Density, Annual Growth and Proportions of Types of Wood of Planted Fast Grown Siberian Larch (*Larix sibirica*) Trees

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Abstract

Siberian larch (*Larix sibirica* Ledeb.) is widely cultivated in Finland as it thrives very well and grows rapidly on fertile sites in the country. As rapid growth affects the wood properties, particularly in softwoods, it is not clear that these fast growing trees would produce raw material of similar quality as trees grown in their native areas. Thus, in this study the proportion of wood types (juvenile wood, mature heartwood, and sapwood) was quantified at three different heights up the trunk (butt end, 4.5 and 9.0 m) in Siberian larch trees cultivated in Finland. Additionally, density and annual growth patterns were studied in the three wood types at the respective heights. The wood located at the butt differed in some respects from the wood located higher up the trunk, but particularly wood density and the proportion of latewood (LW%), important for the mechanical properties, stayed similar up to 4.5 m of height. Thus the lower part of the trunks, also containing the smallest proportion of juvenile wood, seems to be most suitable for structural use. The effect of extractive content on the density is emphasised, as many of the observed correlations were different in mature heartwood and sapwood. Radial density differences are larger in Siberian larch wood grown in Finland than in Siberia, which emphasises the poorer quality of juvenile wood of fast grown planted trees.

Key words: earlywood, juvenile wood, latewood, mature heartwood, proportion of latewood, ring width, sapwood

Introduction

Siberian larch (*Larix sibirica* Ledeb.) is the most planted foreign tree species in Finland (Silander et al. 2000). Since the 1960s more than 20,000 ha have been planted (Metsänhoitoyhdistykset 2005), the total area of all larch stands is more than 30,000 ha (Lepistö and Napola 2005). The wood properties of Siberian larch trees grown in their natural provenances are perceived to be good for structural use (strength, density) (Koizumi et al. 2003). In Finland, as well, these trees are cultivated with the aim of producing timber. Even though the wood properties of Siberian larch have been studied regarding trees grown in their native areas (e.g. Vihrov 1949, Hutorščikov 1959, Hutorščikov et al. 1967, Nekhaichuk and Bryantseva 1984, Koizumi et al. 2003, Karlman et al. 2005), wood properties of planted Siberian larch grown in Finland has been less well investigated, with density being the most studied area (Vuokila 1960, Nevalainen and Hosia 1969, Hakkila and Winter 1973, Kärkkäinen 1978). However, according to the more in depth growth studies, with results concerning bark, heartwood, crookedness, cracking, and knottiness (Lappi-Seppälä 1927, Vuokila 1960, Hakkila and Winter 1973, Verkasalo 1993), the timber of Siberian larch grown in Siberia has been clearly better for structural uses than that grown in Finland (Verkasalo 1993).

In Siberia, the species grows quite slowly (Koizumi et al. 2003, Karlman et al. 2005), while it is cultivated on fertile sites in Finland (Metsänhoitoyhdistykset 2005), to reach a higher growth rate than that of domestic pine (*Pinus sylvestris*) and spruce (*Picea abies*) (Vuokila 1960). In addition, the climates of Finland and those parts of Siberia where larch grows differ from each other (World climate 2008). Establishing plantations in fertile places with a comparatively long growing season encourages fast growth, particularly when the trees are young. Thus the amount of juvenile wood may be large, because the annual rings in this zone become wider. Fast growth may also influence the mature wood, and may affect annual ring width and/or the mean density, and/or the densities, widths or proportions of earlywood and/or latewood. This would affect the structural usability of the wood.

The largest plantations in Finland, established in the 1960s, are now at the age when the first thinning should be performed. Thus information about the wood properties of fast grown Siberian larch grown in Finland is needed; this is also the case for trees at the age of the final felling. In this study proportions of juvenile wood, mature heartwood and sapwood as well as wood density and growth rate were measured for planted 85-year-old Finnish grown Siberian larch wood. Comparisons were made between different heights in the stem and between different wood types, taking into account earlywood and latewood. Furthermore, the findings were compared with the results achieved in earlier studies of plantation grown Siberian larch wood, and with results attained from trees grown in their natural provenances. In addition, conclusions about the effects of the studied properties on timber usability were drawn.

