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Influence of Saw and Secateur Pruning on Stem Discolouration, Wound Cicatrisation and Diameter Growth of *Betula pendula*

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The aim of this case study was to compare the impacts of saw and secateur pruning on silver birch (*Betula pendula* Roth). Data were collected from two saw pruned stands in 2005, and one secateur pruned stand in 2003. All the stands were located in southern Finland. The sample stems were felled, and their butt logs were sawn into flitches, whose knot features and colour defects were measured. In addition, discs were sawn from each stem in order to study the annual ring widths. In this material, pruning with secateurs appeared to cause less colour defects than pruning with a saw. Irrespective of the pruning method used, the colour defects in the stem wood were at their largest in cases where the basal knob or the stem bark appeared to be damaged by pruning. Colour defects spread mainly towards the pith, only in a few cases towards the stem surface. The cicatrisation time of the knots as well as the length of the bark stick remaining inside the stem did not show significant differences between the two pruning methods. Pruning of the lowest living branches appears to have no effect on the diameter growth of silver birch trees.

Keywords *Betula pendula,* colour defects, pruning saw, secateur, technical quality
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1 Introduction

Silver birch (*Betula pendula* Roth) is the most important hardwood species for forest industries in Finland. It is faster growing and has better technical quality, e.g., stem form and knottiness, than European white birch (*B. pubescens* Ehrh.), which is, however, the more common of the two. Almost all birch plantations in Finland are silver birch. A problem of many of the planted stands is the poor stem quality due to branchiness. It is caused by the relatively wide initial spacing used in plantations, typically about 1600 seedlings per hectare (e.g., Niemistö 1995).

Shading, which occurs as a result of tree and species competition, leads to faster dying and self-pruning of the lower branches. In widely spaced birch plantations, on the other hand, self-pruning is postponed due to longer life expectancy and lack of mechanical stresses on the lower branches (e.g., Niemistö 1995, Verkasalo and Rintala 1998, Kannisto and Heräjärvi 2006). Nevertheless, silver birch is only a minor species, regarding pruning, in Finland compared to Scots pine (*Pinus sylvestris* L.).

Haygreen and Bowyer (1989) defined pruning as "*…the practice of trimming branches from the lower portion of the standing trees to reduce the occurrence of knots in subsequently produced wood*". They further stated "*When a branch is removed from the bole of a tree, the sheath of new growth will eventually cover the stub, producing knot-free wood thereafter. Such wood has markedly higher value than knotty wood for solid wood products and veneer, because of its greater strength and improved appearance*." There is much shorter tradition of silvicultural pruning compared to the pruning of yard and garden trees (Dinwoodie 1981, Arvidsson 1986).

In addition to the improved branchiness quality in the pruned stem section, Nicolescu (1999) reviewed several other quality attributes that have been observed to be influenced by pruning. The positive features include increased wood density due to the reduced proportion of earlywood (e.g., Fielding 1965), decreased proportion of compression wood formed around the knots (e.g., Keller and Thiercelin 1984), earlier cessation of juvenile wood formation in the pruned part of the stem (e.g., Savill et al. 1997), reduced wood shrinkage in radial and tangential directions (Pazdrowski 1984, in Nicolescu 1999), longer tracheids in the pruned zone (e.g., Fielding 1965), reduced spiral grain angle (Fielding 1965), and reduced occurrence of pitch streaks and heart shake (Robinson 1965). On the other hand, pruning also causes negative features, such as the formation of enclosed bark and resin pockets (Carrabin 1994), reduced compression strength in the grain direction (Pazdrowski 1981, in Nicolescu 1999), reduced wood hardness (Pazdrowski and Cybulko 1988, in Nicolescu 1999), increase in the size of living branches immediately above the pruned zone (e.g., Fielding 1965, Haygreen and Bowyer 1989), development of stresses giving rise to spring in sawn boards (Lückhoff 1967), and development of epicormic branches in some coniferous and some broadleaved species (e.g., Evans 1982, Savill 1991).

