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Effect of Felling Season, Storage and Drying on Colour of Silver Birch (*Betula pendula*) Wood from Four Different Growing Sites

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Darkening of birch wood during artificial drying is a significant problem regarding the use of its timber as raw material by the mechanical wood industry. In the future, an increasing proportion of birch timber will be obtained from plantation forests, which differ from natural forests in many respects. In this investigation sample boards of *Betula pendula*, both from naturally regenerated stands and plantations, were sawn into the dimensions used as raw material for parquet billets. Growing site, felling season, and storage of logs were taken into account as possible factors affecting wood colour changes during drying. The wood of birches from fertile plantations remained lighter-coloured during conventional drying than the wood of naturally regenerated birches from low- and medium-fertile stands. The reason may be the difference in tree age and growth rate between natural and planted stands. Thus, it could be beneficial to grow birch in fertile stands so that the trees reach log size as young as possible. The results of this study emphasise the good quality of the birch wood from planted stands compared to natural stands with regard to its colour.

Keywords age, birch, colour darkening, conventional drying, environmental factors, plantation, wood
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1 Introduction

Birches (*Betula pendula* Roth and *B. pubescens* Ehrh.) are the most utilised hardwood species in Finland. Due to its hardness and relatively low density, birch wood is very suitable, for example, for parquet surfaces and furniture. An attempt to secure the supply of birch timber through planting mainly silver birch (*B. pendula*) has been made. Since the 1960s, when birch planting started on a larger scale in Finland, ca. 200 000 ha of the species has been planted (Peltola 2007). The importance of birch timber from plantations for the mechanical wood industry will thus increase in the 2010s, when the oldest plantations will be mature for harvesting. This raises the question regarding differences in the properties of birch wood from different origins and about possibilities to process them in a similar way or even in the same processes.

The most critical phase in the processing of sawn birch timber is drying, as colour darkening during drying, even unevenly, is considered to be the biggest problem in its use by the mechanical wood industry (Kivistö et al. 1999). Factors such as felling season, length and season of log storage, as well as climatic conditions before felling are thought to affect colour change in the wood during drying (Kreber and Byrne 1994), as they are known to influence the amount of wood extractives (Mononen et al. 2004, Laitinen et al. 2005). When planted and naturally regenerated birches are considered, the fertility of the growing sites must also be taken into account, although growth rate does not usually affect the basic density of birch wood (e.g. Cameron et al. 1995). Instead, nutrient availability affects the amount of phenolics, concentration of which is highest in trees grown on poor sites (Mansfield et al. 1999, Keski-Saari 2005), and which may change to coloured compounds when polymerising; planting sites have been mostly high fertility forest clear-cutting areas and abandoned agricultural fields. Although the best natural growing sites for birch are highly fertile, however, birch grows as a minor tree species on less fertile sites as well; these are also an important source of birch timber (e.g. Frivold 1982, Luostarinen and Verkasalo 2000). Thus the fertility of the sites selected for plantation may, on average, be higher than the fertility of the sites in which naturally regenerated birch forest grows, which emphasises the faster growth of plantations (Saksa 1998).

In addition to differences in drying behaviour with regard to wood density and shrinkage between planted and naturally regenerated birches (Möttönen and Luostarinen 2006), differences in wood colour darkening may exist. Although the wood colour of both naturally regenerated and planted silver birch has been studied (Luostarinen and Luostarinen 2001, Luostarinen et al. 2002, Möttönen and Luostarinen 2004, 2005), the possible colour differences between origins has not been compared and possible differences in effects of environmental factors on colour are not known regarding this. The objective of this study was to compare the effect of felling season, storage of logs and conventional drying on the colour of silver birch (*Betula pendula*) wood grown on four different growing sites, two planted and two naturally regenerated forests.

2 Materials and Methods

Silver birch trees (Table 1) were felled on four growing sites, on naturally regenerated low-fertility VT (*Vaccinium*-type) and medium-fertility MT (*Myrtillus*-type), and on planted high fertility OMT (*Oxalis-Myrtillus*-type) as well as on an abandoned agricultural field afforested by planting. Each growing site was located on mineral soil in North Karelia, Finland. Trees were felled in three different seasons; in autumn (leaves yellowed and growth ceased), in winter (trees at the beginning of dormancy), and in summer (full leaves and trees growing well). Naturally regenerated trees with decayed wood around the pith were excluded, but darkened wood around the pith, which was very common, could not always be avoided. However, darkened wood was not used for the experiments. Instead, only healthy planted trees with sound (according to visual inspection) wood from pith to bark were accepted as sample trees, due to their smaller size, to get enough boards, of size of 30 × 70 × 1200 mm^3, for drying.

