SILVA FENNICA

Silva Fennica 45(2) research articles

www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

Saw Log Recovery and Stem Quality of Birch from Thinnings in Southern Finland

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Kilpeläinen, H., Lindblad, J., Heräjärvi, H. & Verkasalo, E. 2011. Saw log recovery and stem quality of birch from thinnings in southern Finland. Silva Fennica 45(2): 267–282.

The objective of this study was to examine the timber quality of silver birch (*Betula pendula* Roth) and European white birch (*Betula pubescens* Ehrh.) trees in the first and second thinnings in southern parts of Finland, from the viewpoint of sawing of small-diameter, short logs, in particular. The average stem volume of birch was 0.140 m^3 in the first thinning stands and 0.206 m^3 in the second thinning stands. In planted stands, the trees were larger in the first thinnings but slightly smaller in the second thinnings, compared with naturally regenerated pure birch stands or mixed stands of Norway spruce and birch species. Almost 60% of the harvested and 35% of the remaining stems that could provide saw logs were graded as pulpwood for timber quality due to the occurrence of stem defects. The most common stem defects were multiple crooks and middle crooks. Only minor between-stratum differences were detected in the numbers of defects. Depending on the bucking option, the total percentage of saw and plywood logs from the total birch recovery in the thinning of the sample stands varied between 11.7 and 18.2. The recovery of saw logs was clearly higher in the second thinnings, 12–19%, than in the first thinnings, 8–14%. Of the stand types, saw log recovery was the highest in planted birch stands, 12–19%, but lower in naturally regenerated pure birch stands and mixed stands of Norway spruce and birch. The highest share of saw logs was in the second thinning of planted stands, 17–25%. This study shows that the harvesting recoveries of end-use based timber assortments can be estimated in different kinds of thinning birch stands. Based on tree and log dimensions and stem squality, silver birch firstly from plantations and secondly from mixed stands should be the most interesting source of raw material for the saw milling, furniture and interior product sectors.

Keywords *Betula pendula, Betula pubescens*, European white birch, silver birch, thinning, saw logs, stem quality, stem defects, bucking, recovery
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Received 17 August 2010 **Revised** 15 April 2011 **Accepted** 10 May 2011
Available at http://www.metla.fi/silvafennica/full/sf45/sf452267.pdf

1 Introduction

1.1 Background

Timber from the first and second thinnings of both naturally regenerated and cultivated birch stands (silver birch, *Betula pendula* Roth; European white birch, *B. pubescens* Ehrh.) has a considerable and increasing potential as a raw material for saw mills in northern Europe (e.g., Luostarinen and Verkasalo 2000, Heräjärvi 2002). According to the few previous studies available (Rantanen et al. 2000, Lehtimäki et al. 2002, Lindblad et al. 2003), approximately 10–20 per cent of the birch thinning removal, on average, should be appropriate for sawing in stands particularly selected for saw log harvesting.

The aim in the commercial harvesting of birch saw logs from thinnings was first to provide raw material for furniture industries manufacturing sound-knotted products, such as home tables and shelves (Luostarinen and Verkasalo 2000, Lindblad et al. 2003). The industries started in Finland (and Sweden) during the very late 1990's, but moved thereafter to eastern countries of Baltic Sea Basin (e.g., Verkasalo et al. 2007). Similar products can be manufactured from selected parts of birch trees from final cuttings, but certain visual, physical and mechanical properties may be then different in the final product (knottiness, grain angle, colour, hardness, density, strength and stiffness) (Luostarinen and Verkasalo 2000, Heräjärvi 2002, Lindblad et al. 2003, Möttönen et al. 2004, see also Cameron et al. 1995, Dunham 1996, Dunham et al. 1999). Later, new product innovations were applied for indoor flooring and panelling, partly with physical modification using heat-treatment or pressure-treatment (e.g., Verkasalo and Heräjärvi 2009).

In Finland, the pulp industries are the largest user of small-diameter birch, consuming more than 10 Mill. m^3 of pulpwood annually (Ylitalo 2010). Birch consumption of saw mills is only some per cents of the consumption of pulp industries. Most saw logs are rather large in diameter, i.e., more than 18 cm over bark. Despite of the apparent raw material shortage at the birch using saw mills, according to the timber production analyses, the thinning potential of birch is currently inadequately used in many districts in Finland (Hynynen et al. 2002, Verkasalo 2002, Ylitalo 2010). Birch timber balance is similar in other European countries with birch supply, such as Sweden (Ekström 1987, Johansson 2002), Norway (Vadla et al. 1982) and Estonia (Kiviste and Uri 2002), see also Verkasalo et al. (2007).

Birch is mainly managed with the intention to get high-quality and high-value logs from the final fellings for the plywood and veneer industries. It is well known that birch species, especially silver birch, are sensitive to the timing and intensity of thinning in order to maximise the growth, yield and quality of the trees (e.g., Niemistö 1991, 1995a,b, Niemistö et al. 1997; see also Fries 1964, Erken 1972, Raulo 1979, 1981, Mielikäinen 1980, 1985, Langhammer 1982, Denne et al. 1994, Cameron et al. 1995, Dunham 1996, Valkonen and Valsta 2001). Most of the birch timber is and will be obtained from naturally regenerated birch stands or mixed stands of conifers and birch in Finland. In addition, the area of cultivated birch stands that should be thinned for the first or second time will still increase for some decades. Although these facts are commonly known, little attention has been paid on the potential of thinning-aged birch timber for uses other than pulping or firewood.