Materials and methods

A total of 16 Siberian larch (*Larix sibirica* Ledeb.) trees were felled in December 2005 in the plantation of the Finnish Forest Research Institute, Punkaharju, Eastern Finland (61°81' N, 29°32' E). The trees belonged to the Heikinheimo stand of Raivola provenance. Raivola has proven one of the best provenances cultivated in Finland, regarding growth, its durability against much kind of damages, and the shape of its trunk (Vuokila 1960, Mikola 1992, Silander et al. 2000, Lepistö and Napola 2005). The plantation was established in 1924 with four-year-old seedlings. Thus the trees were 85-year-old when harvested, with breast height diameter of 41.8 cm ± 1.1 cm (standard error of the mean). The trees were felled for studies at Mikkeli University of Applied Sciences concerning sawn Siberian larch timber (Heikkonen et al. 2007). Directly following felling, discs (thickness 5 cm) were sawn from the butt ends of the trees and from the heights of 4.5 m and 9.0 m for the purpose of this study. Only the part of the trunk that had no branches (neither living nor dead) producing logs of Quality A and thus suitable for good quality carpenters' products, was investigated.

In this study, the density (WD) and the annual ring widths (RW) from pith to bark were measured at the moisture content (MC) of 12% (dry weight basis) from a strip sawn from each disc. The strips were randomly sawn from any direction from pith to bark to include samples of all the wood material, i.e. wood material from the whole trunk was included, as is the standard of industries. The thickness and width of the strips were 5 mm, and the length the same as the radius. The strips were scanned with an Itrax X-ray microdensitometer (Cox Analytical Systems, Göteborg, Sweden) with automatic collimator alignment at a geometrical resolution of 40 measurements per millimetre. A standard X-ray flux (30 kV, 35 mA) was used, with an exposure time of 20 ms. The Itrax X-ray images were analysed using Density software to determine the density and width of the annual rings separating earlywood (EW) and latewood (LW) for each annual ring (Bergsten et al. 2001). The mean of the maximum and minimum intra-ring densities were used as the threshold for the EW and LW in each ring: the value above this threshold represented the LW and the values below represented the EW. Furthermore, the difference between mean densities of EW (EWD) and LW (LWD) was calculated for each ring (LWD-EWD), as well as the proportion of LW ($LW\%=LWW/RW*100$; LWW=width of latewood; EWW=width of earlywood). Density values were weighed with the width of appropriate part of the annual ring or whole annual ring, when calculating mean density values. The proportions of wood types (WT%), i.e. juvenile wood, mature heartwood and sapwood were calculated based on the area of the wood types in each disc. The wood types were defined by the observed changes in the WD (transition from juvenile to mature wood at 20 years of age, when the increase in the WD levelled off, and from heartwood to sapwood when an abrupt decline in the WD was observed in mature wood; see results) and the colour difference between heartwood and sapwood.

Statistical analyses were performed using SPSS 16.0 software. Values of WT%, WD, EWD, LWD, RW, EWW, LWW, LW% and the difference between the LWD and EWD were compared between heights and wood types by the General Linear Model using its pairwise comparison option. For those results that were possible to compare with a parametric test, Scheffe test was used, while for those that had to be tested with a non-parametric test, Tamhane test was used. In addition, Pearson correlations for all studied parameters, except WT%, were calculated using the Correlation procedure, both for the entire material combined and separating the three heights (butt, 4.5 and 9.0 m) or three wood types.

Results

Proportions of wood types

The proportion of juvenile wood was lowest at the butt, but it was similar in both the other heights (Table 1), radius of juvenile wood being ca. 10 cm for each height. Furthermore, the proportion of sapwood, which was lower than that of juvenile wood in the two uppermost heights, increased gradually from the butt to the height of 9.0 m. The width of sapwood was ca. 2 cm at each height. However, the proportion of the

Table 1. Average±standard error of the mean and statistical differences according to Scheffe test observed in proportion, based on area, (WT%) of wood types between heights. Different lower case letter indicate significant difference between the heights among a wood type and capital between the wood types among a height (p<0.05)

Cambial age class	Height (m)	N	WT%	Statistical differences
Juvenile wood	Butt	16	20.4±1.3	aA
	4.5	16	32.1±1.1	bA
	9.0	16	33.6±1.5	bA
Mature heartwood	Butt	16	61.8±1.6	aB
	4.5	16	47.2±1.6	bB
	9.0	16	41.6±1.4	cB
Sapwood	Butt	16	17.7±1.3	aA
	4.5	16	20.7±1.5	abC
	9.0	16	24.7±1.6	bC

mature heartwood was higher than that of other wood types at each height, even though its proportion was clearly highest at the butt and lowest at the height of 9.0 m. The proportion of heartwood (juvenile wood + mature heartwood) exceeded 70% at each height, even 80% at the butt.

