Tree-ring widths and wood density variability of non-native species: a case study of Douglas-fir growing in central Europe

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Abstract. The aim of the present study was to analyze the wood density variations along the stem radius of non-native Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) growing in Central Europe. Sample logs (0.5 m; breast height) were obtained from five Douglas-fir trees growing in the Czech Republic, to analyse the tree-ring widths (TRW) and the oven-dry wood density intra-species variability. The first 15 tree rings (close to the pith) were found to be 5.14 ± 1.68 mm wide, while the average TRW gradually decreased. The average oven-dry density of wood produced by non-native Douglas fir growing in the Czech forest was 542.9 ± 66.3 kg m^{-3}, which is notably higher than the home-grown Douglas-fir wood. Along the stem radius, from pith to bark, oven-dry wood density showed an upward trend.

Keywords: oven-dry wood density; *Pseudotsuga menziesii*; latewood proportion; earlywood width.

1 Introduction

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) lies among the most environmentally and commercially promising non-native species in several European countries i.e., Germany, France, United Kingdom (Gartner et al. 2002, Šindelař and Beran 2004, Blohm et al. 2016). In the Czech Republic, recent forestry studies has been focused on partly replacing native tree species with Douglas-fir, mostly targeting on great biomass yield and high lumber production (Menšík et al. 2009, Kubeček et al. 2014, Remeš and Zeidler 2014, Podrázský 2015, Podrázský et al. 2016). Within this frame, estimating intra-species wood variability is a handy tool for the wood industry (Taylor and Wooten 1973).

Wood density varies within the tree from base to top, from pith to bark along the stem radius, from earlywood to latewood within tree-rings (Jozsa et al. 1989, Kennedy 1995, Gartner et al. 2002, Acuna and Murphy 2006). Namely, wood density changes dramatically along the stem radius from the juvenile (close to pith) to mature (close to bark) wood (Gartner et al. 2002). The distinction between juvenile and mature wood was developed mostly for practical rather than biological reasons. Within this frame, the transition threshold was defined around 10–20 years, since the changes in properties were negligible by this age (Acuna and Murphy 2006). In line

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with this, Blohm et al. (2016) found that mature wood began to form around the age of 18 in Douglas-fir trees growing in plantations in Southern Germany. Wagenfür (2000) reported that Douglas-fir oven-dry wood density was 470 kg.m^{-3} while according Rijsdijk and Laming (1994) it was higher (492 kg.m^{-3}). Nevertheless, the homegrown Douglas-fir oven-dry wood density was 419.7 kg.m^{-3}, in the USA (Pong et al. 1986).

In the Czech Republic, the biggest research interest has been recently focused on the environmental parameters (drought tolerance, soil quality) and the high production volumes of the species (Menšík et al. 2009, Viewegh et al. 2014, Kubeček et al. 2014, Podrázský 2015). Nevertheless, to our knowledge, the quality traits of Douglas-fir wood currently produced in the Czech Republic still need to be elucidated. In this study we aimed at outlining the oven-dry wood density variability along the stem radius of the non-native Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) growing in the Czech Republic.

2 Materials and Methods

The research plot was located in the University Forest Enterprise in Křtiny – Vranov, Czech Republic. The research was conducted on Douglas-fir trees growing in a mixed forest stand (Norway spruce 6 %, larch 29 %, Scots pine 6 %, Douglas-fir 22 %, European beech 19 %, lime 14 %, sessile oak 3 % and hornbeam).

Five healthy co-dominant 76-year-old Douglas-fir trees were selected and felled. Logs (50 cm) were cut at breast height (1.3 m) from each tree. A central plank (6 cm thick) including the pith in the axis was produced from the each log. Tree-ring width (TRW) were analyzed along the stem radius (from A-pith to J-cambium). Additionally, the early- and latewood proportions were calculated per tree ring.

Samples of 2×2×3 cm for oven-dry wood density testing were obtained radially from bark to pith. In total, 336 samples were obtained from all 5 trees. The samples were dried up to 0% moisture content in a programmed oven (at 103±2 °C). Each oven-dried sample was measured in three anatomical directions and then weighed. Oven-dry wood density denotes the oven dried weight (0% moisture content) in relation with the respective volume, i.e. at 0% moisture content, calculated as:

$$\rho_k = \frac{m_0}{V_0} \tag{1}$$

where ρ_k: oven-dry wood density (kg.m^{-3}), m_0: mass of wood (kg) at oven-dry moisture content and V_0: volume of wood (m^{-3}) at oven-dry moisture content.