In each season 10 trees were felled on each growing site. Five trees from each site were then

Table 1. Age, diameter, annual growth and height of harvested birch trees. Annual growth was calculated as ratio of radius (diameter/2) and age at the base of trees. SE – standard error of the mean.

Growing site	Age, a (SE)	Diameter at the tree base, cm (SE)	Annual growth, mm (SE)	Diameter at breast height, cm (SE)	Height, m (SE)
VT	76.9 (2.0)	36.4 (1.0)	2.4 (0.1)	29.5 (0.7)	23.3 (0.4)
MT	61.6 (0.9)	35.9 (0.8)	2.9 (0.1)	30.3 (0.7)	24.4 (0.3)
OMT	33	30.9 (0.6)	4.7 (0.1)	22.0 (0.3)	19.8 (0.3)
Field	33	30.4 (0.6)	4.6 (0.1)	21.8 (0.4)	19.3 (0.3)

cut into two 2.5 m long logs, and the remaining trees, intended for storage, were cut into two 3 m long logs. One log was taken from the butt and the other from the top, so that the minimum diameter of the upper end of the top log was 20 cm. The used part of the trunks, from the naturally regenerated birches, was branchless, while only the butt log was branchless in the case of planted birches. Both logs from each tree, for immediate sawing, from each growing site were sawn within two days after felling, while the logs of the five remaining trees were sawn following eight weeks (planted) or ten weeks (natural) storage (unbarked) in the yard of the sawmill. Thus boards from both storage periods could not be included in the same drying lots. The difference in lengths of the storage periods between natural and planted birches was due to the practical arrangements of the drying processes. To get enough dried boards for each experimental group, the wood from planted birches was dried separately from the naturally regenerated birches (a small computer controlled conventional laboratory kiln, Brunner Trockentechnik, was used for the drying). The partition of boards from different growing sites was done this way because of the logistics of log handling.

Initial moisture contents of the logs ($g_{water}/g_{dry\ wood} \times 100\%$), before sawing, are presented in Table 2. For the unstored wood, the moisture content sample was taken from a disc sawn from the base of the trees, for stored logs the sample was taken from a disc sawn 50 cm from the log end. The target moisture content (on dry weight basis) of the wood was set at 5.0% in drying, and the maximal difference in average moisture content, between the surface and the inner wood of the board, was set at 0.5%-units. The drying

Table 2. Initial moisture contents, on dry weight basis (%), measured from logs before sawing. SE – standard error of the mean.

Growing site	Felling season	Storage, weeks	Mean, %	SE
VT	Autumn	0	81.04	2.16
		10	77.46	3.46
	Winter	0	80.35	3.25
		10	79.89	2.41
	Summer	0	65.52	4.50
		10	65.94	5.13
MT	Autumn	0	79.16	2.26
		10	81.26	3.58
	Winter	0	81.73	2.15
		10	82.35	3.94
	Summer	0	68.15	5.10
		10	70.01	4.31
OMT	Autumn	0	81.30	8.35
		8	85.92	6.06
	Winter	0	82.34	5.15
		8	86.03	3.49
	Summer	0	121.97	4.89
		8	79.21	6.85
Field	Autumn	0	94.58	9.83
		8	96.95	7.90
	Winter	0	83.24	7.67
		8	91.34	4.68
	Summer	0	107.73	6.88
		8	75.61	5.60

processes were started within 24 hours after sawing. As the reasons for the colour darkening were investigated in this study, the programmed conventional drying schedule (Table 3), which was the same for all drying lots, a total of 12, was planned so that colour darkening would most probably occur.

Table 3. Programmed conventional drying schedule used in the experiments. Drying stage was divided into 10 moisture content (MC) classes to control the dryings accordingly.