Annual rings

The RW was larger at the butt than at both of the other heights, particularly in the mature heartwood and sapwood, while no difference was observed between 4.5 and 9.0 m (Fig. 1a, Table 2). Additionally, it varied from pith to bark at each studied height in the trunk (Fig. 1a). The RW first increased for several years, reaching its peak at cambial age of 3 years at the heights of 4.5 and 9.0 m and at 7 years at the butt. Then the RW decreased to a stable level by the cambial age of 20 years at the butt, and couple of years earlier at both the other heights. In mature wood the RW stayed at about 1 mm higher level at the butt than higher up the trunk, with variation being larger at the butt. Decreasing trend in the RW started at ca. 60 years of age at the butt, but ca. 10-15 years earlier higher up the trunk, thus at about the same time by calendar years as at the butt.

The EWW was largest at the butt, while no difference was observed between 4.5 and 9.0 m heights (Fig. 1b, Table 2). EWW first increased for several years, reaching the maximum at 3 years of cambial age at the heights of 4.5 and 9.0 m and at 7 years of cambial age at the butt (Fig. 1b). Then the EWW decreased to a stable level by the cambial age of 20 years at the butt, and couple of years earlier at both other heights.

The LWW was larger at the butt than at the other heights particularly in the mature wood (Fig. 1c, Table 2). It was at its largest in juvenile wood, and got nar-

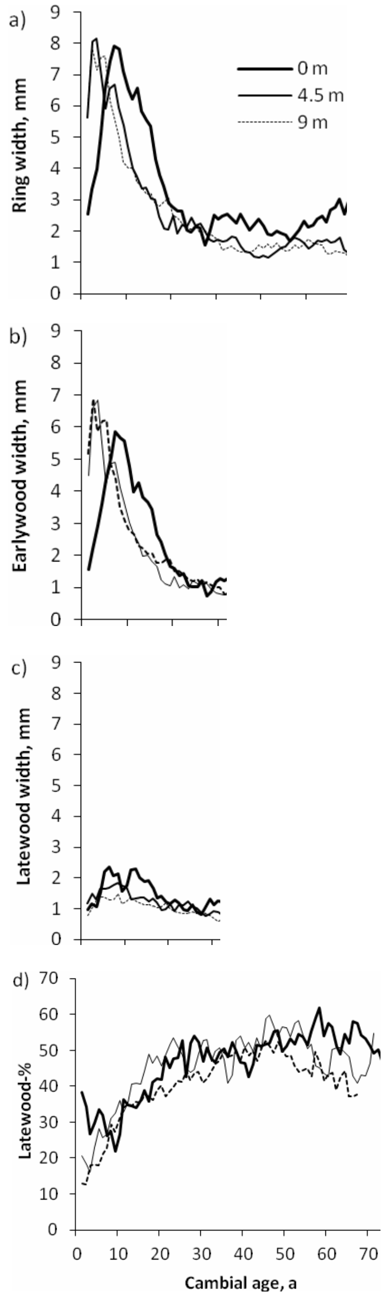

Figure 1. a) Ring width, b) earlywood width, c) latewood width, and d) proportion of latewood by cambial age and wood height in the trunk. The legend shown in a) stands for b), c), and d), too

rower towards the sapwood (Fig. 1c). Conversely, LW% was similar from the butt up to 4.5 m, but subsequently decreased by 9.0 m in the juvenile wood and mature heartwood (Fig. 1d, Table 2). In addition, in the juvenile wood the LW% was lower than in the mature wood (Table 2). At the butt LW% first decreased from ca. 38% to ca. 22% from the pith by cambial age of 9 years, after which it increased up to ca. 60% by the cambial age of 60 years, subsequently decreasing to ca. 50%. Higher up the trunk the LW% was under 20% at cambial ages of 2-4 years, reaching its maximum about 10 years earlier than at the butt (ca. 60% at 4.5 m, and ca. 50% at

