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IDENTIFICATION AND CHARACTERISATION OF DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* (MIRB.) FRANCO) JUVENILE AND ADULT WOOD GROWN IN SOUTHERN GERMANY

More than one-third of Germany's Douglas-fir resources, stock in age-classes from twenty-one to fifty-nine years. As such timber increasingly enters markets, detailed knowledge of the anatomy and properties of its wood is of importance to forest managers and wood processors. Anatomical and mechanical wood analyses in this study were carried out on twenty trees from four scientifically managed plantations in Southern Germany. The age of the trees selected was forty-two years whereby varying growth conditions were considered. Juvenile and adult woods were identified by segmented linear regression of radial profiles of anatomical characteristics, such as latewood percentage, tracheid wall thickness microfibril angle and density. Additionally, the width of earlywood, latewood and growth rings as well as bending modulus of elasticity were determined. Variance was dependent on the trait used for differentiation, juvenile wood comprised of an eleven to thirty-one growth rings resp. radial amounts of fifteen to sixty-five percent. When compared to adult wood, juvenile wood showed corresponding features of approximately thirty percent wider growth rings, thirty four percent lower latewood percentage, fourteen percent thinner tracheid walls, and eighty percent larger microfibril angles, eleven percent lighter wood and fifty-seven percent lower bending modulus of elasticity. As the assortment features fast grown trees, adult heartwood characteristics were slightly inferior to the characteristics of European Douglas-fir.

Keywords: Douglas-fir, plantation trees, juvenile/adult wood identification, histometry

Introduction

At the end of the 19th century Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) was re-introduced to Europe, as a fast growing species extending the

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spectrum of conifers. Forestry nowadays regards the rather summer drought resistant coastal form (*var. menziesii/viridis*) as a promising alternative to Norway Spruce, which might in the future suffer due to extended periods of summer droughts, and therefore, is intended to enlarge the amount of plantations. The majority of German plantations can be found in the Southwest, where Douglas-fir stocks, on three to six percent of the federal countries forest area [Thünen Institute 2014]. On commercial plantations, tree ages vary mostly between twenty-one and fifty-nine years, while rotation periods range from eighty and 120 years for achieving high value timber. Consequently, the amount, characteristics and quality of juvenile wood (JW) have to be considered. JW can be defined as wood that is formed under the hormonal influence of the apical meristem by young cambium initials while trees are exposed to lateral forces like winds or passing animals [Lichtenegger et al. 1999; Barnett and Bonham 2004]. The cylinder of JW formed from the base to the top of a tree, is interpreted as a mechanic optimisation providing flexibility to young tissues prone to breakage. When gravitation forces exceed lateral forces, adult wood (AW) formation starts at the stem base where leverage is maximal and hormonal influence of the apical meristem is minimal. Depending on genetic and external influences, the amount of JW in Douglas-fir varies by seventeen to thirty growth rings [Abdel-Gadir and Krahmer 1993b].

As compared to the relatively constant characteristics of AW, the anatomical traits of JW show significant variations. In detail, conifer JW is characterised by bigger microfibril angles, shorter and thinner walled tracheids and lower latewood percentages. From these, physical and mechanical properties like lower density, transverse shrinkage and strength can be derived [Bendtsen 1978]. Because of its lower wood quality, JW is rejected for many applications. The aim of this study [Blohm 2015] is to identify JW, determine its properties and to quantify differences compared to adult wood. Accordingly, the obtained results are valuable for both foresters and wood processors in order to optimise silvicultural regimes as well as to quantify JW.

Materials and methods

Investigations were carried out on twenty coastal Douglas-fir trees of the seed origin ‘Südbaden’ from scientifically managed sites of a growing space experiment. Site elevations and average annual precipitations ranged from 410-780 m and 740-1100 mm. Selected trees were harvested in the summer of 2012 at an average age of 42 ±1 years representing the widest span of tenable planting/growth conditions.

From each of the trees, at breast height a disc was obtained out of which the diameter marking the angle bisector of maximum and minimum radius was cut avoiding reaction wood or opposite wood. The radius containing less fibre deviations was chosen for the anatomical investigations.