Stage of process	T_d [b)]	DF [c)]	EMC [d)]
Heating	37	- [e)]	15
Drying [a)], >70%	37	2.0	-
60–70%	38	2.4	-
50–60%	39	2.4	-
40–50%	40	2.7	-
30–40%	41	3.2	-
25–30%	42	3.2	-
20–25%	42	3.2	-
15–20%	60	3.5	-
10–15%	65	3.5	-
<10%	65	3.5	-
Conditioning	70	-	3
Cooling	-	-	5

[a)] Based on wood moisture content; [b)] Dry temperature, ˚C; [c)] Drying force (DF=MC/EMC); [d)] Equilibrium moisture content, %; [e)] Not included in schedule

Spectral measurements were made with a portable spectrophotometer, Minolta CM-2002, using a 2° standard observer and standard illuminant D_{65} (e.g. Minolta 1994). The reflectance spectra of sound green and stored wood (knots and other defects were avoided) were measured from the surface of the boards immediately after planing. The spectra of sound dried wood were measured after split-sawing the dried boards and planing the split surface, representing the inner wood of the boards. The spectral measurements for undried and dried wood were performed for different boards, because measuring the boards to be dried at this stage would have delayed the start of the drying process. Additionally, necessary planing of the board surface for spectral measurements might have changed the drying behaviour of the boards, which was not desirable. In addition, a few boards containing bark and other defects that may affect the colour of sound wood during drying had to be included in order to fill the kiln, but the spectra of these boards were not measured after drying. As a consequence of these and the different size of each log, the numbers of boards in lots (see Tables 4 and 5) used for measurements differed from each other.

The spectral result of one board was obtained by averaging three measurements made from different places on the same board. L*a*b* colour coordinates were calculated from the measured spectra. These coordinates indicate the location of the colour in a three-dimensional colour space. The L* coordinate is scaled so that zero corresponds to black and one hundred to white. Large negative values of a* indicate green and positive values indicate red; large negative values of b* indicate blue and positive values indicate yellow (e.g. Hunt 1991; Minolta 1994). In the case of birch wood a* and b* coordinates are positive. The colour difference between two measurements, ΔE_{ab}*, calculated here for the difference between undried and dried wood, and differences between different lots of dried wood, was calculated as follows (Eq. 1) (e.g. Hunt 1991, Minolta 1994):

$$\Delta E_{ab}^* = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \quad (1)$$

The results were analysed with SPSS-statistics using GLM (General Linear Model) analysis of variance and Kruskall-Wallis procedures by comparing the averages of the colour coordinates by growing sites, felling seasons and storages. GLM was used when the terms of parametric tests (normality, uniformity of variances) came true, while Kruskall-Wallis test was used when both or one of these terms were not valid. Interactions between felling time, growing site and storage period could not be taken into account, because in such calculations the terms of parametric tests did not come true in most of the cases. Because different boards for undried and dried spectra were measured, the ΔE_{ab}* values were calculated for average colour of undried and dried wood and no statistical testing was performed between them.

3 Results

3.1 Felling Season

Several differences in colour were observed between the growing sites within a felling season (Table 4). The undried wood from the VT site was darkest in autumn, while the undried wood from the field site was lightest in summer. The redness

Table 4. Averages of colour coordinates of different growing sites and felling seasons. $_u$ – undried, $_{dr}$ – dried. Lower case letters indicate statistical difference between growing sites within felling season between those growing sites of which average is followed by a different letter. Capitals indicate statistical difference between felling seasons within growing site when the average is followed by a different letter. ΔE_{ab}* is calculated as the difference between undried and dried wood within a row. SE – standard error of the mean. Both unstored and stored boards are included in N.