Table 2. Average±standard error of the mean and statistical differences observed in measured factors between heights among a wood type and between wood types among a height. Different lower case letter indicate significant difference between the heights and capital between the wood types (p<0.05). Normal text: Scheffe test, bold text: Tamhane test. RW – annual ring width, EWW – earlywood width, LWW – latewood width, LW% – proportion of latewood, WD – mean wood density, EWD – earlywood density, LWD – latewood density, and LWD-EWD diff – difference between LWD and EWD

Cambial age class	Height (m)	N	RW (mm)	EWW (mm)	LWW (mm)	LW%	WD (kg/m^3)	EWD (kg/m^3)	LWD (kg/m^3)	LWD-EWD diff. (kg/m^3)
Juvenile wood	Butt	16	5.2±0.2aA	3.5±0.2aA	1.7±0.1aA	33.4±1.3aA	379±7aA	310±6aA	506±6**a**A	196±5**aA**
	4.5	16	4.7±0.1aA	3.3±0.1a**A**	1.5±0.1ab**A**	30.9±1.4aA	379±8aA	301±7aA	549±9**bA**	248±9**b**A
	9.0	16	4.7±0.2a**A**	3.4±0.1aA	1.2±0.0bA	26.6±0.7bA	371±6aA	298±5aA	563±5**bA**	265±5**b**A
Mature heartwood	Butt	16	2.4±0.1aB	1.2±0.1aB	1.2±0.1**a**B	51.5±1.3aB	460±8aB	323±6aA	589±7aB	240±6**aB**
	4.5	16	1.7±0.1bB	0.8±0.1b**B**	0.9±0.0**bB**	50.8±1.4aB	463±8aB	290±8bA	627±8b**B**	325±11**b**B
	9.0	16	1.7±0.1b**B**	1.0±0.1abB	0.8±0.0**b**B	45.2±1.3bB	448±8aB	301±12abA	629±7b**B**	336±8 **b**B
Sapwood	Butt	16	2.3±0.2**a**B	1.1±0.1aB	1.2±0.1**a**B	50.6±1.6aB	415±8aC	276±10**a**B	554±7aC	279±12a**B**
	4.5	16	1.4±0.1**b**B	0.7±0.1b**B**	0.6±0.1**bC**	47.2±1.3aB	398±10aA	220±4**b**B	596±12a**B**	377±10bC
	9.0	16	1.4±0.1**bC**	0.7±0.1bB	0.6±0.0**b**C	45.9±1.8aB	385±7aA	224±5**b**B	582±15a**A**	358±18bB

9 m), additionally LW% started to decrease higher up the trunk earlier than at the butt (Fig. 1d).

Density

Differences in density factors between the studied heights could most often be observed between the butt and the other heights. However, the WD of a given wood type did not differ between the studied heights (Table 2). Instead, between the wood types the WD differed particularly at the butt, but it was largest in the mature heartwood at both the other heights, as well (Table 2). During the first five years from the pith WD decreased, after which it started to increase (Fig. 2a). The increase levelled off at ca. 20 years of cambial age, but the maximum WD of ca. 450-470 kg/m^3 was reached at about 40-60 years of cambial age, depending on the height. A clear change in the WD was observed at the border between heartwood and sapwood, the WD being lower in sapwood.

In the case of EWD, LWD, and difference between LWD and EWD, the value of the butt commonly differed from that of the two other heights except in the case of EWD in the juvenile wood. Conversely, no difference was observed between 4.5 and 9.0 m (Table 2). The EWD was highest at the butt, while the LWD and thus the difference between the LWD and EWD were smallest at the butt. The EWD decreased from the pith to the cambial age of 5 years like the WD after which the EWD increased slightly, particularly at the butt until the border between heartwood and sapwood, at which point EWD decreased clearly (Fig. 2b). Instead, LWD increased starting from the second growth ring in the two uppermost positions, and from the fifth growth ring at the butt, until the cambial age of ca. 18-20 years, after which it started to decrease slowly without any clear drop when passing from heartwood to sapwood (Fig. 2c). The difference between LWD and EWD grew from the pith to ca. 20 years and to ca. 10 years of cambial