1.2 Objective

The objective of this study was to examine the timber quality of European white and silver birch trees in marked stands of first and second thinnings in southern parts of Finland, from the viewpoint of commercial sawing of small-diameter, short logs, in particular. Saw logs were defined as follows: all logs meeting the minimum top diameter of 11 cm (over bark) and the fixed length of 2.2–3.3 metres or 3.0 metres depending on the used bucking option. Dimensions, stem form, branch characteristics and technical defects of the birch trees in planted, naturally regenerated and mixed stands were studied. Finally, the recovery of different timber assortments and their grade distributions were investigated in harvesting trials of commercial stands. Based on measurements of standing trees, the outcomes of three different theoretical bucking options were compared using the bucking-to-value simulator, which maximises the value of each stem based on the dynamic programming approach (see Näsberg 1985, Ahonen and Mäkelä 1995).

2 Materials and Methods

The study material was sourced from 48 birch-dominated stands (28 first thinning and 20 second thinning stands) in central and eastern Finland, where a considerable proportion of cutting potential of birch from thinning stands will be in the future in Finland (Fig. 1). The structure of the study material is consistent with the future's birch resources, due to the stratification to the provinces according to the cutting potentials of birch, estimated by the MELA group of Finnish Forest Research Institute (Metinfo 2011).

The sites were fertile OMT (*Oxalis-Myrtillus* type) and medium fertile MT (*Myrtillus* type) mineral soil types (see: Lehto and Leikola 1987, Hotanen et al. 2008). The study stands were subjectively selected according to the current silvicultural status and the possibility to extract at least a moderate volume of small-diameter saw logs in commercial harvesting operations. The data were furthermore divided into three strata: 26 planted birch stands, 12 naturally regenerated pure birch stands and 10 mixed stands of birch and Norway spruce (*Picea abies* Karst.) (Table 1). At least one third of the number of stems in mixed stands contained both birch and spruce (Lindblad et al. 2003). In the case of planted stands, few white birch trees observed were naturally regenerated among the planted silver birch. In naturally regenerated pure and mixed birch stands, white birch was more frequent than silver birch. Although the stands were also classified into the first and second thinnings, this classification was not necessarily unambiguous in some of the study stands.

Depending on the size and homogeneity of the stand, from one to four sample plots were established in each stand. The size of a single sample plot in birch dominated stands varied from 24×30-metre rectangles in the first thinning stands to 24×40-metre rectangles in the second thinning stands; larger sample plots were needed in the second thinning stands in order to include a representative number of trees in the plot. Unlike

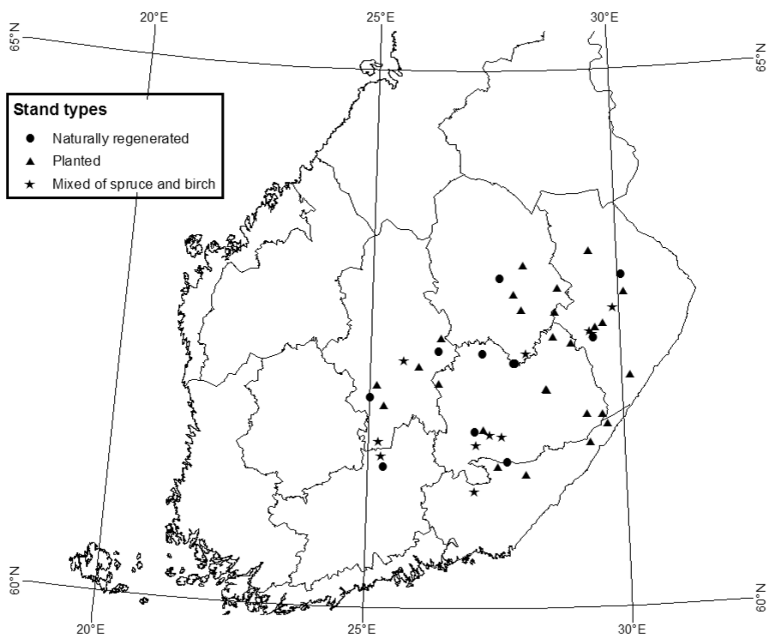

Fig. 1. Locations of the study stands in south-eastern Finland.

Table 1. Characteristics of the study materials.

Stratum	N of sample stands	N of sample plots	Total area of sample plots, ha	N of sample trees		Total volume, m^3	
				B. pendula	*B. pubescens*	*B. pendula*	*B. pubescens*
Planted stands							
1. First thinning	19	37	2.76	2941	62	445.5	4.6
2. Second thinning	7	20	1.78	1410	0	275.0	0.0
Naturally regenerated stands							
3. First thinning	4	8	0.62	34	810	7.0	87.2
4. Second thinning	8	18	1.49	57	1144	20.7	243.7
Mixed stands							
5. First thinning	5	11	0.78	28	490	4.4	56.4
6. Second thinning	5	15	1.31	142	650	35.6	97.5
All	48	109	8.74	4612	3156	788.1	489.3

in birch dominated stands, circular sample plots with 15-metre radius were established in mixed stands. Establishing right-angled sample plots in the birch dominated stands was based on the idea that the effect of skid roads should be taken into account in the estimation of harvesting removal. The same system was planned to be applied in the mixed stands, as well. However, it showed that in mixed stands the prospective locations of skid roads could not be estimated reliably. Therefore, circular sample plots that are clearly less laborious to establish and measure, were finally used in mixed stands. The harvested trees in each sample plot were selected and marked in the forest by experienced field workers according to the prevalent Finnish thinning regimes that are based on basal area of tree stock prior to and after the thinning. The procedure combined thinning from below and thinning for quality, aiming to increase the dimensions of the remaining stock and developing the technical quality of the butt logs (Recommendations for good… 2007).

All standing birch trees from the sample plots were detected for birch species, and measured and graded for dimensions and saw log quality. The trees assessed to be harvested were bucked into timber assortments (plywood logs, saw logs, and pulpwood) according to their dimensions and exterior defects. Location of each assortment along the tree height was recorded. All trees were also classified into log, pulpwood and waste-wood stems. This was done using the bucking-to-value simulator developed at the Finnish Forest Research Institute by Kilpeläinen (2001). Here, the stem defects were neglected, and only the dimensions defined the stem class.