Origin	Growing site	Felling season	N_u	N_{dr}	L^*_u	a^*_u	b^*_u	L^*_{dr}	a^*_{dr}	b^*_{dr}	ΔE_{ab}^*
Natural	VT	Autumn	41	44	86.8b	1.7b	18.0b	79.2aA	4.8aA	18.6aA	8.23
		SE			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
		Winter	40	43	87.3a	1.7b	17.5a	80.5abB	4.6bA	18.6abA	7.47
		SE			(0.2)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	
		Summer	24	49	87.3a	1.7b	17.9a	78.1bC	5.2bB	19.8aB	10.02
		SE			(0.3)	(0.1)	(0.3)	(0.3)	(0.1)	(0.2)	
Natural	MT	Autumn	48	46	87.5a	1.3a	17.2a	79.7aA	4.5aA	18.7aA	8.56
		SE			(0.2)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
		Winter	51	43	87.7ab	1.3a	17.1ab	81.2aB	3.9aB	19.1aAB	7.28
		SE			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		Summer	25	52	88.1ab	1.3ab	17.1ab	79.6aA	4.5aA	19.3abB	9.35
		SE			(0.3)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
Planted	OMT	Autumn	44	48	87.1abA	1.0c	16.3c	81.5bA	3.6bA	18.3aA	6.49
		SE			(0.2)	(0.1)	(0.2)	(0.3)	(0.1)	(0.1)	
		Winter	46	51	87.5abAB	1.2a	16.7b	81.0abA	4.0adB	18.5bA	7.30
		SE			(0.2)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
		Summer	32	57	88.0abB	1.1a	16.5bc	80.0acB	3.9cB	19.6abB	9.02
		SE			(0.2)	(0.1)	(0.3)	(0.2)	(0.1)	(0.1)	
Planted	Field	Autumn	42	48	87.1abA	1.0c	16.4c	81.8bA	3.5bA	18.3aA	6.16
		SE			(0.2)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		Winter	50	56	88.0bB	0.9c	16.1c	80.4bB	4.2bdB	18.9abB	8.75
		SE			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	
		Summer	30	56	88.4bB	1.0a	16.2c	81.0dAB	3.7cA	19.1bB	8.39
		SE			(0.2)	(0.1)	(0.2)	(0.2)	(0.1)	(0.2)	

and yellowness of the undried wood were usually at their lowest in planted birches regardless of felling season.

After drying, the colour of the wood of the birch originating from the VT site was darkest while the wood originating from the field site was the lightest, when felled in summer and in autumn, respectively (Table 4). The trend of redness between sites was opposite to that of lightness; redness decreasing when fertility of the growing site increased.

Some differences in only the lightness were observed between felling seasons within OMT and field site for undried wood, while some differences were observed in all three colour coordinates in this respect for dried wood. These differences were not similar for all the examined growing sites (Table 4). Wood from the VT, MT and OMT sites became darkest during drying if felled in summer but wood from the field site became darkest if felled in winter. On the other hand, winter wood from the VT and MT sites and autumn wood from the OMT and field sites were lightest after drying. The dried wood from the VT and MT sites were the least red but the wood from the OMT and field sites were the reddest if felled in winter. The yellowest wood was obtained from all the growing sites when trees were felled in summer.

Table 5. Averages of colour coordinates of different growing sites and storages. $_u$ – undried, $_{dr}$ – dried. Lower case letters indicate statistical difference between growing sites within storage between those growing sites of which average is followed by a different letter. Capitals indicate statistical difference between storages within growing site when the average is followed by a different letter. ΔE_{ab}* is calculated as the difference between undried and dried wood within a row. SE – standard error of the mean. Boards of each felling time are included in N.

Origin	Growing site	Felling season	N_u	N_{dr}	L^*_u	a^*_u	b^*_u	L^*_{dr}	a^*_{dr}	b^*_{dr}	ΔE_{ab}^*
Natural	VT	0 weeks	63	71	87.1b	1.7b	18.0bA	79.0bA	5.1bA	19.2a	8.87
		SE			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		10 weeks	42	65	87.1a	1.7b	17.4aB	79.5aB	4.6aB	18.9a	8.27
		SE			(0.2)	(0.1)	(0.2)	(0.3)	(0.1)	(0.2)	
Natural	MT	0 weeks	66	70	87.9a	1.3a	17.1a	80.3a	4.3a	19.1a	8.41
		SE			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		10 weeks	58	71	87.5a	1.3a	17.2a	80.0a	4.3a	19.0a	8.28
		SE			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
Planted	OMT	0 weeks	56	81	87.3cA	1.1ac	16.6aA	80.7ac	3.8c	18.8ab	7.46
		SE			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		8 weeks	55	75	88.6bB	1.0c	15.8bB	80.9b	3.9b	18.9a	8.79
		SE			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	
Planted	Field	0 weeks	63	86	87.2bdA	0.9c	16.2c	81.2c	3.7c	18.6b	7.04
		SE			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	
		8 weeks	59	74	88.5bB	1.0c	16.2b	80.8ab	3.9b	18.9a	8.66
		SE			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	

3.2 Storage

The storage of birch logs before sawing and drying had little effect on birch wood colour (Table 5). Storage of 8 or 10 weeks significantly affected the lightness of the undried wood only for the wood from the OMT or field sites; in these cases storage made the wood lighter. The trend of lightness between storages was different in MT grown wood. No differences in redness between storages were observed in undried wood, while the difference in yellowness between storages in the undried wood grown in the OMT site was opposite to the difference in lightness.