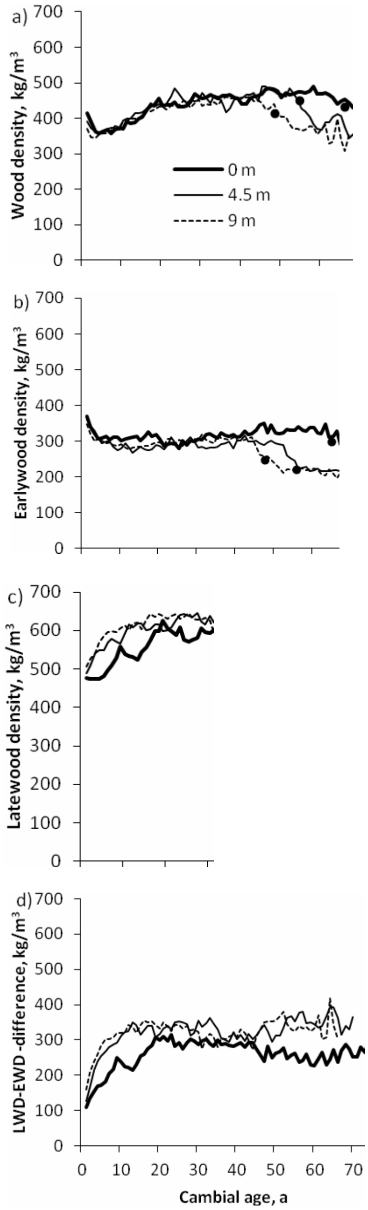

Figure 2. a) Wood density, b) earlywood density (EWD), c) latewood density (LWD), and d) difference between LWD and EWD by cambial age and wood height in the trunk. The legend shown in a) stands for b), c), and d), too. The dots in the figure a) and b) show the transition point between heartwood and sapwood

age at the butt and at the other heights, respectively, subsequently staying at a similar level but being smallest at the butt (Fig. 2d, Table 2).

Correlations between density and ring width factors

When all the heights and wood types were combined, several significant correlations were observed between measured factors (Table 3). Both high EWD and LW% increased the WD more significantly than high LWD. In addition, the WD was negatively correlated with the EWW but positively correlated with the LWW. But as the EWW and LWW correlated positively with each other, no clear correlation was observed between the WD and RW.

constant from young to old trees and from the butt to the top, the proportion of heartwood increases evenly with the aging of the tree (Anonymous 1971, Hakkila and Winter 1973, Lyck and Bergstedt 2007). In this study juvenile wood and mature heartwood were separated, which was not done in any of the studies cited. Thus no information concerning the proportion of juvenile wood was found. In this study, however, the amount of juvenile wood was high, as it made up a cylinder of diameter ca. 20 cm at the centre of the trunks. As juvenile wood of larch has clearly poorer mechanical properties than mature heartwood (Juvonen et al. 1986), an amount like this is significant from the point of view of usage even though the proportion naturally decreases with the aging of the tree.

Table 3. Pearson correlation coefficients between measured factors. N=48 (all heights together). ** – significant at 0.01 level, * – significant at 0.05 level. See abbreviations in the legend of Table 1

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	-0.116						
LWD-EWD diff.	-0.753**	0.741**					
WD	0.730**	0.305*	-0.291*				
EWW	-0.064	-0.436**	-0.246	-0.401**			
LWW	0.295*	-0.484**	-0.520**	0.302*	0.468**		
RW	0.118	-0.502**	-0.412**	-0.019	0.794**	0.832**	
LW%	0.331*	-0.226	-0.374**	0.667**	-0.270	0.602**	0.248

The correlations changed when separating the material according to heights (Table 4a-c) compared to analyzing the combined material. For instance, the relations of the EWD and LWD to their widths were different at different heights: at the butt only LWD correlated negatively with LWW, in the middle of the studied trunk part no correlations were observed, and at the uppermost studied height only EWD correlated negatively with the EWW. Furthermore, high LW% increased the WD at the heights of 4.5 and 9.0 m. However, several correlations, i.e. the positive correlations between the EWD and WD, and between EWW, LWW and RW, were similar at each height.

In addition, the wood type affected the correlations observed between different growth and density factors (Table 5a-c). The correlations that were different from those observed in the material sorted according to height were those that included a density factor.