Prior to the measurements, the radii were cut to the dimensions 2 mm × 7 mm (tangential × longitudinal), extracted with acetone, reconditioned at forty percent relative humidity and 20°C, resulting in a moisture content of about seven percent. One transverse surface was polished with sandpaper down to 1500 grit size. Methods include growth ring measurements as described by Aniol [1983, 1987] regarding both earlywood (EW) and latewood (LW) width, which result in the growth ring width (GRW) and the latewood percentage (LW%). By means of SilviScan-3® radial profiles of tracheid wall thickness (TW), density (D), microfibril angle (MFA) and bending modulus of elasticity (MOE) were determined [Lundqvist and Evans 2004]. The SilviScan-3® system is an automated tool for rapid determination of wood microstructure. It consists of an image analysis unit, an x-ray diffractometer and an x-ray densitometer, which combine to give a range of primary and secondary data. Data were exported both as radial profiles at 25 micron intervals and as growth ring statistical parameters (average, median, percentiles and standard deviation). In order to differentiate JW and AW, growth ring average LW%, TW, MFA and D were plotted against cambial age. Following the segmented linear regression model suggested by Abdel-Gadir and Krahmer [1993a], each cambial age was presumed to mark the demarcation of JW and AW. The best segmentation of JW and AW was identified by the method of least squares while both connected, but also separated segments were assumed (see fig. 2).

For statistical comparison of JW and AW characteristics, the *H*-test of Kruskal and Wallis [1952] was applied with significance levels as proposed by Miller [1966].

Results and discussion

Segmented linear regression applied on LW%, TW, MFA and D identifies different cambial ages for the beginning of AW formation [Bendtsen 1978]. As shown in figure 1 exemplarily for one of the trees, using LW% results in a cambial age of twelve years to mark the beginning of AW formation, while MFA values result in cambial age of twenty-two years. Table 1 gives average cambial ages of initial AW formation and the average amounts of JW of the radii. The cambial age of initial AW formation, determined by usage of the D agrees quite well with the cambial age of twenty-six determined by Abdel-Gadir and Krahmer [1993a], while another study using D and MFA resulted in mostly younger cambial ages [Bawcombe 2012]. Wood traits, however, LW% and TW were not yet used for JW and AW demarcation of Douglas-fir.

In figure 2, radial profiles of average MFA, LW%, MOE, TW, GRW and D with cambial age are depicted, regarding segmentations of JW and AW for wood traits used for identification. It is obvious, that LW% (fig. 2b) and TW (fig. 2e) influence D (fig. 2f) resulting in the D check pattern described in Douglas-fir

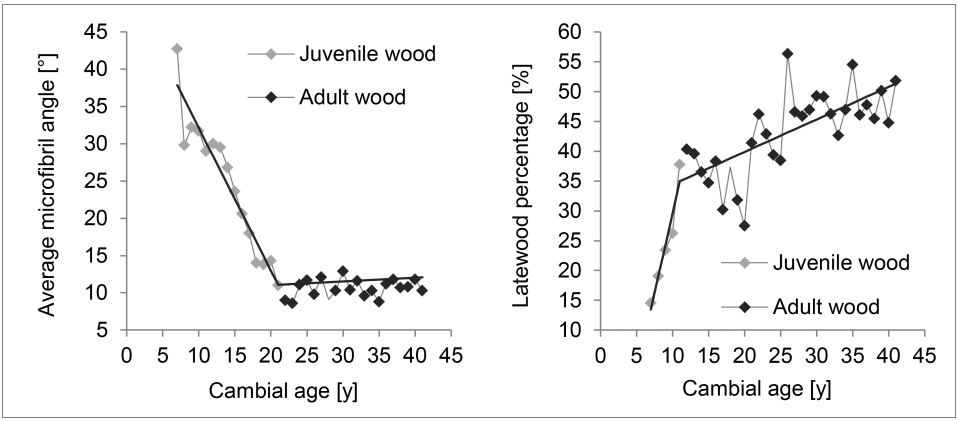

Fig. 1. Segmented linear regression results for the identification of the beginning of adult wood formation by average microfibril angle [°] (left, $R^2 = 0.95$) and latewood percentage [%] (right, $R^2 = 0.77$) with cambial age [y]

Table 1. Average onset of adult wood (AW) formation [cambial age] and amount of juvenile wood (JW) along radii [%] as identified by latewood percentage (LW%), tracheid wall thickness (TW), microfibril angle (MFA) and density (D)

		LW%	TW	MFA	D
Average cambial age of initial AW formation	[y]	18 ±6	20 ±4	23 ±4	25 ±7
Average amount of JW	[%]	38 ±23	45 ±16	53 ±15	51 ±14

[Di Lucca 1989; Abdel-Gadir and Krahmer 1993a; Fabris 2000; Gartner et al. 2002; Peterson et al. 2007; Bawcombe 2012]. The check pattern is characterised by an initial D maximum in early formed growth rings, followed by a local minimum in cambial ages coincident with maximal GRW (fig. 2e) and a subsequent increase.