3 Results and Discussion

2.1 Tree rings

The close to the pith (1-15 tree-rings) the average TRW was 5.14 ± 1.68 mm, getting promptly narrower (3.61 ± 1.55 mm) in the next set of 15 tree-rings. Nevertheless, average TRW gradually decreased and conceivably held steady approaching to cambium (Table 1, Fig 1). Blohm et al. (2016) reported that juvenile wood average TRW was 6.2 mm while the respective value for mature wood was 4.8 mm for Douglas-fir grown in Germany. This is not in line with our findings, considering the mature wood TRWs. Surely, according several studies on Douglas-fir, the transition threshold from the juvenile to the mature might vary due to variability per individual tree (Di Lucca 1989, Fabris 2000), genetic predisposition (McKimmy and Campbell 1982, Vargas-Hernandez and Adams 1991, Abdel-Gadir and Krahmer 1993), or just the sampling height (Fabris 2000, Gartner et al. 2002).

Table 1. Average tree-ring widths along the stem radius.

	Interval of tree-rings from pith to cambium				
Tree rings	1–15	16–30	31–45	45–60	61–76
Average (mm)	5.14	3.61	2.65	2.45	2.24
Standard deviation (mm)	1.68	1.55	1.32	1.21	1.17
Coefficient of variation (%)	28.26	42.78	50.03	49.37	52.23

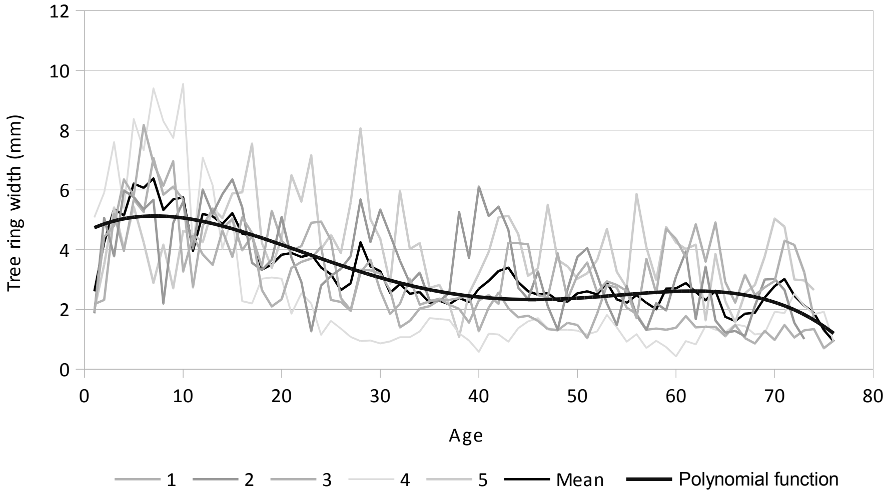

Fig. 1. Tree-ring widths along the age depicted per tree (1-5) and mean values.

The average width of earlywood behaved similarly to the average TRW along the stem radius. The average width of the latewood remained almost invariable as the tree was aging, besides a slight increase noticed around the age of 60. Diametrically opposed trend showed the proportion of the late-wood which steadily increased with the age (Fig 2).

In Germany, lower latewood percentage (34%) was reported in the juvenile wood compared with the mature wood (Blohm et al. 2016). In our study, we found that the late-wood proportion of the TRW was around 30% in the juvenile wood, whereas it reached almost 50% in the mature wood (ca. 76 years). This can provide us information on wood density since Wimmer (1995) reported that in conifers, the tree-ring density was mainly influenced by the radial diameter and cell-wall thickness of latewood tracheids.

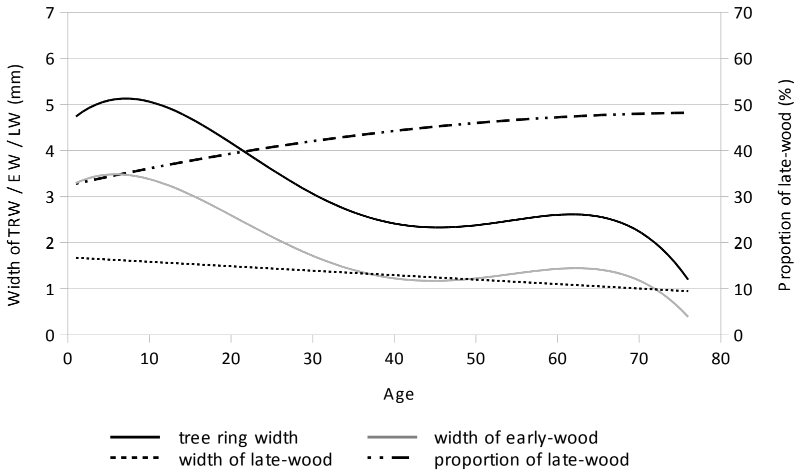

Fig. 2. Tree-ring widths (TRWs), earlywood and latewood trends and proportions.