Pruned birch wood is used by the furniture industries, carpenters and veneer factories. Birch pruning as an instrument for improving stem wood quality was noted in Finland obviously for the first time in the 1930's and 1940's, when Lappi-Seppälä (1934), Laitakari (1937) and Lehonkoski (1949) studied the profitability of birch pruning. At that time, the recommendation was to prune dead branches to improve the quality of veneer logs. Another recommendation was that only high quality trees that are supposed to be grown until final felling should be pruned. Obviously, these promising studies increased interest regarding birch pruning since the 1930's, and for some reason, pruning was falsely advised to be a kind of common method to increase the wood quality and profits (Heiskanen 1958). The pruning enthusiasm decreased in the beginning of the 1950's when the first peeling results of pruned birch logs were published. The quality of the veneers was poor because of insufficiently pruned branches, too late pruning age, wrong choice of pruned tree, incorrect pruning methods, working equipment and poor overall quality of pruning work (Heiskanen 1958). Based on this, birch pruning was assessed to be unprofitable. However, the Finnish Forest Research Institute started a study concerning defects caused by pruning in 1955. The results finally showed that pruning increased the value of birch wood (Heiskanen 1958).

Among others, Heiskanen (1958, 1964), Vuokila (1976), Verkasalo and Rintala (1998), and Kannisto and Heräjärvi (2006) have noted that birch pruning impacts on a tree's health. In fact, most tree species are rather sensitive to wounding, such as pruning (see: Wilkes 1982, Shigo 1984). In the case of birch, pruning of dead branches appears not to negatively impact the trees' health if the pruning is done without damaging the stem bark. When the branches in birch trees are alive, it seems to be important to prune only branches smaller than 20 mm in diameter. Thicker branches cicatrise more slowly and, thus, the risk for discolouration increases (e.g., Verkasalo and Rintala 1998, Kannisto and Heräjärvi 2006, see also Hallaksela and Niemistö 1998). Moreover, the development of knot-free wood will be postponed. After pruning, the growing wood tissue heals over the branch stub, which usually causes some bark to remain inside the stem. This dead wood or bark, henceforth referred to as bark sticks, starts from the cut knot's surface and extends some distance towards the tree surface.

A living crown of about 50% of the tree height should be left in order to avoid reduced tree growth. It has been noted that the pruning of one or two lowest living whorls of branches can even increase the growth of a tree (e.g., Vuokila 1976, Lange et al. 1987, Giefing et al. 2004), since the energy efficiency of the lowest living branches can already be negative. However, normally pruning slows down the height and diameter increment for some years, depending on the proportion of green branches pruned (Heiskanen 1958, Vuokila 1976, Kannisto and Heräjärvi 2006).

A pruning saw usually has a curved blade with precision sharpened and usually reverse set toothing, i.e., it cuts only on the pull stroke. A bark knife, which is attached to the blade, prevents bark stripping by cutting the bark on the underside of the branch before sawing. For such saws, also telescopic handles up to 4–6 metres are available. This type of saw is the most common pruning tool, mainly used for Scots pine and larch in Finland. Pruning scissors or secateurs are especially designed for pruning at a height of 0–2.5 metres, and with one or two extension handles up to the height of 3.5–6 m. Secateurs are mostly used for pruning hardwoods.

This study focuses on silver birch pruning done by two different methods: pruning saw and secateurs. The aims of this case study are to analyse the discolouration caused by pruned knots, and to compare the cicatrisation times of pruned knots between the two pruning methods. In addition, the impacts of pruning on the diameter growth of pruned trees are investigated.

2 Materials and Methods

2.1 Sample Stands and Experimental Design

The material consists of two saw pruned *B. pendula* stands with ages of 32 and 34 years, and one 33-year-old secateur pruned stand. All trees were pruned during the summertime according to the current recommendations for birch pruning. All three stands were planted on a former agricultural field, and they were about to achieve the dimensions of the second commercial thinning. The silvicultural condition of the stands was assessed to be normal.

Mean height and mean diameter at breast height (dbh) of the birch trees were calculated based on measurements of 300 m^2 circular sample plots with the sample trees at the centre point of the plot. Information regarding planting times as well as silvicultural treatments, including thinnings and pruning years was obtained from the forest owners (Table 1).

The sample trees were randomly selected from the pruned trees in the stands. However, trees growing in untypical conditions, such as at the edge of the stand, next to the hauling tracks, etc. were avoided. Three sample trees, all pruned up to a six-metre height, were selected from both saw pruned stands. The secateur pruned stand was pruned only up to a height of three metres. Therefore, in order to ensure an adequate number of knots in the study material, altogether 10 trees were sampled from the secateur pruned stand.