Only in two cases did storage affect the colour of the dried wood within a site: lightness was higher and redness lower in wood grown in VT if stored (Table 5). Instead, between sites the colour of unstored dried wood differed with regard to all colour coordinates so that wood grown in the field and OMT sites were lighter, less red and less yellow than the wood grown in VT and MT sites; with wood from the VT site being the darkest and reddest. The differences in lightness and redness between sites were similar in stored wood, while the differences in yellowness were small between sites.

3.3 Colour Change during Drying

Birch wood was always lighter coloured before than after drying (Tables 4 and 5). The colour of the inner wood of the boards became visibly darker and more reddish during drying. Colour change (ΔE_{ab}*) from undried to dried in wood from VT, MT and OMT sites was largest if felled in summer but in field grown wood the change was more pronounced in winter. In VT and MT grown wood the colour change was smallest in winter but in wood from the OMT and field sites it was smallest in autumn. The differences in colour change between storage times were small in wood from VT and MT sites, but in wood from the OMT and field sites the difference was clear, colour change being larger in stored wood (stored

Table 6. Colour difference (ΔE_{ab}^*) of dried wood between growing sites by felling seasons.

Origin	Growing site	Felling season	VT			MT			OMT			Field	
			Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter
Natural	VT	Winter	1.32										
		Summer	1.68	2.75									
Natural	MT	Autumn	0.59	0.81	2.06								
		Winter	2.25	1.11	3.43	1.66							
		Summer	0.86	1.14	1.73	0.61	1.72						
Planted	OMT	Autumn	2.61	1.45	4.05	2.05	0.91	2.33					
		Winter	1.97	0.79	3.40	1.41	0.64	1.69	0.67				
		Summer	1.57	1.32	2.31	1.12	1.30	0.78	2.01	1.49			
Planted	Field	Autumn	2.92	1.73	4.34	2.36	1.08	2.62	0.32	0.96	2.26		
		Winter	1.37	0.51	2.66	0.79	0.88	0.94	1.39	0.75	0.86	1.68	
		Summer	2.17	1.14	3.34	1.15	0.28	1.62	0.95	0.67	1.14	1.15	0.81

Table 7. Colour difference (ΔE_{ab}^*) of dried wood between growing sites regarding storage lengths.

Origin	Growing site	Storage (weeks)	VT		MT		OMT		Field
			0	10	0	10	0	8	0
Natural	VT	10	0.77						
Natural	MT	0	1.53	0.88					
		10	1.30	0.59	0.32				
Planted	OMT	0	2.18	1.45	0.71	0.88			
		8	2.27	1.57	0.75	0.99	0.24		
Planted	Field	0	2.68	1.95	1.19	1.40	0.55	0.47	
		8	2.18	1.48	0.67	0.90	0.17	0.10	0.54

wood was slightly lighter than unstored wood before drying, darker after drying).

3.4 Colour Differences between Seasons and Storages

Colour differences (ΔE_{ab}^*) between dried wood lots from different sites in different seasons (Table 6) and after different storage periods (Table 7) were most often small. They were at their largest between summer-felled VT wood and wood from other growing sites regardless of felling season, with wood from VT being darkest. Furthermore, regarding storage times, the largest colour differences were observed between unstored wood from the VT site and both unstored and stored wood from the OMT and field sites, wood from the VT site again being the darkest.

4 Discussion

According to this study, differences in wood colour existed between growing sites as well as between naturally regenerated and planted birch trees. Generally the more fertile the growing site was, the lighter the wood was, particularly after drying. Charrier et al. (1992) also found differences when studying the lightness of oak (*Quercus robur* L., *Q. petreae* (Mattuschka) Liebl.)