The following characteristics were measured or estimated from the birch trees in sample plots: diameter at breast height (dbh), diameter at six-metre height (d_6), height of the tree, height of the lowest dead and living branch, all technical defects and their effective locations along the stem, and, as a result, quality of the tree graded into timber assortments by section. Defects were classified into two groups: defects inhibiting sawing (class 1) and defects decreasing the quality of products (class 2). Defects in class 1 included sweep, crook in the butt, multiple crooks, and other stem form defects (incl. crooks in the middle section of stems, forks and large vertical branches). Defects in class 2 included branchiness (dry or rotten branches bigger than 3 cm in diameter, grouped branches and small vertical branches), decay, and surface defects such as scars and checks. Defects were detected only from stem sections more than 10 cm in diameter.

Altogether 7768 trees from 109 sample plots were measured from the total area of 8.74 hectares. Their stem volumes were calculated using taper curve models based on the tree species, dbh, d_6 and height of the tree (Laasasenaho 1982). Of all sample trees on the plots, 3921 trees were assessed to be removed in the thinning. Those trees comprised the data for the computer-based

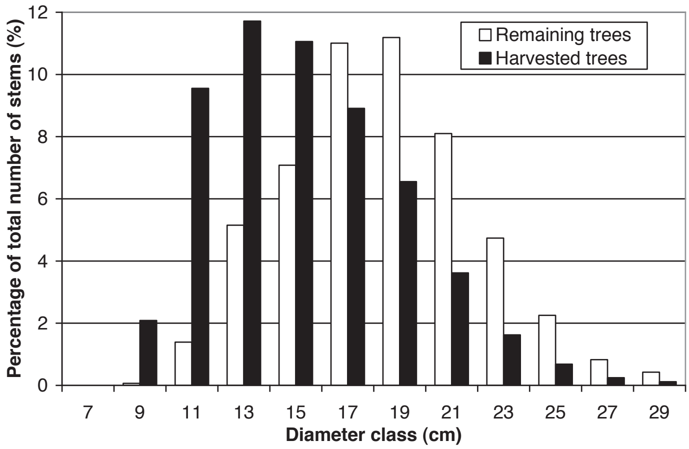

Fig. 2. Dbh series for remaining and harvested birch trees. The "harvested trees" were selected by experienced field workers, but no real harvesting was done.

bucking. It must be kept in mind that these trees represented the harvesting removal, i.e., the smallest trees or the poorest quality trees from the entire material of 7768 trees. Due to the practice of selective thinning, the remaining 3847 trees represent the highest quality. Fig. 2 presents the dbh series commonly for the entire data, but separately for the trees that were assessed to remain and those to be harvested. After the thinning, the proportion of silver birch stems was 65% of all trees, whereas before the thinning the corresponding percentage was 59.

For harvested sample trees, volumes of different timber assortments were calculated using the bucking-to-value simulator (Kilpeläinen 2001). In the bucking software, several bucking alternatives are simulated for each stem, and the value output of each alternative is calculated according to the dynamic programming approach. Finally, the optimal alternative is selected based on the stem value. The software calculates the volumes and values for each bolt, stem, sample plot and stand. It takes into account the dimensions and the defects in the measured trees. The quality requirements for saw and plywood logs that were applied in this study were presented, e.g., by Heräjärvi and Verkasalo (2002). However, the diameter of sound knots was not restricted in this study, and the diameter of black knots was limited up to 30 mm. In the simulation software, the possible

Table 2. Timber assortments of birch allowed in simulated bucking options 1–3.

Timber assortments	Minimum top diameter, cm	Log lengths, m	Bucking options 1	2	3
Plywood logs	18	3.1–5.5	×	×	×
Saw logs	11	2.2	×		×
		3.0		×	
		3.3	×		×
Pulpwood	7	2.7–3.3	×	×	
		2.5–5.0			×

diameter–length combinations of logs, as well as the quality requirements and values need to be defined for each timber assortment as input parameters. The stem parts that contain defects, including jump cuts, off-cuts and top-cuts, are bucked into pulpwood or waste wood. Stem parts that do not meet the requirements for the dimensions of any commercial timber assortment are classified as waste wood.

Bucking the stems was executed according to three alternative combinations of logs and pulpwood (Table 2) in order to study how different dimension requirements of logs and pulpwood affect on the relative proportions of timber assortments. Bucking was steered in the software according to the approximate prevalent unit prices of different timber assortments (e.g., Ylitalo 2010).

Stand-level mean values were compared between the strata (planted, naturally regenerated and mixed stands) by using one-way analysis of variance (ANOVA) to identify which characteristics (incl. defects in stems) were significantly different in various types of birch stands. Characteristics between the remaining and harvested trees were compared using paired samples t-test, and those between the first and second thinning stands using the independent samples t-test. To normalize the distributions of variables (x), proportional values (p) of trees containing defects in individual stands were formulated by using transformation: $p = \arcsin(\sqrt{(x)})$ (Ranta et al. 1994). The stratum wise characteristics, i.e., the harvesting recoveries, were evaluated based on observations only. This was reasoned by the smaller number of study stands in some of the strata (see Table 1). Statistical tests or analysis were not performed on the proportions of timber assortments, because they were obtained as a result of bucking simulation.

3 Results

The characteristics describing the quality attributes of the sample stands and all trees in the stands are presented in Table 3. The mean diameters at breast height (dbh), mean height and average tree volume in all sample stands were 15.4 cm, 17.6 m and 0.168 m^3, respectively. In silver birch dominated planted stands, the trees (average stem volume 0.168 m^3) appeared to be slightly smaller than in naturally regenerated stands (0.187 m^3).

Table 3. Mean characteristics of the sample stands and trees by stratum and birch species. The figures are based on measurements of all trees in the sample plots, i.e., both harvested and remaining trees.