Each stem was marked with an arrow indicating north. Next, the trees were felled and cut into 2-metre-long bolts beginning from the stump, and to cover the entire pruned height. Due to the lower pruning height, the secateur pruned trees from stand 3 provided only two 2-metre-long bolts per tree. Correspondingly, three bolts were obtained from the saw pruned stands. Defect free

Table 1. Characteristics of the sample stands.

	Site	Average			Pruning time	Pruning height, m	Thinnings
		Age, a	Dbh, mm	Height m			
Stand 1, Liperi (62°30´N, 29°30´E) Saw pruned	Former agr. field	32	21.1	20.6	1990–1991	6	Slightly thinned several times
Stand 2, Liperi (62°30´N, 29°30´E) Saw pruned	Former agr. field	34	23.9	22.7	1989–1990	6	Slightly thinned several times
Stand 3, Keitele (63°20´N, 26°10´E) Secateur pruned	Former agr. field	33	20.0	22.5	1987–1988	3	Thinned in 1997

sample discs with 2–3 cm thickness were cut at the stump height and at 2-metre-height of every tree. These discs were transported to the laboratory, sanded, and used to measure the annual ring widths using the WinDENDRO image analysis system (see: http://www.regentinstruments.com/products/dendro/DENDRO.html). Each bolt and disk was coded with stand number, tree number, within-stem position, and an arrow indicating north.

2.2 Sawing Method and Measurements of Knots

Each bolt was first pith-centrally sawn into south and north cants using a circular saw. Then, starting from the heart, the cants were sawn into 19-mm-thick flitches. Immediately after sawing, each flitch was coded by tree number, bolt number, bolt side (north/south) and the flitches' position in the bolt.

The following steps were done separately for flitches originating from the south and north side of the tree. All the flitches from one side of a bolt were spread out on a table. For each flitch, the knots were numbered running from the base to the top of the flitch. The distance of each knot from the flitch's base was measured. After marking the knots in the pith flitch, their type (pruned, naturally pruned or un-pruned), condition (green, dry or rotten) and diameter were measured or evaluated. These measurements were done first for the pith flitch and then for the next flitches towards the surface of the stem. Not only the knots but also the defects around them were measured. Often the characteristics of interest did not appear clearly enough on the surface of the flitch. Therefore when necessary, the flitches were cross cut using a table saw. This was the case most often in the measurement of cicatrised knots that required the flitches to be cut in order to measure the length of partly pruned branch or bark sticks inside the stem.

Furthermore, in many cases the flitches had to be cross cut in order to see the colour defects and their spreading distances. The difference between naturally and artificially pruned knots could be seen from the cross cut surface of the knot.

Based on their quality, the knots were classified into:

1) Green knots: knot is green if at least 50% of its perimeter is physiologically attached to the surrounding wood material.
2) Dry knots: knot is dry if more than 50% of its perimeter is loose from the surrounding wood material.
3) Rotten knots: knot is rotten if its wood material is clearly softened because of the rot.

The colour defects were also graded into three classes:

1) Colour defect: moderate colour change, usually because of chemical reaction or preliminary stage of rot.
2) Hard rot: the dark but still hard wood material,

caused by an infection of a decaying fungus.
3) Soft rot: wood material is dark and soft, and wears away when you scratch it.

The spreading distances of the colour defects towards the pith and surface were measured from the cross cut points of pruned knots. The spreading distance of colour defects was measured from each knot in every flitch. The maximum observed spreading distance was used in the calculations. The length of time for the cicatrisation was calculated from the annual rings, and finally, the thickness of knot-free sapwood was measured.

2.3 Statistical Analyses

The average annual ring widths of saw and secateur pruned stands at stump height and 2-m-height were compared using Tukey's test.

Differences in the average spreading distance of colour defects from pruned knots to the stem wood, as well as the occurrence of defects (proportion of defected knots from all knots) between the saw pruned knots from stands 1 and 2, and between the saw and secateur pruned knots, were analysed using the analysis of variance (ANOVA). The dependent variable was the proportion of knots with colour defects. The model is:

$$y_{ij} = m + \text{stand}_i + e_{ij} \quad (1)$$

where y_{ij} is the value of dependent variable (proportion of knots with colour or rot defects) for tree j at stand i, m is constant and e_{ij} is the error term.