2.2 Oven-dry wood density

Lausberg et al. (1995) noticed high density variation among Douglas-fir trees from the same provenance. Other studies stated that Douglas-fir wood density was featured by strong inter- and intra-tree-ring heterogeneity (Vonnet et al. 1995, Rathgeber et al. 2006). We found that the oven-dry density among the trees ranged from 517.0 ± 49.5 kg m^{-3} to 596.4 ± 78.7 kg m^{-3} (Table 2). Furthermore, the average oven-dry wood density was 542.9 ± 66.3 kg m^{-3} and ranged between 402.7 and 648.9 kg m^{-3}. This resonates well with Wagenfür (2000) and Rijsdijk and Laming (1994) and confirms again the higher wood density of non-native Douglas-fir growing in Europe, in comparison with the home-grown trees.

The oven-dry wood density was found low close to the pith but gradually increased along the stem radius (Fig. 3). Douglas-fir juvenile wood density was reported several times to be relatively low during the first 15-20 years of growth, followed by a rapid increase around 30 years, and eventually resulted in rather constant or even ascending wood density trend up to more than 50 years (Jozsa and Kellogg 1986, Gatner et al. 2002, Acuna and Murphy 2006). In horizontal distribution, from the pith to the cambium, wood density increased, culminating close to the bark (Gartner et al. 2002, Acuna and Murphy 2006). Our results cast no doubt on the prevalent reports on non-native Douglas-fir growing in the central Europe.

Table 2. Average oven-dry wood density per tree and total.

	Oven-dry wood density					
Tree no.	1	2	3	4	5	Total
N	64	75	62	61	74	336
Average ($kg \cdot m^{-3}$)	541.6	517.0	522.0	537.4	596.4	542.9
Standard deviation ($kg \cdot m^{-3}$)	53.9	49.5	49.9	99.4	78.7	66.3
Minimum ($kg \cdot m^{-3}$)	407.9	415.7	392.2	396.6	400.9	402.7
Maximum ($kg \cdot m^{-3}$)	619.3	621.6	635.8	666.1	701.9	648.9
Coefficient of variation (%)	10.0	9.6	9.6	18.5	13.8	12.8

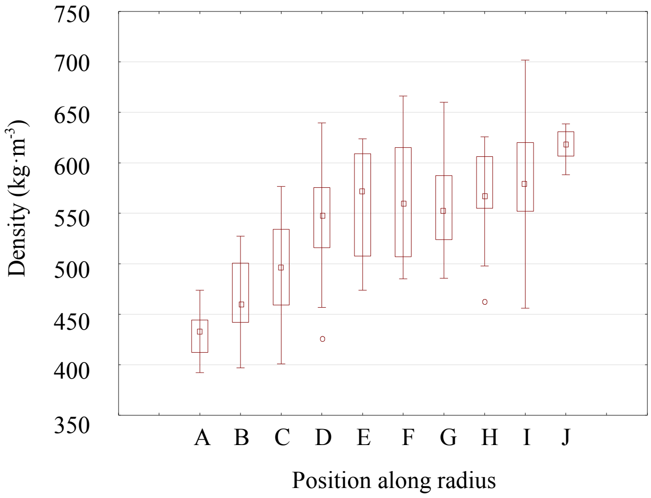

Fig. 3. Oven-dry wood density along stem radius from pith to cambium (A-J).

Nevertheless, wood density can be affected by silvicultural treatments or the growing site can affect wood density values at a given cambial age (Erickson and Harrison 1974, Smith 1980, Jozsa and Brix 1989, Cown and Parker 1979, Fabris 2000, Gartner et al. 2002).

4 Conclusions

Douglas-fir is of great interest in forestry as it combines strong productivity and high wood quality (Rathgeber et al. 2006). To illustrate the quality of the raw material before use, wood density is a reliable indicator and certainly one the most determinant wood properties (Gartner et al. 2002, Rathgeber et al. 2006). We found that non-native Douglas-fir trees growing in the Czech Republic produce notably denser wood than the homegrown Douglas-fir trees. Along the stem radius, the oven-dry density followed an upward trend, which culminated close to the bark.

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