fresh knots also differed significantly between strata and sites. Differences between crown layers, on the other hand, were not significant. In this analysis, basal area was used as covariant.

Significant interactions were observed between strata and site in the analyses of all crown limits (Table 6).

Table 6. ANCOVA-table for analyses of the crown limits (F = fixed factor; C = covariant; I = interaction).

Variable	Source	df	MS	F	p
Length, dm					
Knotfree	Stratum (F)	5	1957.133	4.475	0.001
R^2=0.357	Site (F)	1	534.170	1.221	0.270
	Crown layer (F)	1	804.377	1.839	0.176
	CI (C)	1	7026.454	16.066	0.000
	Stratum × site (I)	4	3938.450	9.005	0.000
Dead knots	Stratum (F)	5	4686.057	11.165	0.000
R^2=0.487	Site (F)	1	1950.046	4.646	0.032
	Crown layer (F)	1	2085.732	4.970	0.027
	CI (C)	1	4024.043	9.588	0.002
	Stratum × site (I)	4	3555.500	8.471	0.000
Dead and	Stratum (F)	5	2998.169	3.261	0.007
fresh knots	Site (F)	1	6471.431	7.039	0.009
R^2=0.368	Crown layer (F)	1	1287.369	1.400	0.238
	Basal area (C)	1	6997.418	7.612	0.006
	Stratum × site (I)	4	3976.748	4.326	0.002
Whole tree	Stratum (F)	5	15063.826	56.263	0.000
R^2=0.826	Site (F)	1	956.878	3.574	0.060
	Crown layer (F)	1	9057.616	33.830	0.000
	CI (C)	1	1402.225	5.237	0.023
	Mean age (C)	1	9521.856	35.564	0.000
	Nr of stems / ha (C)	1	3951.689	14.759	0.000
	Stratum × site × crown layer (I)	14	937.646	3.502	0.000

3.4 Number and Size of Knots

The number of fresh knots per log metre was adjusted by using the average competition index as covariant. The strata differed significantly from each other in number of fresh knots per log metre (Table 7). On the other hand, differences between sites and crown layers were not significant. The number of fresh knots per metre in the small-sized log was also adjusted by using the competition index. Differences between the strata were significant, contrary to those of the sites and crown layers.

The number of dry knots per log metre also differed significantly between strata, but sites and crown layers did not. The competition index was used as covariant. Number of dry knots per small-sized log metre was also adjusted by using the competition index. Differences between strata, sites and crown layers were insignificant.

The number of rotten knots per log metre was adjusted by using the mean age of birch and the number of stems per hectare as covariants. The strata differed from each other but the sites and crown layers did not. No significant covariants were found for the number of rotten knots per metre in the small-sized log. Differences between strata, sites and crown layers were also insignificant.

The number of knot bumps per log metre was adjusted by using the average competition index. Differences between strata were significant; on the other hand, sites and crown layers did not differ significantly from each other. The number of knot bumps per metre in the small-sized log was adjusted by using the average competition index and the mean age of birch. Differences between strata were significant; conversely, site and crown layer did not have any significant effect.

The number of vertical branches per log metre was so small that analysis of covariance was not useful for verifying the differences. The number of vertical branches per metre in the small-sized log was analysed, however, and the differences between strata were significant. More than 90 percent of all vertical branches were fresh.