As TW also shows the check pattern, this trait is considered as the key predictor of D shown by the strong correlation ($R^2 = 0.94$) of traits [Rathgeber et al. 2006]. Contrary to former studies, LW% does not follow the check pattern, which explains the weak correlation ($R^2 = 0.23$) calculated for LW% and D of 730 growth rings. LW% instead increases continually until the cambial age of eighteen , after which rather constant percentages were recorded. The average MFA (fig. 2a) and MOE (fig. 2c) reveal reverse trends and by means of high-resolution correlation, MFA is one of the traits predicting MOE ($R^2 = 0.63$). Even stronger, positive correlations were calculated for MOE and D ($R^2 = 0.79$) as well as for MOE and TW ($R^2 = 0.82$).

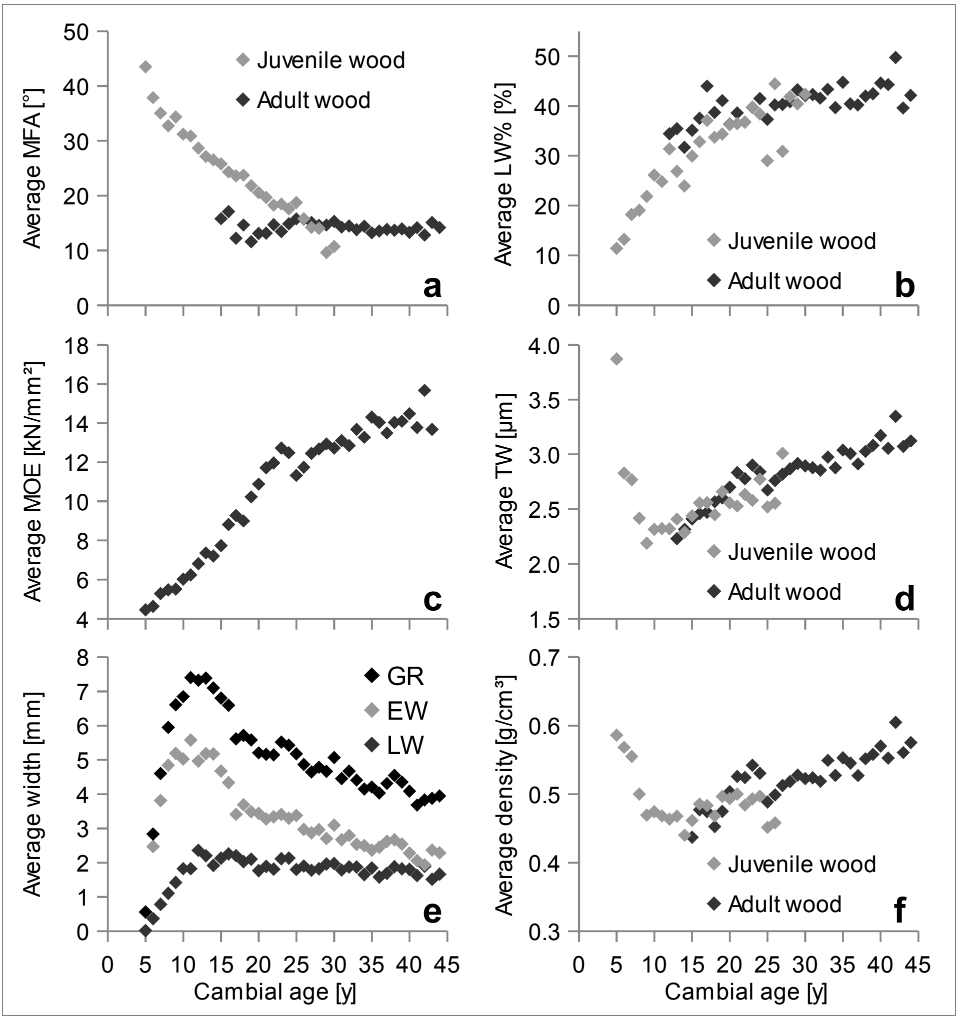

Fig. 2. Radial profiles of properties with cambial age [y]: a – average microfibril angle (MFA) [°] differentiated for juvenile and adult wood, b – average latewood percentage (LW%) [%] differentiated for juvenile and adult wood, c – average bending modulus of elasticity (MOE) [kN/mm^2], d – average tracheid wall thickness (TW) [µm] differentiated for juvenile and adult wood, e – average width of growth ring (GR), earlywood (EW) and latewood (LW) [mm], f – average density (D) [g/cm^3] differentiated for juvenile and adult wood

Once JW and AW are differentiated, the average values of anatomical characteristics can be calculated. Of all the characteristics investigated, AW values differ conclusively ($p \leq 0.001$) from JW values as shown in table 2. In comparison with earlier studies, AW average values indicate rather inferior quality, as the assortment features of fast grown trees. The only exceptions are

LW% of AW, which is in line with both average values of Douglas-fir grown in Northwest America and Europe [Knigge 1958; Lachenbruch et al. 2010; Bawcombe 2012] and D of both JW and AW which agrees with average values of Douglas-fir grown in Wallonia [Pollet et al. 2013].