The cicatrisation time of the pruning wound and the length of the remaining partly pruned branch or bark material that has grown inside the stem (bark stick), were compared using a linear mixed model. In the measurements, a knot was considered to be perfectly cicatrised when knot-free wood began to develop. The dependent variables in the analyses were "ln (cicatrisation time + 1)" and "ln (length of bark stick + 1)", where "ln (…)" stands for natural logarithm. The covariate in the model was "ln (knot diameter + 1)". The transformation was necessary to fulfil the assumptions of homogenous variances and normal distribution of error term. The logarithm transformation of the covariate, on the other hand, was needed to fulfil the assumption of liner relationship between the dependent variable and the covariate. The model is:

$$y_{ijk} = m + \text{stand}_i + \text{tree}_{ij} + e_{ijk} \quad (2)$$

where y_{ijk} is logarithm transformed measurement of branch k of tree j at stand i, m is constant, stand_i is the fixed effect of stand i, tree_{ij} is the random effect of tree j at stand i and e_{ijk} is the error term. Since the dependent variables were transformed, estimates of the contrasts show the differences between the transformed values. However, the significances (p-values) are valid both to the original and the transformed values.

All statistical analyses were done using SPSS 14.0 software.

3 Results

3.1 Impacts of Pruning on Annual Ring Width

The results of the Tukey test show that the average ring widths differ between stands 1, 2 and 3 both at stump height and at 2-metre height (Table 2). This result can also be seen in Figs. 1 and 2, which show the average ring widths per year at both heights. After year 1990, the ring widths did not differ between the stands.

At stump height, the saw pruned stand 1 had the widest annual rings, followed by saw pruned stand 2. The average annual ring width per year in the secateur pruned stand was ca. 1 mm less than those in the saw pruned stands. At 2-m

Table 2. Comparisons of the differences in the annual ring widths between the stands and measurement heights. Results of Tukey tests.

Stump height		2-metre-height	
Stand pair	p-value	Stand pair	p-value
1 vs. 2	0.966	1 vs. 2	0.691
1 vs. 3	0.040	1 vs. 3	0.213
2 vs. 3	0.070	2 vs. 3	0.036

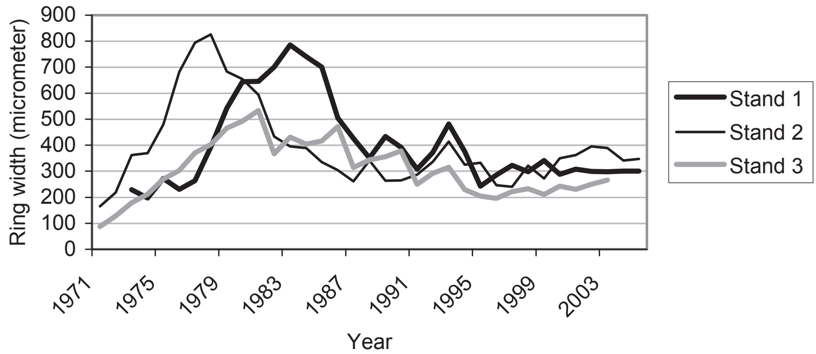

Fig. 1. Average annual ring widths at stump height.

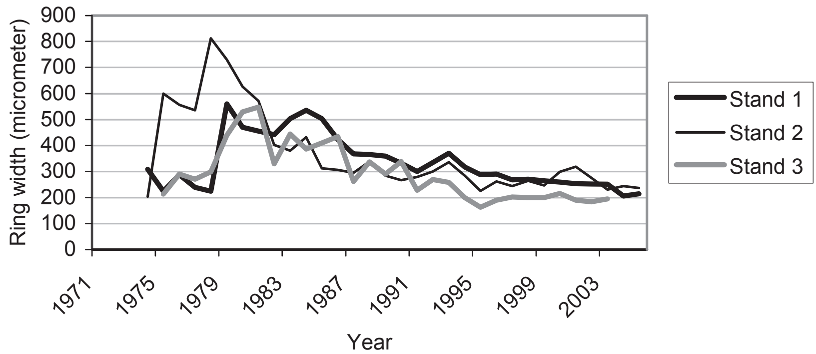

Fig. 2. Average annual ring widths at 2-metre-height.

Table 3. The average growth of the sample trees at stump and 2-metre heights.

Stand nr. (age)	Stump height		2-metre-height	
	Radial increment, mm/a	Std. deviation, mm	Radial increment, mm/a	Std. deviation, mm
1 (32)	4.02	1.64	3.36	1.01
2 (34)	3.93	1.60	3.66	1.58
3 (33)	3.05	1.09	2.94	1.08

height, stand 2 showed the widest annual rings, followed by stand 1. Similarly at this height, stand 3 showed the slowest average growth (Table 3).