Stratum	Dbh	Height	Height of the lowest dead branch		Height of the lowest living branch		Average tree volume	N of stems per ha	Volume in stand
	cm	m	m	% of tree height	m	% of tree height	dm^3		m^3/ha
				Planted stands					
1. First thinning	14.7	17.5	3.5	19	7.9	44	152	1103	164
2. Second thinning	17.0	19.3	4.2	22	7.6	39	213	809	164
B. pendula	15.4	18.0	3.7	20	7.8	42	169	1005	162
B. pubescens	12.3	16.1	3.4	20	8.9	52	89	95	1
All	15.3	18.0	3.7	20	7.8	42	168	1024	164
				Naturally regenerated stands					
3. First thinning	13.2	15.8	3.2	20	7.7	47	113	1341	148
4. Second thinning	17.4	19.1	5.5	28	9.5	50	224	837	183
B. pendula	21.1	19.7	4.4	21	9.2	46	325	44	14
B. pubescens	15.7	17.9	4.7	25	8.8	49	179	961	158
All	16.0	18.0	4.7	25	8.9	49	187	1005	171
				Mixed stands					
5. First thinning	14.3	15.2	2.4	16	6.7	45	117	679	80
6. Second thinning	15.6	17.1	4.2	24	7.8	44	168	621	103
B. pendula	18.2	17.7	3.3	18	7.7	43	224	70	15
B. pubescens	14.5	15.9	3.3	20	7.2	45	132	580	77
All	14.9	16.1	3.3	20	7.3	44	143	650	91
				All stands					
First thinning	14.4	16.8	3.3	19	7.7	45	140	1061	147
Second thinning	16.8	18.7	4.7	25	8.4	44	206	773	156
B. pendula	17.1	18.3	3.8	20	8.1	43	212	570	94
B. pubescens	14.6	16.8	3.9	22	8.2	48	145	371	56
All	15.4	17.6	3.9	21	8.0	44	168	941	151

However, the difference between the strata was insignificant (ANOVA: $df_1=2$, $df_2=45$, $F=1.829$, $p=0.172$). The average stem volume was 0.140 m^3 in the first thinning stands and 0.206 m^3 in the second thinning stands.

In planted stands, the birch trees were on average larger in the first thinning, compared with naturally regenerated pure birch stands or mixed stands of Norway spruce and birch. As an exception, in the second thinnings the birch trees were slightly larger in naturally regenerated stands than in planted stands. Silver birch trees were larger than white birch trees in all strata; this affected also the differences between the types of regeneration.

Naturally regenerated stands were slightly better self-pruned and had smaller proportion of living crown. The difference in the average heigth of the lowest dead branch between the strata was significant (ANOVA: $df_1=2$, $df_2=45$, $F=3.482$, $p=0.039$). The differences were insignificant in case of the heigth of the lowest living branch and the proportion of living crown.

According to the measurements of standing trees, smaller trees were more often defect-free than larger trees (Table 4). This is partly reasoned by the fact that the defects were recorded only from the stem sections with more than 10 cm in diameter. In comparison to the smaller dbh classes, larger trees were more seldom rejected in to pulpwood due to the defects. In small-sized stems, already one defect most often totally prevented the bucking of saw logs. The percentage of log-sized stems rejected in to pulpwood decreased along with the increment of the dbh up to the dbh of 18 cm. From this dbh on, the percentage remained relatively constant at a level of 14–29% for all stems and 28–46% for the harvested stems in all sample stands.

In case of silver birch, 3.1% of harvested log-sized stems were defect-free, and 49% of them were downgraded in to pulpwood. For white birch, the respective percentages were 2.8 and 66.

The harvested log-sized stems appeared to have only slightly poorer overall quality than the remaining ones in the study material. Of the remaining log-sized stems, on average 4.5% were totally defect-free, whereas the respective percentage in the harvested stems was 2.8. Almost 60% of the harvested and 35% of the remaining log-sized stems were graded in to pulpwood for timber quality due to the occurrence of different stem defects. Differences were clear especially in larger diameter classes.

Defects inhibiting sawing (class 1) were more common than defects decreasing the quality of saw log (class 2). The most common defects in birch stems were multiple crooks and crooks in the middle sections of stems (Table 5). The percentage of trees with multiple crooks in individual birch stands varied from 4 to 94 (mean 62%). Crooks in the middle sections of stems were detected in 13–99% of trees, on average (mean 53%). Other common defects in the trees were grouped branches and crooks in the butt section, they influenced in 17% and 15% of the sample trees, respectively. Sweep, forks, decay, surface defects, oversized and vertical branches were recorded in less than 10% of the trees.

Only minor between-stratum differences were detected in the numbers of defects. Multiple crooks were more common in the sample trees in naturally regenerated stands than in planted and mixed stands (80%, 50% and 70%, respectively). Differences between these strata were statistically significant according to the ANOVA ($df_1=2$, $df_2=45$, $F=11.496$, $p=0.000$).

More surface defects were detected in naturally regenerated stands (5% of the sample trees) than in planted and mixed stands (3% and 2% of the trees, respectively) (ANOVA: $df_1=2$, $df_2=45$, $F=3.829$, $p=0.028$). On the other hand, crooks in the butt section were more common in silver birch dominated planted stands (19% of the sample trees) than in white birch dominated naturally regenerated (9%) and mixed stands (13%) (ANOVA: $df_1=2$, $df_2=45$, $F=5.142$, $p=0.010$). Other defects were equally numerous in the different strata.

Branchiness and crooks in the middle sections of stems were more common defects in the remaining trees than in the harvested trees, partly due to the bigger stem size (Fig. 2). Depending on the stratum, branchiness was estimated as a defect in 27–40% of the remaining trees (average 35%), but only in 15–24% of the harvested trees (average 20%) (t-test: $t=-10.810$, $df=47$, $p=0.000$). Crooks in the middle sections of stems were also more common in the remaining trees (59% of the stems) than in the harvested trees (46%) (t-test:

Table 4. Numbers and average percentages of defect-free stems and stems with defects in all sample trees grouped by dbh class. Only log or pulpwood sized stems [a)] are included [b)].