Table 2. Characteristics of juvenile wood (JW) and adult wood (AW) and JW/AW ratio

		Juvenile wood	Adult wood	JW/AW ratio
Growth ring width	[mm]	6.2 ± 38 %	4.8 ± 44 %	1.30
Latewood percentage	[%]	27 ± 44 %	41 ± 22 %	0.66
Tracheid wall thickness	[µm]	2.4 ± 38 %	2.8 ± 43 %	0.86
Microfibril angle	[°]	27 ± 33 %	15 ± 53 %	1.80
Density	[g/cm^3]	0.470 ± 43 %	0.526 ± 52 %	0.89
Bending modulus of elasticity	[N/mm^2]	9077 ± 20 %	13193 ± 10 %	0.43

Conclusion

The studies revealed that besides JW and AW differentiation by means of segmented linear regression of radial D and MFA profiles, also LW% and TW enable distinction. Characteristics of the identified juvenile wood are of conclusive inferior quality when compared to adult wood. Average characteristics of the investigated adult wood are slightly lower than reported for European Douglas-fir due to the involvement of fast grown trees in the assortments selection.

References

Abdel-Gadir A.Y., Krahmer R.L. [1993a]: Estimating the age of demarcation of juvenile and mature wood in Douglas-fir. Wood and Fiber Science 25 [3]: 242-249

Abdel-Gadir A.Y., Krahmer R.L. [1993b]: Genetic variation in the age of demarcation between juvenile and mature wood of Douglas fir. Wood and Fiber Science 25 [4]: 384-394

Aniol R.W. [1983]: Tree ring analysis using Catras. Dendrochronologia 1: 45-53

Aniol R.W. [1987]: A new device for computer assisted measurement of tree-ring widths. Dendrochronologia 5: 135-141

Barnett J.R., Bonham V.A. [2004]: Cellulose microfibril angle in the cell wall of wood fibres. Biological Reviews 79: 461-472

Bawcombe J. [2012]: A study of Douglas-fir anatomical and mechanical properties and their interactions, Dissertation. University of Bath, Bath

Bendtsen B.A. [1978]: Properties of wood from improved and intensively managed trees. Forest Products Journal 28 [10]: 61-72

Blohm J.H. [2015]: Quality and properties of juvenile and adult wood of Douglas fir (*Pseudotsuga menziesii*) from southern Germany. (in German). Dissertation. University of Hamburg

Di Lucca C. [1989]: Juvenile-mature wood transition. Kellogg, R.M., Vancouver B.C.: Forintek Canada Corp.

Fabris S. [2000]: Influence of cambial ageing, initial spacing, stem taper and growth rate on the wood quality of three coastal conifers. Dissertation. University of British Columbia, Vancouver B.C.

Gartner B.L., North E.M., Johnson G.R., Singleton R. [2002]: Effects of live crown on vertical patterns of wood density and growth in Douglas-fir. Canadian Journal of Forest Research 32: 439-447

Knigge W. [1958]: Studies on the relationships between wood properties and growth characteristics of the guest tree species Douglas fir (*Pseudotsuga taxifolia* Britt.). (in German). J. D. Sauerländer's, Frankfurt am Main

Kruskal W.H., Wallis W.A. [1952]: Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association 47 [260]: 583-621

Lachenbruch B., Johnson G.R., Downes G.M., Evans R. [2010]: Relationships of density, microfibril angle, and sound velocity with stiffness and strength in mature wood of Douglas-fir. Canadian Journal of Forest Research 40: 55-64

Lichtenegger H., Reiterer A., Stanzl-Tschegg S., Fratzl P. [1999]: Variation of cellulose microfibril angles in softwoods and hardwoods – a possible strategy of mechanical optimization. Journal of Structural Biology 128: 257-269

Lundqvist S.O., Evans R. [2004]: Illustration of wood and fiber measurements with SilviScan. In: STFI Report: STFI

Miller D.A. [1966]: 'Significant' and 'highly significant'. Nature 210: 1190

Peterson M.G., Dietterich H.R., Lachenbruch B. [2007]: Do Douglas-fir branches and roots have juvenile wood? Wood and Fiber Science 39 [4]: 651-660

Pollet C., Henin J.M., Jourez B., Hebert J. [2013]: Impact of growth rate on the mechanical properties of Douglas-fir grown in Wallonia (Southern Belgium). IUFRO, Nancy: Measurement methods and modelling approaches for predicting desirable future wood properties

Rathgeber C.B.K., Decoux V., Leban J.M. [2006]: Linking intra-tree-ring wood density variations and tracheid anatomical characteristics in Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). Annals of Forest Science 63: 699-706

Thünen Institute [2014]: Third National Forest Inventory – Results. (in German). Thünen Institute (ed.)

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