Discussion and conclusions

Heartwood proportion was large in all trunk heights in this study, and earlier measurements concerning heartwood and sapwood proportions are comparable with the results of this study (Hutorščikov 1959, Anonymous 1971, Hakkila and Winter 1973, Sipi 1988, Eggertsson 2007, Lyck and Bergstedt 2007): sapwood is usually narrow, ca. 2 cm, which was also observed in this study. As the width of the sapwood remains fairly

The decrease in the RW to quite a stable level as well as the levelling off of the WD increase at ca. 18-20 years of age indicated maturation of wood at that age. Increase in the WD was connected with increase in the LWD in the juvenile zone, while the EWD stayed at a stable level after it had decreased at cambial ages under 10 years; only a slight increase in the EWD was observed in the mature zone. Similar maturation age has been observed for Siberian larch by Koizumi et al. (2003) and Karlman et al. (2005), while Kärkkäinen (1978) found an increase in the mean density until ca. 30 years of cambial age. After maturation a decreasing trend in the RW was observed around the cambial age of 45-60 years: as it simultaneously occurred with the decrease in density factors and in LW% in all studied trunk heights, the reason may be aging of the tree or cambium, or growing conditions. In addition, the decrease in RW was connected both with EWW and LWW because even though EWW was markedly larger than LWW in the juvenile wood, their proportions were similar in the mature wood irrespective of the RW. Similar findings concerning the relation between the EWW and LWW have been made by Zhu et al. (1998) for the mature wood of Japanese larch (*Larix kaempferi*). In Siberian grown larch RW has been measured to be clearly narrower, decreasing from ca. 3 mm of juvenile wood to ca. 1 mm of old cambial ages (Anonymous 1971, Koizumi et al. 2003), than in the trees studied in this work.

Table 4. Pearson correlation coefficients between measured factors a) at the butt, b) at the height of 4.5 m, and c) at the height of 9.0 m. N=16 for each height. ** – significant at 0.01 level, * – significant at 0.05 level. See abbreviations in the legend of Table 1

a)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	0.810**						
LWD-EWD diff.	-0.260	0.356					
WD	0.823**	0.906**	0.181				
EWW	-0.395	-0.627**	-0.403	-0.693**			
LWW	-0.574*	-0.543*	0.021	-0.370	0.509*		
RW	-0.547*	-0.677**	-0.245	-0.630**	0.896**	0.838**	
LW%	-0.072	0.133	0.334	0.444	-0.505*	0.392	-0.118

b)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	0.349						
LWD-EWD diff.	-0.462	0.670**					
WD	0.716**	0.732**	0.126				
EWW	-0.124	-0.154	0.048	-0.418			
LWW	0.331	0.133	-0.136	0.466	0.149		
RW	0.108	-0.031	-0.115	-0.023	0.808**	0.703*	
LW%	0.258	0.184	-0.030	0.684**	-0.614*	0.550*	-0.114

c)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	-0.359						
LWD-EWD diff.	-0.832**	0.816**					
WD	0.731**	0.006	-0.449				
EWW	-0.564*	-0.257	0.196	-0.680**			
LWW	-0.371	-0.419	-0.020	-0.077	0.572*		
RW	-0.467	-0.236	0.149	-0.357	0.744**	0.662**	
LW%	0.314	-0.586*	-0.542*	0.527*	-0.104	0.557*	0.209

Table 5. Pearson correlation coefficients between measured factors a) in juvenile wood, b) in mature heartwood and c) in sapwood. N=48 for each wood type. ** – significant at 0.01 level, * – significant at 0.05 level. See abbreviations in the legend of Table 1

a)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	0.185						
LWD-EWD diff.	-0.440**	0.801**					
WD	0.901**	0.392**	-0.191				
EWW	-0.153	-0.345*	-0.222	-0.446**			
LWW	0.370**	-0.523**	-0.704**	0.355*	0.146		
RW	0.061	-0.535**	-0.526	-0.181	0.872**	0.611**	
LW%	0.446**	-0.268	-0.517**	0.604**	-0.4345**	0.814**	0.055

b)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	0.038						
LWD-EWD diff.	-0.727**	0.658**					
WD	0.706**	0.414**	-0.247				
EWW	-0.166	-0.409**	-0.156	-0.573**			
LWW	-0.031	-0.588**	-0.380**	-0.105	0.651**		
RW	-0.110	-0.540**	-0.288*	-0.380**	0.914**	0.901**	
LW%	0.142	-0.251	-0.279	0.557**	-0.411**	0.395**	-0.026

c)