The average annual ring width appeared to increase a year after pruning, however, slightly decreasing later in all stands. A possible reason for the general growth decline after pruning is the fact that living branches were also pruned in addition to dead ones. On the other hand, the diameter growth starts declining anyway at a certain age. However, this usually does not occur at such a young age as that of the materials used in this study. When the average widths of annual rings grown five years after pruning were compared using Tukey test, no differences were observed between the three stands.

3.2 Colour Defects

Pruned knots had spread colour defects in all directions inside the stem. The most obvious directions for discolouration were tangential (47.4% of the pruned knots), upwards (46.8%) and downwards (35.6%). Only 6.8% of the knots had spread colour towards the pith, and in the case of about 8% of those knots, the discolouration reached the pith. Even smaller was the percentage of knots that had spread colour towards the surface (4.4%). The average spreading distances up- and downwards were 17.9 and 20.3 mm, respectively. In the most severe cases, discolouration was observed as much as 565 mm upwards and 390 mm downwards from the knot.

ANOVA tests were conducted to detect the differences in the defect probabilities and average spreading distances between the pruning methods. Only knots smaller than 20 mm in diameter were included in these analyses, since larger knots were not available from all stands.

Firstly, saw pruned stand 1 was compared with the saw pruned stand 2. According to this comparison, only the occurrence of defects spreading until the pith differed significantly ($p=0.016$) between the stands. About three times more knots spread colour until the pith in stand 1 compared to stand 2. Notwithstanding this fact, the mean value of stands 1 and 2 was still chosen to represent the saw pruning method, since the other directions did not differ between the two stands.

Next, secateur pruned stand 3 was compared to the mean value of the saw pruned stands. Significant differences in the numbers of colour spreading knots were found in the tangential direction, upwards, towards the surface and towards the pith. Defects were, at minimum, twice as common in saw pruned than in secateur pruned trees in tangential direction, upwards and towards the pith. Defects spreading towards the surface were as much as 13 times more common in saw pruned trees. In fact only one knot from the total of 241 secateur pruned knots in this material spread colour towards the surface. In case of those secateur pruned knots that had spread colour towards the pith, the discolouration often extended all the way until the pith.

Finally, the knots were grouped into 5 mm diameter classes. Again, the differences between

Table 4. Proportions of colour spreading knots from all knots, and average distances of discolouration per knot diameter class in saw and secateur pruned silver birch trees. Spreading distance values with significant difference ($p<0.05$) between the two pruning methods are indicated by bold font. Results of ANOVA.

Knot diameter, mm	Subset		Tangent	Up	Down	Surface	Towards the pith	Until the pith
1–5	Saw pruned knots	Colour spreading knots, %	61.3	55.6	54.5	9.1	11.2	6.2
	knots	Spreading distance, mm	**5.1**	**10.2**	**15.0**	5.1	3.1	4.3
	Secateur pruned	Colour spreading knots, %	20.2	21.8	19.8	0	0	0
	knots	Spreading distance, mm	**1.0**	**3.0**	**1.8**	-	-	-
6–10	Saw pruned	Colour spreading knots, %	64.0	60.9	48.0	6.4	5.2	4.4
	knots	Spreading distance, mm	**7.5**	**12.4**	**16.3**	7.0	4.3	7.4
	Secateur pruned	Colour spreading knots, %	25.3	25.9	23.3	0	4.4	6.9
	knots	Spreading distance, mm	**3.3**	**47.4**	**16.8**	-	2.8	0.4
11–15	Saw pruned	Colour spreading knots, %	56.2	56.2	20.5	5.6	10.3	11.1
	knots	Spreading distance, mm	**9.0**	**11.3**	17.4	3.6	5.6	5.8
	Secateur pruned	Colour spreading knots, %	21.5	25.5	22.1	3.3	7.7	18.9
	knots	Spreading distance, mm	**4.9**	**10.6**	17.1	0.1	3.0	0.5
16–20	Saw pruned	Colour spreading knots, %	65.6	54.0	23.3	5.7	17.2	9.1
	knots	Spreading distance, mm	**11.6**	28.3	50.6	5.0	3.7	6.2
	Secateur pruned	Colour spreading knots, %	25.0	37.5	38.9	0	1.4	36.1
	knots	Spreading distance, mm	**7.6**	16.6	19.6	-	1.7	0.7

the two saw pruned stands were first tested. The test showed significant ($p=0.026$) differences only in knot diameter class 1–5 mm and discolouration towards the pith, the average spreading distance being about 1.5 mm smaller in stand 2 than in stand 1. Based on the general similarity, also here the mean values of stands 1 and 2 were used to represent the saw pruned data in the knot diameter class wise comparisons of the two pruning methods. As shown in Table 4, the diameter of the branch at the time of pruning and the average defect spreading distance are, in general, positively correlated.