Dbh class, cm	All stems		Log sized stems				Pulpwood sized stems
	N	Defect-free, %	N	Defect-free, %	Defected, %	Rejected in to pulpwood due to defects, %	N
8.0–9.9							
All stems	444	19	-	-	-	-	444
Harvested stems	400	19	-	-	-	-	400
10.0–11.9							
All stems	1135	11	60	9	13	78	1075
Harvested stems	904	11	43	6	14	80	861
12.0–13.9							
All stems	1409	5	1357	5	27	68	52
Harvested stems	859	4	826	4	24	73	33
14.0–15.9							
All stems	1547	5	1547	5	45	50	-
Harvested stems	692	3	692	3	40	57	-
16.0–17.9							
All stems	1378	3	1378	3	58	38	-
Harvested stems	509	3	509	3	51	46	-
18.0–19.9							
All stems	910	2	910	2	69	29	-
Harvested stems	281	1	281	1	57	42	-
20.0–21.9							
All stems	494	1	494	1	73	26	-
Harvested stems	126	1	126	1	53	46	-
22.0–23.9							
All stems	228	1	228	1	73	25	-
Harvested stems	53	-	53	-	66	33	-
24.0–25.9							
All stems	83	2	83	2	84	14	-
Harvested stems	19	-	19	-	72	28	-
26.0–							
All stems	73	1	73	1	71	28	-
Harvested stems	12	-	12	-	63	38	-
All stems	7701	6	6130	4	52	45	1571
Harvested stems	3855	6	2561	3	39	58	1294

[a)] Log and pulpwood sized stems were determined in bucking according to the dimension requirements of sawlogs and pulpwood without any detected defects. At least one saw log was bucked from log sized stems and one pulwood bolt but no saw logs was bucked from pulpwood sized stems.
[b)] Defects were recorded from the stump to the height where the stem diameter was 10 cm.

t = –7.410, df = 47, p = 0.000). On the other hand, sweep, crook in the butt, and decay were more common in the harvested than in the remaining trees. Only 0.8% of the remaining trees had a visible decay, whereas the respective percentage in the harvested trees was 2.6. The difference was significant (t-test: t = 6.704, df = 47, p = 0.000). Although the remaining and harvested stems seemed to be rather equally sweeped, 3.5 and 4.5 per cent, respectively, the difference was also significant (t-test: t = 2.295, df = 47, p = 0.026). The same concerned butt crooks, which were recorded in 14% of the remaining and 16% of the harvested stems (t-test: t = 2.011, df = 47, p = 0.050). Occurrence of other defects did not differ between the remaining and harvested stems.

On avarage, the proportions of defect-free stems were at the same level (6% of all stems) on both birch species, but differences in single defect types on silver and white birch stems were detected.

Table 5. Occurrence of defects in harvested (H) and remaining (R) trees in the sample stands grouped by stratum. One or more defects were defined in each tree from the stump to the height where the stem diameter was 10 cm.

Defect	Planted		Naturally regenerated		Mixed stands	
	H	R	H	R	H	R
	Proportion of sample trees, %					
First thinnings	Class 1: Defects inhibiting sawing					
Sweep	5	5	4	3	5	1
Crook in the butt	20	20	10	9	21	12
Multiple crooks	52	51	75	81	72	79
Other form defects [a)]	61	75	35	57	54	64
	Class 2: Defects decreasing the quality of sawn timber					
Branchiness [b)]	22	38	12	26	13	30
Decay	3	1	2	1	1	1
Surface defects [c)]	5	2	6	6	2	1
Defect free trees	6	5	9	2	11	5
Second thinnings	Class 1: Defects inhibiting sawing					
Sweep	2	2	4	3	8	3
Crook in the butt	19	14	9	8	10	6
Multiple crooks	56	36	81	80	67	65
Other form defects [a)]	49	57	50	63	48	52
	Class 2: Defects decreasing the quality of sawn timber					
Branchiness [b)]	32	47	16	27	16	28
Decay	1	0	5	1	2	1
Surface defects [c)]	1	2	4	6	3	1
Defect free trees	5	9	4	4	6	8
All stands	Class 1: Defects inhibiting sawing					
Sweep	4	4	4	3	6	2
Crook in the butt	20	19	9	8	15	9
Multiple crooks	53	47	79	80	69	72
Other form defects [a)]	58	70	45	61	51	58
	Class 2: Defects decreasing the quality of sawn timber					
Branchiness [b)]	24	40	15	27	15	29
Decay	2	1	4	1	2	1
Surface defects [c)]	4	2	5	6	2	1
Defect free trees	6	6	6	3	9	7

[a)] Other form defects impeding sawing, such as crooks in the middle section of stems, and forks.
[b)] Branchiness includes dead or rotten branches bigger than 3 cm in diameter, grouped and vertical branches.
[c)] Surface defects include surface scars and checks.

Most common defects in silver birch stems were multiple crooks (73% of stems), crooks in the middle sections of stems (40%) and brachiness (18%). In white birch stems, crooks in the middle-sections of stems were the most common defects (55% of stems). Other major defects included multiple crooks and branchiness (49% and 30% of white birch stems, respectively).

Birch species also differed from each other in branchiness. Grouped branches were identified in 24% of all white birch stems and 5.4% of silver birch stems. On the other hand, dead or rotten branches bigger than 3 cm in diameter were detected in 8.1% of silver birch stems and 2.9% of white birch stems.

Irrespectively of the bucking option, the harvesting recoveries were between 53.4 and 54 m^3 per hectare.

The average total percentages of saw and plywood logs from the harvesting recovery in all sample

Table 6. Average harvesting recoveries by different assortments of birch in alternative bucking options[a)] in study stands grouped by stratum and thinning type. Percentages from the harvesting recovery in parentheses.