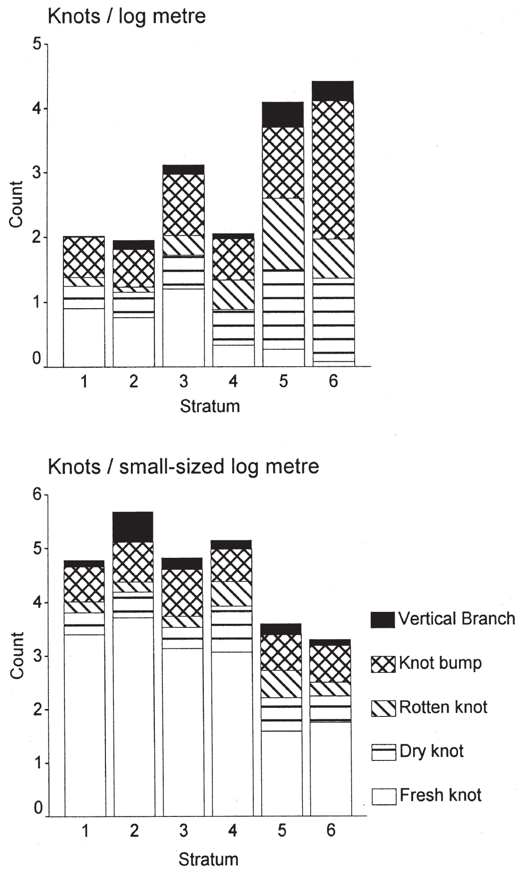

Fig. 5. Average number of different kinds of knots per log and small-sized log metre, by stratum.

The log section contained, on average, less than one fresh knot per metre. In strata 4 to 6, the number of fresh knots on the log section was of no practical importance. Vertical branches, as well as knot bumps, were more common in birch grown on peatland than in those grown on mineral soils. Dry and rotten knots were more common in the log sections of white birch than silver birch. On average, the total number of knots per log metre was four on peatlands, three in pure white birch stands on mineral soils and two in silver birch stands as well as in mixed stands of white birch and spruce on mineral soils (Fig. 5).

In the small-sized log section, fresh knots were dominant on mineral soils. In white birch on peatlands, 50 to 60 percent of the knots were also fresh (Fig. 5). On mineral soils, the differences between silver birch and white birch were small. On average, the total number of knots per metre in a small-sized log was five on mineral soils and three on peatlands. Knot bumps were common not only on the lower parts of the stem but also between fresh knots in the top part of the stem.

The diameter of the thickest fresh knot in the log section varied from 25 mm in stratum 6 to 43 mm in stratum 2. Differences between sites and crown layers were not significant (Table 8). On mineral soils, the diameter of the thickest fresh knot in the log section differed only slightly between silver birch and white birch (39 mm and 38 mm, respectively). In the small-sized log section, diameter of the thickest fresh knot varied from 29 mm in stratum 3 to 42 mm in stratum 1. On mineral soils, the thickest fresh knot in the small-sized log section of silver birch was, on average, 41 mm and that of white birch was 31 mm. When the size of the tree was taken into account, the differences in the size of fresh knots between the two birch species practically disappeared.

The diameter of the thickest dry knot in the log section varied from 16 mm in stratum 6 to 22 mm in stratum 1. On mineral soils, dry knots in the log section of silver birch were, on average, 4 mm thicker than those of white birch. In principle, the sizes of dry knots in the log section differed only slightly between strata. In a small-sized log section, the diameter of the thickest dry knot varied from 13 mm in stratum 6 to 21 mm in stratum 5. On mineral soils, diameter of the thickest dry knots in the small-sized log section did not differ between the birch species.

The diameter of the thickest rotten knot in the log section varied from 17 mm in stratum 3 to 30 mm in stratum 1. In general, rotten knots were bigger in the log section of silver birch than in that of white birch. Mean difference between the two birch species was 9 mm on mineral soils, and 7 mm altogether, respectively. The size of the thickest rotten knot in the small-sized log section varied from 13 mm in stratum 6 to 22 mm in stratum 2. In the small-sized log section, rotten knots were considerably bigger in silver birch than in white birch.

Only a few vertical branches appeared in the log section of codominant trees. In dominant trees, the diameter of the thickest vertical branch

Table 7. ANCOVA table for analyses of the number of different type of knots per metre in the log and small-sized log (F = fixed factor; C = covariant; I = interaction).