Property	EWD	LWD	LWD-EWD diff.	WD	EWW	LWW	RW
LWD	-0.244						
LWD-EWD diff.	-0.717**	0.851**					
WD	0.630**	0.423**	-0.037				
EWW	0.322*	0.071	-0.123	0.204			
LWW	0.504**	-0.514	-0.382**	0.455**	0.801**		
RW	0.446**	-0.056	-0.281	0.362*	0.936**	0.960**	
LW%	0.496**	-0.343*	-0.515**	0.576**	-0.046	0.503**	0.273

The measured density of Siberian larch was highest, ca. 470 kg/m^3, at about the same cambial age of ca. 40-60 years that was observed by Kärkkäinen (1978), even though clearly smaller. The mean WD of larch wood was around 410-440 kg/m^3 depending on the trunk height. Earlier measured basic density values, which are slightly lower for a given density than values calculated at the MC of 12%, for the wood of Siberian larch have been clearly higher: from 476 to 540 kg/m^3 in Finnish grown (Hakkila et al. 1972, Hakkila and Winter 1973, Kärkkäinen 1978, Juvonen et al. 1986, Tuimala 1993) and from 490 to 830 kg/m^3 in Siberian grown larch (Hutorščikov 1959, Anonymous 1971, Sairanen 1982, Karlman et al. 2005, Heikkonen et al. 2007). The low values measured in this study were partly due to the fact that the mean density was calculated for the strips with each ring equally represented according to its RW, while the proportion of the denser mature wood is higher in the whole trunk than that of the clearly lighter juvenile wood. Another reason for the low values may be the origin, as large variation in WD of Siberian larch has been measured between origins (Koizumi et al. 2003). Instead, even though e.g. in spruce (*Picea abies*) significant increase in the average WD higher up the trunk has been found (Jyske et al. 2008), the effect of the trunk height on the average WD was small in the studied larches, as no significant differences in it in a given wood type between different heights was observed.

In this study, the typical large WD differences in larch wood between juvenile wood, mature heartwood and sapwood (Kärkkäinen 1978, Koizumi et al. 2003) was evident. However, in these Siberian larches grown in Finland, WD differences between the wood located near the pith and radially in outer heartwood locations were larger than in the trunks of Siberian larch grown in Siberia (Heikkonen et al. 2007). In addition, the decline in WD observed in a few of the cambially youngest annual rings was more pronounced than that in Siberian larches grown in Siberia (Koizumi et al. 2003). Similar decline has also been observed in juvenile wood of *Picea abies* (Saranpää et al. 2002, Molteberg and Høibø 2006), and it was connected to the decrease of the EWD (Jyske et al. 2008), like in larch in this study. The slight increase in WD in the mature zone was due to the slight increase in EWD, while the maximum LWD was observed in cambially younger wood, right after the maturation. Instead, opposite of *Picea abies* (e.g. Jyske et al. 2008) and *Pinus sylvestris* (e.g. Velling 1974), the mean density is clearly higher in heartwood than in sapwood in larch (Côté et al. 1966, Cōté and Timell 1967, Kärkkäinen 1978, Koizumi et al. 2003). Density difference was observed particularly in the EW, which is in accordance with the observation that the extractive concentration of mainly EW increases during heartwood formation (Côté et al. 1966, Côté and Timell 1967). Kärkkäinen (1978), in addition to this study, found that the WD starts to decrease at cambial ages around 60 years at the butt in heartwood zone, which suggests that decrease in the LWD is not connected to extractives but rather to the age of the tree or cambium, or to growing conditions.

The difference between the LWD and EWD was large, which has also been observed by Hakkila and Winter (1973), and Koizumi et al. (2003) for Siberian grown trees, in which the difference was larger. The difference between the LWD and EWD was smallest near the pith increasing up to ca. 20 years of cambial age, as the LWD increased until that age, and staying at almost stable level from that onwards in larch. This is different from *Picea abies*, in which the intraring density difference was largest at the outermost rings (Jyske et al. 2008). The smaller difference between the LWD and EWD at the butt than at the other heights may be due to the fact that the samples from the butt were from the area of the butt swelling, in which also several other measured wood properties, particularly ring width factors, differed from those existing higher up the trunk. If the small density difference of the butt region reaches at least a couple of metres up the trunk, the properties of this area of the trunk would be better for carpenters' use than the upper trunk, as density differences as small as possible make machining easier and least irregular, and thus the machined wood surface as smooth as possible. However, correlation between the LWD and EWD was found only at the butt end in this study, while in *Picea abies* a positive (Zubizarreta et al. 2007) and in *Picea mariana* a negative (Zhang and Morgenstern 1995) correlation between them has been found higher up the trunk. Thus, in larch, a situation in which the difference between the LWD and EWD would be smaller than in this study might be possible at least at the other heights than at the butt.