Bucking option	Plywood logs	Saw logs	Pulpwood	Harvesting recovery	Waste wood	Total cutting drain
			Volume, m^3/ha			
Bucking 1			First thinning stands			
Planted	0.2 (0.4)	8.3 (15.2)	46.1 (84.4)	54.6	5.5	60.2
Naturally regenerated	0.0 (0.0)	2.3 (5.1)	42.0 (94.9)	44.2	9.0	53.3
Mixed	0.6 (1.7)	3.2 (9.6)	29.5 (88.7)	33.2	4.6	37.9
All	0.3 (0.5)	6.5 (13.3)	42.5 (86.2)	49.3	5.9	55.2
			Second thinning stands			
Planted	2.7 (4.3)	14.7 (23.7)	44.5 (72.0)	61.9	3.8	65.7
Naturally regenerated	2.2 (3.3)	10.6 (15.8)	54.5 (80.9)	67.4	4.4	71.8
Mixed	0.6 (1.5)	6.6 (15.7)	34.8 (82.8)	42.0	3.7	45.7
All	2.0 (3.4)	11.0 (18.7)	46.1 (77.9)	59.1	4.0	63.1
			All stands			
Planted	0.9 (1.6)	10.0 (17.7)	45.7 (80.7)	56.6	5.1	61.7
Naturally regenerated	1.5 (2.5)	7.8 (13.1)	50.3 (84.4)	59.7	6.0	65.6
Mixed	0.6 (1.6)	4.9 (13.0)	32.1 (85.4)	37.6	4.2	41.8
All	1.0 (1.8)	8.4 (15.8)	44.0 (82.4)	53.4	5.1	58.5
Bucking 2			First thinning stands			
Planted	0.2 (0.4)	5.3 (9.8)	49.0 (89.8)	54.6	5.6	60.2
Naturally regenerated	0.0 (0.0)	0.9 (2.0)	43.4 (98.0)	44.3	9.0	53.3
Mixed	0.6 (1.7)	1.4 (4.3)	31.2 (94.0)	33.2	4.7	37.9
All	0.2 (0.5)	4.0 (8.1)	45.0 (91.4)	49.3	5.9	55.2
			Second thinning stands			
Planted	2.7 (4.3)	10.7 (17.3)	48.5 (78.4)	61.9	3.8	65.7
Naturally regenerated	2.2 (3.3)	5.9 (8.8)	59.4 (87.9)	67.5	4.3	71.8
Mixed	0.6 (1.5)	4.1 (9.7)	37.3 (88.8)	42.0	3.7	45.7
All	2.0 (3.3)	7.1 (12.1)	50.0 (84.6)	59.1	4.0	63.1
			All stands			
Planted	0.9 (1.5)	6.8 (12.0)	48.9 (86.5)	56.5	5.1	61.7
Naturally regenerated	1.5 (2.5)	4.2 (7.1)	54.0 (90.4)	59.7	5.9	65.6
Mixed	0.6 (1.6)	2.7 (7.3)	34.2 (91.1)	37.6	4.2	41.8
All	1.0 (1.8)	5.3 (9.9)	47.1 (88.3)	53.4	5.1	58.5
Bucking 3			First thinning stands			
Planted	0.2 (0.4)	8.9 (16.0)	46.3 (83.6)	55.3	4.9	60.2
Naturally regenerated	0.0 (0.0)	2.5 (5.4)	43.1 (94.6)	45.6	7.7	53.3
Mixed	0.6 (1.7)	3.3 (9.9)	29.9 (88.4)	33.8	4.0	37.9
All	0.2 (0.5)	7.0 (13.9)	42.9 (85.6)	50.1	5.1	55.2
			Second thinning stands			
Planted	2.7 (4.3)	15.5 (24.9)	44.1 (70.8)	62.3	3.4	65.7
Naturally regenerated	2.2 (3.3)	11.1 (16.3)	54.5 (80.4)	67.8	4.0	71.8
Mixed	0.6 (1.5)	6.8 (16.1)	35.0 (82.4)	42.4	3.3	45.7
All	2.0 (3.4)	11.6 (19.4)	46.0 (77.2)	59.6	3.6	63.1
			All stands			
Planted	0.9 (1.5)	10.6 (18.6)	45.7 (79.9)	57.2	4.5	61.7
Naturally regenerated	1.5 (2.5)	8.2 (13.6)	50.7 (83.9)	60.4	5.2	65.6
Mixed	0.6 (1.6)	5.1 (13.3)	32.4 (85.1)	38.1	3.6	41.8
All	1.0 (1.8)	8.9 (16.4)	44.2 (81.8)	54.0	4.5	58.5

[a)] Log lengths in alternative bucking options:
Bucking 1: saw logs 2.2 and 3.3 m, pulpwood 2.7–3.3 dm (approximate length).
Bucking 2: saw logs 3.0 m, pulpwood 2.7–3.3 m (approximate length).
Bucking 3: saw logs 2.2 and 3.3 m, pulpwood 2.5–5.0 m (free length).

stands were 17.6, 11.7 and 18.2 in bucking options 1, 2 and 3, respectively (Table 6). The recovery of saw logs was higher in the second thinning stands (12–19%) than in the first thinning stands (8–14%). Of the stand types, the percentage of saw logs was the highest in silver birch dominated planted stands, varying from 12 to 19, depending on the bucking option. Saw log recoveries were, on the other hand, at their lowest, 7–14%, in white birch dominated naturally regenerated stands and mixed stands of Norway spruce and birch. The highest share of saw logs, 17–25%, was obtained from the second thinning of planted stands.

In the birch dominated thinning stands, the recovery of plywood logs was marginal, and almost constant irrespectively of the bucking option. In the entire material, 1.0 m^3 of plywood logs were obtained per hectare, the observed recoveries being 2.0 m^3 per hectare in the second thinning stands and as low as 0.2 m^3 per hectare in the first thinning stands. Based on average recoveries, the highest share of plywood logs was obtained from the naturally regenerated stands, still not more than 2.5% of the total harvesting recovery. In the planted and mixed stands, the respective percentages were 1.5–1.6. In the second thinnings, the percentage of plywood logs was the highest in the planted stands, but in the first thinnigs in the mixed stands (Table 6).