Irrespective of the knot diameter, significant differences in the average defect spreading distances could be seen between the pruning methods in a tangential direction, towards the surface and towards the pith. In all cases the saw pruned knots indicated wider discolouration than the secateur pruned ones. The average colour spreading distances in a tangential direction were rather small, between 5–7 mm in both pruning methods. The secateur pruned knots indicated wider vertical discolouration.

In the case of the knot diameter class 1–5 mm, obvious differences between the pruning methods could be seen in a tangential direction, upwards and downwards. The average colour spreading distances in the secateur pruned stand were 4.1 mm, 7.2 mm and 13.2 mm smaller tangentially, upwards and downwards, respectively, compared to the saw pruned stands. Since there were insufficient observations of discolouration towards the surface and pith in the secateur pruned stand, no tests could be done.

In the case of knot diameter class 6–10 mm, again clear differences between the pruning methods could be shown tangentially, upwards and downwards. The average colour spreading distances in the secateur pruned stand were 4.2 mm smaller in tangential direction. On the other hand, secateur pruned knots had spread colour, on average, 35 mm more upwards and 0.5 mm more downwards than the saw pruned knots.

Differences in the colour spreading distances between the two pruning methods were also found in the knot diameter class 11–15 mm in a tangential direction and upwards. In this diameter class, the secateur pruned knots had spread 4 mm less colour tangentially and 0.7 mm less colour upwards than the saw pruned knots, on average.

In the biggest diameter class, 16–20 mm, the pruning methods differed from each other only in a tangential direction. Here, the average defect spreading distance of the secateur pruned knots was 4 mm smaller than that of saw pruned knots.

3.3 Cicatrisation Time and Bark Sticks

In this material, almost all pruned knots were completely cicatrised. No correlation was found between the cicatrisation time (or the length of the bark stick) and the vertical location of the pruned knots. Only small variations were seen between the average cicatrisation time and the average knot diameter of the stands (Table 5).

No differences could either be shown between stands 1 and 2 in the cicatrisation time ($p=0.747$) and the length of the bark stick ($p=0.938$). Furthermore, the linear mixed model showed that variable "stand" did not have any influence on the analysis: no differences were detected when the secateur (stands 1+2) and saw pruning (stand 3) methods were compared (cicatrisation time:

Table 5. Average cicatrisation times, lengths of bark sticks, and knot diameters in separate stands.

	Cicatrisation time, a	Length of the bark stick, mm	Knot diameter, mm	N of observations
Stand 1	6.3	7.9	8.5	162
Stand 2	6.7	8.4	9.5	167
Mean, stand 1+2	6.5	8.2	9.0	329
Stand 3	6.8	10.8	10.3	241

Table 6. Average cicatrisation times and average lengths of the bark sticks according to knot diameter classes in secateur and saw pruned stands. Numbers of observations in parentheses.

Knot diameter class, mm	Cicatrisation time, years		Length of the bark stick, mm	
	Secateur pruned stand	Saw pruned stands	Secateur pruned stand	Saw pruned stands
1–5	5.2 (33)	5.0 (80)	6.5	5.5
6–10	6.8 (125)	6.6 (149)	10.5	8.5
11–15	7.4 (46)	7.5 (73)	10.8	9.6
16–20	7.3 (30)	8.2 (27)	14.1	10.5
> 20	10.0 (7)	-	21.6	-

$p=0.777$, length of the bark stick: $p=0.460$) for the entire knot material.

Significant differences were, however, detected in the knot diameter class wise analysis. The larger the branch at the time of pruning, the longer the cicatrisation time and the bark stick. Stands 1 and 2 did not differ from each other in terms of the average cicatrisation time or the length of the bark stick. Thus, the mean value of the two stands was again used to represent the entire saw pruned material. Table 6 shows the average cicatrisation times as well as the lengths of the bark sticks inside the wood in 5 mm knot diameter classes. Independent of the diameter class, the bark stick in the secateur pruned stand was slightly longer than in the saw pruned stands. The average cicatrisation times varied from 5 years (smallest knots) to 10 years (largest knots), the differences between the pruning methods being insignificant.