In this study, the WD and RW correlated strongly negatively only at the butt of the trees and in mature heartwood while in sapwood the correlation was positive. In larch of Siberian origin the negative correlation has also been observed (Heikkonen et al. 2007), and a marked reduction in Siberian larch WD has been observed in RWs over 3 mm (Karlman et al. 2005). A negative correlation between the RW and WD has also been observed in *Picea abies* (Molteberg and Høibø 2006). Contrary to *Picea abies*, in which fast growth both decreases LW% and LWD (Mäkinen et al. 2002), in larch RW did not affect LW%, but fast growth decreased the LWD, and thus the WD as a consequence. Thus a fast growth rate may decrease WD slightly, even though Zobel and van Buijtenen (1989) concluded that the WD of *Larix* species is usually not affected by growth rate. The observed different correlations in heartwood and sapwood between RW, EWW and LWW, and corresponding density factors emphasise the effect of extractives on the density of larch wood.

As a conclusion, the results showed that several of the measured properties differ clearly between the wood types and some between the heights. Thus the correlations were also partly different due to the used grouping mode of the samples. Concerning the heights, most of the measured differences were observed between the butt and the other heights, except LW% which diminished up to 9.0 m of height. Furthermore, high growth rate did not induce as large a EWD-LWD difference at the butt as higher up the trunk. Thus, according to the density results, the best part of a fast grown planted Siberian larch trunk for carpenters' use is the lowermost part of it, at least if the properties remain unchanged at least a couple of metres up the trunks. In addition, planted trees should be quite old when felled to contain as much mature heartwood of good quality, from a carpenter's perspective, as possible, as fast grown trees contain a marked amount of less dense and poorer juvenile wood.

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ПЛОТНОСТЬ, ЕЖЕГОДНЫЙ ПРИРОСТ И ПРОПОРЦИИ ВИДОВ ДРЕВЕСИНЫ В БЫСТРОРАСТУЩИХ ПОСАДКАХ ДЕРЕВЬЕВ СИБИРСКОЙ ЛИСТВЕННИЦЫ (*LARIX SIBIRICA)*

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Резюме

Порода сибирской лиственницы (*Larix sibirica*) широко выращивается в Финляндии, поскольку она успешно произрастает и быстро растёт на плодородных участках. Известно, что быстрый рост деревьев влият на свойства древесины, особенно мягкой хвойной древесины, однако нет четкого представления о том, будут ли быстрорастущие плантации деревьев производить древесину аналогичного качества с деревьями, растущими в естественной природной среде. Таким образом, в данном исследовании изучили пропорции видов древесины (ювенильная древесина, зрелая ядровая древесина, заболонь), плотность и ежегодный прирост посаженных деревьев Сибирской лиственницы разделили по трём видам древесины и трем высотам. Древесина, расположенная в нижней комлевой части ствола в некоторых аспектах отличается от древнсины в верхней макушечной части ствола, особенно по плотности и пропорциям видов древесины. Важно при механической обработке чтобы плотность и пропорции видов древесины оставались аналогичными до высоты ствола 4,5 м., а затем уменьшаются до 9,0 м. Таким образом, нижняя часть ствола содержит наименшую долю ювенильной древесины, а так же является наиболее пригодной для механической обработки. Представлен эффект выделенного по плотности в лиственничной древесине содержимого, поскольку многие из наблюдаемых корреляций были различны в зрелой ядровой древесине и заболони, кроме того радиальных различий плотности больше у деревьев в Финляндии, чем сибирской лиственницы, растущей в Сибири. Это подчеркивает низкое качество ювенильной древесины у быстрорастущих посаженных деревьев.

Ключевые слова: ранняя древесина, ювенильная древесина, спелая древесина, зрелая ядровая древесина, пропорции спелой древесины, ширина годовых колец, заболонь