The largest volumes of saw logs, 8.9 and 8.4 m^3 per hectare were bucked in options 3 and 1, respectively. Option 2 provided only 5.3 m^3 of saw logs per hectare due to only one available saw log length (3.0 m). The highest share of saw logs was obtained from planted stands, for example, ca. 18% of the total hectare wise recovery in bucking options 1 and 3.

4 Discussion and Conclusions

The purpose of this study was to determine the potential of birch thinning stands to provide saw logs. In addition to the actual measurements in sample stands, harvesting recoveries were studied by simulating in accordance with three different bucking options.

Generally, the material of 48 stands and almost 8000 measured sample trees can be considered representative for the purpose of this study. However, in mixed stands of spruce and birch, the circumstances for timber quality development are so variable depending on site fertility, relative proportions of species, silvicultural management history, and other reasons that they limit the possibilities to generalise the results. In case of pure birch stands with rather straightforward management regime, the results can be applied more safely.

Geographically, the materials represent a major cutting potential of birch in Finland. However, some relatively important birch growing areas in southern, western and central Finland were not included in this material. There are distinctive differences between the two birch species in growth rate, stem form, branchiness, ability to utilise the fertility of the ground, as well as the silvicultural management recommendations. These features have been described and analysed widely in the literature (e.g., Heiskanen 1957,1966, Verkasalo 1997, Heräjärvi 2001,2002, Heräjärvi and Verkasalo 2002, Lehtimäki et al. 2002, Lindblad et al. 2003, Kaurala et al. 2004, Arponen et al. 2008). In case of silver birch, the planted trees represent genetically bred materials that differ from the natural trees in their branchiness, stem form and growth rate. In our material, the number of silver birch trees representing the natural origin was very small compared to the other strata. This deficiency sets limits to the possibilities to generalise the results from this part.

The principle in selecting the removed trees in thinning was a combination of thinning from below and thinning for quality. However, in the second commercial thinning, also thinning from above can be considered. This procedure would increase the thinning recoveries of saw and plywood logs to some extent, but also postpone the final felling for some years. Thinning from above has positive impacts at least to the branchiness of the remaining trees.

Data collection included some subjective estimation of characteristics of timber quality from standing trees, classification for straightness being the most challenging of them. However, the coherent training and long-term experience of the field groups of the organisation strongly diminished this drawback. Only stem sections with diameter over 10 cm were assessed for quality.

In case of remaining trees that are still growing rapidly, this does not provide sufficient information concerning the prospective quality of the trees in next thinning or final felling. Evaluation of standing trees for the suitability for mechanical wood processing has also the weakness that internal defects affecting the processing value partly remain unknown. For birch, the largest uncertainty lies in the detection of heart decay, brown streaks and internal checks. However, only brown streaks caused by larval tunnels of *Phytobia betulae* and discoloured or firm-decayed wood caused by different mammals are frequent in younger trees such as those in this data (Niemistö et al. 1997, Hallaksela and Niemistö 1998, Niemistö 1998, Ylioja et al. 1998; Verkasalo 1997).

Regarding the stem dimensions and quality of birch from thinning stands, the results were generally in line with the few previous studies available from Cameron et al. (1995), Niemistö (1995a, 1998), Dunham (1996), Niemistö et al. (1997) and Lindblad et al. (2003). It should be noted that mixed stands of birch and spruce are the dominant types of birch forests in most other countries in Europe. Practical experiences have shown there generally severe crookedness and knottiness, for example, steep knot angle, obviously traceable to bad management history (e.g., Walfridsson 1976, Langhammer 1982, Agestam 1985, Ekström 1987, see also Cameron et al. 1995).

Niemistö et al. (1997) published an extensive study where 30-year old planted silver birch was examined so that the 600 largest trees per hectare (potential plywood log stock for final felling stage) were taken into account. Compared with that study, sample trees of the current study were 2–4 cm smaller in diameter and 1.5–3.5 metres shorter in height, on average. The lowest dead branch was 0.3–1.7 metres lower but the lowest living branch was higher in naturally regenerated pure stands and lower in mixed stands, indicating a more delayed thinning except for the planted stands. Compared with the birch trees harvested from thinning stands in the report by Lehtimäki et al. (2002), the branchiness was at about a similar level in the current study.

At a log level, the distribution of knots depends on the log's vertical location in a tree. In the study of Lindblad et al. (2003), the 1.1-metre sections of birch logs from thinning operations were made up of 48% of knot-free logs and 17% of fully or partly sound-knotted logs. Cut from the tree base of three metre length, knot-free sections accounted for 75%, but only 35% from 3–6 m height and 15% from 6–9 m height. Respectively, sections with fully or partly sound knots accounted for 2%, 15% and 35%. However, birch is a challenging species to determine the internal knottiness from the external knottiness (e.g., Heräjärvi 2002, Lindblad et al. 2003). Only 6% of the sample trees were defect-free in this study from the viewpoint of sawmilling, whereas the percentage was 36 in the study of Niemistö et al. (1997) from the viewpoint of plywood manufacturing. Surface defects were less frequent in this study, indicating also less stem defects from previous tending and harvesting operations.