Variable	Source	df	MS	F	p
Knots per metre in the log section					
Fresh	Stratum (F)	5	1.501	2.849	0.017
R^2=0.346	Site (F)	1	0.409	0.776	0.379
	Crown layer (F)	1	0.391	0.742	0.390
	CI (C)	1	5.876	11.155	0.001
Dry	Stratum (F)	5	3.048	5.501	0.000
R^2=0.310	Site (F)	1	0.835	1.508	0.221
	Crown layer (F)	1	0.158	0.285	0.594
	CI (C)	1	6.594	11.902	0.001
Rotten	Stratum (F)	5	3.044	11.104	0.000
R^2=0.371	Site (F)	1	0.154	0.563	0.454
	Crown layer (F)	1	0.000	0.000	0.989
	Mean age (C)	1	1.100	4.011	0.047
	Nr of stems / ha (C)	1	3.719	13.565	0.000
Knot bumps	Stratum (F)	5	4.126	4.307	0.001
R^2=0.438	Site (F)	1	0.791	0.825	0.365
	Crown layer (F)	1	0.043	0.045	0.832
	CI (C)	1	28.302	29.546	0.000
	Stratum × site (I)	4	5.268	5.500	0.000
	Stratum × site × crown layer (I)	4	3.445	3.597	0.008
Knots per metre in the small-sized log section					
Fresh	Stratum (F)	5	23.596	6.603	0.000
R^2=0.286	Site (F)	1	4.525	1.266	0.262
	Crown layer (F)	1	4.783	1.338	0.248
	CI (C)	1	45.600	12.760	0.000
	Stratum × site (I)	4	16.191	4.531	0.002
Dry	Stratum (F)	5	0.501	1.417	0.219
R^2=0.179	Site (F)	1	1.304	3.685	0.056
	Crown layer (F)	1	0.017	0.048	0.827
	CI (C)	1	1.621	4.582	0.033
Rotten	Stratum (F)	5	0.388	1.792	0.115
R^2=0.135	Site (F)	1	0.336	1.551	0.214
	Crown layer (F)	1	0.002	0.010	0.919
Knot bumps	Stratum (F)	5	1.411	4.041	0.002
R^2=0.321	Site (F)	1	0.911	2.608	0.108
	Crown layer (F)	1	0.069	0.197	0.658
	CI (C)	1	6.986	20.003	0.000
	Mean age (C)	1	2.080	5.956	0.015
Vertical branches	Stratum (F)	5	2.027	3.609	0.004
R^2=0.143	Site (F)	1	1.159	2.063	0.152
	Crown layer (F)	1	0.025	0.045	0.832
	Stratum × crown layer (I)	5	1.375	2.448	0.035
	Site × crown layer (I)	1	2.288	4.073	0.045

Table 8. ANCOVA table for analyses of the diameter of the thickest knot by knot type in the section of log and small-sized log (F = fixed factor; C = covariant; I = interaction).

Variable	Source	df	MS	F	p
Thickest knot in the log section					
Fresh	Stratum (F)	5	153.028	2.119	0.070
R^2=0.271	Site (F)	1	24.681	0.342	0.560
	Crown layer (F)	1	2.237	0.031	0.861
	Stratum × site (I)	3	407.680	5.645	0.001
	Stratum × site × crown layer (I)	2	279.187	3.866	0.024
Dry	Stratum (F)	5	52.391	1.440	0.217
R^2=0.183	Site (F)	1	22.830	0.628	0.430
	Crown layer (F)	1	73.436	2.019	0.159
Rotten	Stratum (F)	5	170.618	1.956	0.104
R^2=0.304	Site (F)	1	18.765	0.215	0.645
	Crown layer (F)	1	14.926	0.171	0.681
Thickest knot in the small-sized log section					
Fresh	Stratum (F)	5	430.352	3.226	0.008
R^2=0.186	Site (F)	1	33.318	0.250	0.618
	Crown layer (F)	1	3.777	0.028	0.867
	Nr of stems / ha (C)	1	832.330	6.239	0.013
Dry	Stratum (F)	5	85.564	3.990	0.002
R^2=0.286	Site (F)	1	179.240	8.358	0.005
	Crown layer (F)	1	39.068	1.822	0.180
	Nr of stems / ha (C)	1	287.450	13.404	0.000
Rotten	Stratum (F)	5	473.253	8.491	0.000
R^2=0.596	Site (F)	1	723.232	12.976	0.001
	Crown layer (F)	1	661.811	11.874	0.001
	Stratum × site (I)	4	611.805	10.977	0.000
	Stratum × crown layer (I)	5	619.923	11.123	0.000
Vertical branch	Stratum (F)	5	669.250	1.323	0.269
R^2=0.263	Site (F)	1	757.895	1.498	0.226
	Crown layer (F)	1	1067.309	2.110	0.152

in the log section ranged from 57 mm in stratum 2 to as much as 160 mm in stratum 1. In all dominant white birch, the mean diameter of vertical branch in the log section was 70 mm. In the small-sized log section, vertical branches appeared in both dominant and codominant trees. Diameter of the thickest vertical branch in the small-sized log section varied from 47 mm in stratum 4 to 70 mm in stratum 1.