wood from different growing sites after artificial drying. Birch trees growing in low soil fertility have been observed to produce more condensed tannins in their wood, which affect the wood colour in birch, than birches growing on soil of higher fertility. However, the concentration of condensed tannins in undried wood does not alone determine the effect of these compounds on colour darkening, because they are also formed during drying (Luostarinen and Möttönen 2004a, b, Möttönen and Luostarinen 2005). Furthermore, other chemical differences in birch wood originating from different growing sites may affect colour darkening during drying, as lignin (Liepins 1933) and carbohydrate (Mononen et al. 2004) concentrations of birch wood have been observed to differ between sites. The facts that the wood from the field and OMT sites were lighter in colour after drying than those of the MT and VT sites, and the colour change (ΔE_{ab}*) from undried to dry was, on average, smaller in the wood of planted birches than in naturally regenerated birches, may depend also on the higher proportion of lighter coloured earlywood in wood originating from more fertile sites as a consequence of higher growth rate (see Table 1); the latewood is not pronounced in diffuse porous hardwoods like birch (e.g. Fagerstedt et al. 1996). In fact, the main part of the latewood contributing to wood colour is the terminal parenchyma (one cell layer in birch), which contains darkening compounds (McMillen 1975, Luostarinen 2006). Higher growth rate also results in trees growing on fertile sites reaching the size of logs younger than trees growing on poor sites, which may be beneficial as such for light colour of wood (Klumpers et al. 1993). The result of Klumpers et al. is in accordance with the results of this study, that the younger wood of planted birches was lighter. Additionally genotypes may differ between sites as well as other differences in growing conditions (water, light, herbivores etc.) may affect wood chemistry (Kozlowski and Pallardy 1997) and thus colour, but these could not be determined from the sites examined here.

Regarding the colour of undried birch wood, no differences were found between felling seasons; this was also found for oak between felling dates (Charrier et al. 1992). Colour differences between dried birch wood felled in different seasons were found in this study; which may be due to seasonal differences in birch extractive (Perilä 1958, Perilä and Toivonen 1958), carbohydrate (Piispanen and Saranpää 2001, Mononen et al. 2004) or lipid (Piispanen and Saranpää 2004) concentration. Although concentrations of different compounds fluctuated differently, total extractive concentration has been observed to be smallest in birch wood in autumn and winter (Perilä and Toivonen 1958): autumn-felled dried birch wood from the OMT and field sites, and winter-felled dried birch wood from VT and MT sites were the lightest and least red within the sites in this study. Even though some compounds may become coloured during drying, the possible differences in the concentrations between seasons apparently did not affect the colour of undried birch wood.

In this study, the effect of storage on colour differences was smaller than that of felling season, although the storage of logs is considered to be harmful for birch wood as it causes defects in the wood, particularly in summer (e.g. Heiskanen 1959, Verkasalo 1993). Indeed, the interaction between storage and felling season would have been highly relevant if it were possible to calculate in this study. Additionally, some variation in colour may have been caused by the fact that boards from different storages had to be dried in different lots; however; this variation is most probably smaller than the variation which would have been caused by different felling dates during the same season, especially in summer. The difference in the length of storage period between naturally regenerated and planted birches may have had a small effect on colour change during storage; but probably it has been very small as the total difference was also very small. The storage of logs influenced birch wood final colour after drying only in the case of VT grown wood, by making the stored wood lighter, and both less red and less yellow than unstored wood. The structure of the wood compounds change during storage (Assarsson and Croon 1963, Donetzhuber and Swan 1965, Assarsson and Åkerlund 1967, Lavoie and Stevanovic 2006). For example, the amount of condensed tannins has been observed to decrease in birch wood during storage (Luostarinen and Möttönen 2004a), and according to Paasonen (1967) the extractives turn from hydrophobic to hydrophilic during the storage of birch wood. Thus, in stored wood the compounds causing colour darkening may move easier, with water, to the surface of the timber piece during drying and partly lose their significance regarding colour of sawn timber planed for end-use.

Although the colour differences, observed here, are important when the physiological or chemical basis of the colour darkening is considered, their significance, in practice, is smaller. According to our experience, a colour difference of $\Delta E_{ab}* = 1.8$ or greater between two separate samples of birch wood is distinct. Log storage decreased the colour difference between VT wood and wood from any other site from almost 3 to under 2, which is a significant decrease in practice. There also existed colour differences over 3, when comparison was made between summer-felled VT-grown wood (darker) and any wood from any other growing site. The colour differences around 3 to 4 are clearly visible (according to the classification of Lahtinen and Tolonen (2001) "visually observable difference") and are harmful to some products. Thus, according to this study, the cultivation of birch in fertile plantations can be recommended, as the wood of fast grown planted birches is even better than that of naturally regenerated birches with regard to colour.

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