Multiple crooks and crooks in the middle sections of the stem were prevalent in this study, more frequent than in the material of Niemistö et al. (1997), and clearly more common than in the material of Lehtimäki et al. (2002). These form defects are typical for birch logs, and much more common than, e.g., uniform sweepness. The practical importance for saw milling lies in the fact that irregular deviations from straightness are very difficult to manage in the optimisation of sawing to maximise the recovery of sawn timber (Heräjärvi 2002, Lehtimäki et al. 2002, Lindblad et al. 2003). This can be seen in the high log consumption ratio when sawing small-diameter logs (Lehtimäki et al. 2002, Lindblad 2003) and conventional large logs (Luostarinen and Verkasalo 2000, Heräjärvi 2002) with 2.8–4.4 m^3 and 2.6–3.2 m^3 of logs per one cubic metre of sawn timber, respectively. It is also reflected to the lowering sawn timber yield when full-square timber is aimed for, and in the ineffective application of curve sawing. In the sawing simulation by Lindblad et al. (2003), the yield of full-square sawn timber decreased only by 5–10 percentage units, while the sweepness of birch logs grew from less than 5 mm/m up to more than 15 mm/m, or the crookedness grew from less than 10 mm/m up to more than 15 mm/m.

In the sites with a high fertility such as in this study, silver birch in particular grows rapidly both in the diameter of the bole and branches, as shown by the before-mentioned researchers. This causes also a risk of too heavy branchiness for the log quality. However, tree spacing and thinning rate affect largely, heavy thinning resulting in enhanced diameter development in the bole through greater ring width and more and thicker branches in comparison with light thinning and no thinning (Cameron et al. 1995). Nevertheless, the physical properties of wood remain largely unaffected. In a planting design of silver birch high initial density resulted in thin branches, early branch death and early self-pruning, the adequate density being 1600 trees per hectare, except for the most fertile sites (Niemistö 1995a). The diameter of the thickest branch in the butt log was 23 mm at the density of 5000 trees per hectare, growing to 30 mm at the density of 800 trees per hectare.

The results on harvesting recovery of saw logs of this study are unique in the scientific forum, hence, in this respect there are no reference results available. However, there is no reason to expect unrealistic outcomes from the simulated harvesting recoveries. Two provincial exploratory studies in Finland showed results differing to some extent from this study. Rantanen et al. (2000) observed the recovery and percentage of birch saw logs being 2–27 m^3 per hectare and 3–23% in individual marked second-thinning stands of birch in a more or less random sampling, the results being somewhat lower than reported in this study. Lehtimäki et al. (2002) noted the respective results of 4–22 m^3 per hectare and 14–30% in a more critically selected stand data, the results being therefore at a similar level to this study. In mixed stands dominated by conifers, the proportion of saw log from the entire harvesting recovery of birch was relatively high: depending on the bucking option, from 4–10% and 10–16% in the first and second commercial thinnings, respectively (Table 6). This can be explained by the fact that in mixed stands the birch trees have more severe competition for light, which may lead to straighter stem form and more efficient dying and self-pruning of lower branches. Many authors have also reported that the birch trees that have been saved growing in mixed stands until the time of final felling actually represent the highest possible quality and saw or plywood log recovery in Finland (e.g., Heiskanen 1957, 1966, Verkasalo 1997, Heräjärvi 2001, Kaurala et al. 2004).

Depending on the stratum (stand type), the proportion of logs suitable for sawing varied roughly between 10 and 20 per cent. The recovery of logs was the highest in planted birch stands and the lowest in naturally regenerated pure birch stands. However, the results of this study were based on rather strict quality requirements. In practical timber procurement, the saw log recoveries might be somewhat higher. Especially, the defect class 2 (defects decreasing the quality of sawn timber) might have been treated in this study too strictly. The conclusion is supported by the results of Lindblad et al. (2003) with approximately one third of saw logs in the thinning recovery in practical cutting of birch stands with a single-grip harvester compared with one quarter according to the measurement and evaluation of standing tree stocks. In the study of Arponen et al. (2008), planted silver birch trees from four selected later thinning stands provided even a higher saw log recovery of 43–57 per cent, when the minimum log diameter of 12 cm was applied in the evaluation of standing stocks.

The availability of diameters and lengths of saw logs and pulpwood had an effect of 5–10 percentage units on the recovery of saw logs. Short stem parts with adequate quality for saw milling are typical in thinning stands, thus, short log lengths are needed. In this study, decreasing the number of log lengths from two to one reduced the saw log percentage as much as by one third. The availability of different pulpwood lengths was almost as important: both the approximate length (3 m ± 10%) and free length (2.7–5.0 m) indirectly added to the saw log percentage.

Small diameter of the trees in the removal sets also limits bucking saw logs from thinning stands of birch. In the study of Lindblad et al. (2003), saw log percentage increased from dbh class 13 cm to dbh class 17 cm, and remained thereafter at an approximately constant level. Lindblad et al. (2003) applied similar minimum saw log diameter than we did in this study. Accordingly, larger tree dimensions along with less defects in the potential log section mainly explain the higher saw log recovery in the second thinnings compared with the first thinnings. The higher technical quality of the timber recovery in the second thinnings can be expected due to the elimination of the trees with the lowest quality in the first thinnings (see:

Rantanen et al. 2000, Lindblad et al. 2003). This is also obvious judged from the results of Arponen et al. (2008).

The advanced wood processing technology, for example, cross-cutting, finger jointing, laminating and surface treatment supported by machine vision, nevertheless, enables economic processing of birch lumber with variable lengths and some defects, as well. Apparently, in the bucking simulations even relatively small defects caused timber assortment downgrade from saw log to pulpwood, especially in case of smaller-diameter logs. This would not be the case in real life. It must also be kept in mind that in commercial thinning the best trees should remain standing. Thus, it is unacceptable to increase the saw log recovery at the expense of silviculture.

Based on this study, harvesting recoveries of end-use based timber assortments can be estimated in different kinds of thinning birch stands. In addition, the results provide birch users with information concerning timber quality attributes in various thinning stand types. Judged from the tree and log dimensions and stem quality, silver birch firstly from plantations and secondly from mixed stands, particularly from the second and later thinnings should be in the largest interest for the saw milling, furniture and interior product sector, and, thus, for saw log production in the forest management. Accordingly, a careful selection of birch thinning stands for timber procurement may provide a considerable raw material potential for mechanical wood processing.

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