4 Discussion

This case study aimed at identifying the impacts of two different pruning methods on the knot cicatrisation, discolouration and tree growth of silver birch. The material consisted of sample trees from three cultivated silver birch stands. Two stands were pruned using a pruning saw, and one stand was pruned using secateurs. The material was relatively small, only six saw pruned and ten secateur pruned birch trees. However, the results showed clear and consistent differences between the two pruning methods, and at least preliminary conclusions can be drawn based on this study.

In the samples taken from the stand pruned with secateurs, the material consisted of only 37 knots thicker than 15 mm and 7 knots thicker than 20 mm. In the samples from the saw pruned stands, there were only 27 knots thicker than 15 mm, and all the measured knots were smaller than 20 mm in diameter. Due to the small number of observations, the results concerning colour defects caused by pruning thick branches are only indicative. The defect spreading distances were, in many cases, difficult to measure, especially in the case of knots with a small diameter. The heart rot that appeared in many stems, made it even more difficult to measure the pruning induced colour defects which spread towards the tree pith. Finally, the differences in colour defects between knots that had been pruned dead or alive could not be estimated, since the vitality of the branch at the time of pruning was, in most cases, difficult or impossible to assess at the time of material measurements.

In all three stands, the radial growth of trees had increased for about one year after pruning. Subsequently, the growth rate decreased back to its original level in all stands. This effect was already described by Heiskanen (1958) and Vuokila (1976). Obviously, although green branches were pruned, enough living crown was left in the trees so that the growth was not markedly decreased after pruning. Since all sample trees were pruned in this material, it is impossible to assess pruning's effects, per se, to the diameter growth of trees. Neither saw nor secateur pruning appeared to have significant effects on the diameter growth of trees. However, this comparison is not well justified due to the differences in the pruning height.

In all directions, except towards the tree pith, the probability of discolouration in the saw pruned trees was more than two times higher than in the secateur pruned trees. In general, the age of the trees, site, soil type and genetic differences between the stands may influence the spreading of colour defects. According to Rayner and Boddy (1988) and Hallaksela (1994), microbes can more easily grow along the grain direction and radially than in tangential direction inside the trees. This was generally the case also in the materials of this study. One reason for more severe discolouration in case of saw pruned trees may be the rougher cross cut surface of the branch, providing wider area for the microbes and bacteria to access wood.

No statistical differences were found in the length of the bark stick and the cicatrisation times between the secateur and saw pruned knots. Apparently, if the knot diameter is less than 20 mm at the time of pruning, irrespectively of the pruning method, it should cicatrise within a period of 5–8 years.

Colour defects caused by the pruned knots did not reach the knot-free sapwood. The total area of discoloured wood was smaller than that observed in previous studies made with saw pruned birch trees (Heikinheimo 1953, Heiskanen 1958, Vuokila 1982, Verkasalo and Rintala 1998). Previously, Heikinheimo (1953) noted obvious colour defects after pruning birch. He showed that in branches more than 10-mm-thick that had been pruned alive, approximately 50% spread colour to the surrounding wood. Sample trees had been slowly growing (ca. 1 mm/a) and he supposed that in faster growing trees the defects would be less severe.

Vuokila (1976, 1982) stated that colour defects which originate from pruned knots in birch trees are mostly caused by bark injuries which are invariably caused by careless pruning work. The most recent finding is in full agreement with this statement (see: Kannisto and Heräjärvi 2006). Vuokila (1976) also mentioned that careful pruning work does not have any influence on the occurrence of such defects that could decrease the birch stem's value. Based on the results of Kannisto and Heräjärvi (2006) and the current study, it is obvious that correctly pruned birch trees (careful work, correct pruning time and selection of pruned trees, not too large branches) will eventually provide butt logs with considerably higher value than in unpruned trees.

Previously, the recommendation was to cut birch branches as close to the stem as possible, without injuring the bark. When pruning like this, injuries often occur in the living tissue of the basal knob, i.e., the joint between the branch and stem, and the risk for infection increases. Therefore it is recommendable to leave a stump of about 5 mm for each branch in order to avoid the damages to the basal knob.

In general, this study supports the hypothesis that a pruning secateur is more suitable tool than pruning saw in the case of birch.

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