3.5 Surface Defects and Decay

Surface defects were detected from the stump up to the height where the stem diameter was 5 cm. Altogether, 59 percent of the trees had some kind of surface defect. The majority of the defects (38%) were caused by woodpeckers. These defects, however, had caused no serious damage to the wood, and they were located primarily in the upper parts of the stem. The percentage of more serious defects, firstly, a different kind of open scars was 23 and, secondly, that of overgrown scars was 21. Thirdly, 6% of the defects were surface cracks and, finally, 1% were caused by harvesting operations. Of the all surface defects, 11% were caused for some reason other than those listed above, e.g., steel objects nailed into the stem.

The occurrence of decay was analysed in five cross-sections: at heights of 0, 4, 8, 12 and 16

Table 9. Percentages of trees with observed decay at heights of 0, 4, 8, 12 and 16 metres by stratum (– = no observations available in this category).

Stratum	Height 0 m		4 m		8 m		12 m		16 m	
	Decay type %									
	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft
1	80	17	55	0	56	1	24	3	6	0
2	76	7	72	1	43	1	25	0	17	0
3	34	10	26	0	1	5	5	0	6	0
4	45	17	39	4	1	2	2	0	10	0
5	59	9	47	8	30	0	10	0	–	–
6	52	14	26	4	15	1	16	0	–	–

metres. Because no covariants correlated with decay, no adjustments were made. The observed percentages of hard and soft decay at different heights by the stratum are presented in Table 9.

The most common type of decay was heart-rot originating from the root system, which made up 70% of all observations. Heart-rot is caused by ageing of the tree, which decreases its ability to resist decay fungi. Woodpeckers had caused 9%, and different kind of scars 5% of the decay. Other reasons found for decay were vertical branches (5%), rotten knots (5%) and surface cracks (2%). For three percent of the cross-sections, the reason for decay could not be determined.

4 Discussion

The objective of this study was to examine the natural variations in the technical properties of mature silver and white birch in southern and central Finland, especially for saw milling. In order to best serve the needs of the mechanical wood industry, the results were presented separately for the normal log and small-sized log sections. The material was divided into six strata according to birch species and growing conditions. The strata were further divided into categories by site (OMT / Rhtkg and MT / Mtkg) and crown layer (dominant trees and codominant trees). The number of sample stands was 20; a total of 261 sample trees were cut from the stands. In order to make each stand comparable to the others, analysis of covariance was used. Thus, differences in certain background factors between the stands were adjusted to the same level.

The sample stands represented typical cases of pure birch forests and mixed forests of conifers and birch at final cutting age. The number of sample stands had to be limited because the field work is both laborious and expensive. In this study, the number of sample trees (Table 2) cannot be considered representative in the following categories studied: codominant silver birch on the MT site in stratum 1, codominant white birch on the OMT site in stratum 3, dominant white birch on the MT site in stratum four and dominant white birch on Mtkg site in stratum 6. Only two to four trees were sampled from those categories. The remaining eighteen categories were represented by 5–27 sample trees, which can be considered to be a representative number. The results, however, should not be generalised without a comprehensive study of the silvicultural history and the present situation of the stand in question.

Geographically, the sample stands were situated in central and eastern Finland, which are the most important areas for growing stock of large birch and therefore are the areas where birch is used in veneer and saw mills. In western and northern Finland, the growing stock of birch consists mainly of poor-quality and small-sized white birch, which, so far, is used mainly as raw material for pulp mills.

In many cases, significant interactions were observed between the stand and the tree factors studied. This is understandable considering, for instance, light conditions and root competition in pure birch stands and in mixed stands of birch and conifers. Significant interaction, for instance, between the stratum and the crown layer, implies that changes in variable z between crown layers one and two in stratum x, are not identical to the changes of the same variable between the same crown layers in stratum y.

The natural differences in spacing between pure birch stands and mixed spruce-dominated stands were not considered in this study. In order to estimate the differences in technical properties, all stand types were adjusted to the same level of given covariants, spacing, among other things. This procedure also made the results easier to present.

When the dominant trees on MT sites are excluded, there were no significant differences in stem size between the birch in pure birch stands and those in mixed stands dominated by conifers (Fig. 2). On mineral soils, birch stems were slightly larger in mixed stands than in pure birch stands. On peatlands, however, the difference between pure and mixed stands was opposite. Mielikäinen (1985) found that it is advantageous to maintain a silver birch admixture in the spruce-dominated stand in order to maximise the growth of both tree species. The maximum percentage of silver birch was 25. White birch admixture did not have the same effect. Compared to this study, Heiskanen (1957) presented results on diameters at a slightly lower level. In his study, however, crown layers were not separated. Verkasalo (1997) also presented smaller diameters for silver birch on MT site and for white birch on Rhtkg and Mtkg sites. Geographically, Verkasalo's material differed from the material of this study by being concentrated in western Finland, where the growth conditions are poorer than in central and southern Finland.

The average stem form of silver birch was straighter than that of white birch. In particular, white birch stems on peatland were deformed by curved butts. This may be due to, e.g., sinking of the ground after ditching. Heiskanen (1957) and Verkasalo (1997) also found that peatland birch are more crooked than those growing on mineral soils.

Fig. 4 shows the heights of the crown limits by stratum, site and crown layer. White birch stems were well self-pruned in mixed stands on OMT sites, and the log section of those trees was almost totally knotfree. Small-sized logs with fresh knots, which are nowadays wanted by furniture manufacturers, were best obtained from the largest (dominant) silver birch. Small-sized log sections of white birch, as well as those of codominant silver birch, typically contain many dead knots. As a difference from the only comparable previous study (Verkasalo 1997), the stem section that contains both fresh and dead knots was considerably longer. In Verkasalo's study, however, numbers and types of knots and knot bumps were measured *before* the bolts were delimbed. In this study the results are presented as the number of different types of knots on the surface of the bolt *after* flush delimbing. Thus, the real appearance of knot bumps, and fresh, dry and rotten knots may have been better identified in this study.

In the section of the small-sized log, the thickest fresh knot was, on average, 10 mm larger in diameter in silver birch than in white birch. Rotten knots and vertical branches were also larger in silver birch. On the other hand, the size of dry knots in the section of small-sized log did not differ between birch species. The number of knot bumps per log metre was considerably larger in peatland white birch than in birch growing on mineral soils (Fig. 5). This is explained by the slow growth of trees on peatlands; self-pruned knots do not heal over rapidly when the tree grows slowly.

The occurrence of decay was, surprisingly, not statistically significantly dependent on the mean age of the stand. This may be due, for example, to the fairly small deviation in age between the stands (77 ± 15 a). Silver birch, which were, on average, slightly older than white birch, were, nevertheless, more often decayed than the white birch. According to Heiskanen (1957) and Verkasalo (1997), in both birch species decay increases with the age of the tree.

Due to the great risk of natural hazards, the amount, size and seriousness of the surface defects are not, in general, predictable. Surface defects usually cause some kind of damage also in the wood of birch. Spreading of the damage, however, cannot be easily estimated; e.g., season, weather and time-span of exposure affect the sensitivity to decay fungi. Thus, observations on surface defects are not recommended to be generalised in case of this study, as well as most other studies.

According to the results of the study, most of the technical properties of birch differ only slightly between pure birch stands and mixed stands of birch and conifers. The only notable exception is that in mixed stands of conifers and white birch the proportion of knotfree section of stem is significantly longer than in pure white birch stands. Thus, not only silver birch, because of the growth and yield of the stand, but also vigorous and good-quality white birch, because of the possibility to provide high-quality logs, can be maintained profitably as an admixture in coniferous forests until final cutting.

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